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АРХИТЕКТУРА

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REVIEW ARTICLE

ARCHITECTURE OF ALMATY IN THE 20TH CENTURY: IN SEARCH OF CULTURAL IDENTITY

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Abstract. *This article outlines the findings of a study focused on uncovering the sources of Almaty's identity, which have evolved over time through various architectural ideas. The Soviet era was particularly influential in shaping the city's architectural development. The study examines the current urban environment, including buildings and structures within Almaty's historical district. The research methodology employs a comprehensive approach, incorporating several methods. These include gathering projects and illustrative materials (such as drawings, photographs, and plans) from archives, scientific publications, and digital resources; conducting field surveys of buildings and elements of the urban environment constructed in Almaty during the 20th century; and performing chronological, compositional, and comparative analyses, along with generalizing the findings. The study revealed that the cultural identity of Almaty's architecture in the 20th century stemmed from a blend of architectural trends prevalent across the Soviet Union, yet adapted to the regional context of Kazakhstan. Within the framework of a socialist economy, Almaty's architecture reinterpreted traditional motifs to establish a link between the built environment and the local cultural heritage. In the 21st century, understanding cultural identity is crucial for crafting a compelling image of a city. It plays a key role in developing strategies for socio-cultural and economic transformation, and can be instrumental in attracting investment and tourism*

Keywords: *architecture of Almaty, regional architecture of Kazakhstan, regional identity, cultural identity*

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ҒЫЛЫМИ МАҚАЛАСЫ

XX ҒАСЫРДАҒЫ АЛМАТЫ СӘУЛЕТ ӨНЕРІ: МӘДЕНИ БІРЕГЕЙЛІКТІ ІЗДЕНУ ЖОЛЫНДА

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Аңдатпа. *Мақалада әртүрлі сәулеттік идеялар арқылы Алматының уақыт өте келе қалыптасқан бірегейлігінің көздерін анықтауға бағытталған зерттеудің қорытындылары ұсынылған. Қаланың сәулет өнерінің дамуына кеңестік дәуір айтарлықтай ықпал етті. Зерттеу қазіргі қалалық ортаны, сондай-ақ Алматының тарихи ауданындағы ғимараттар мен құрылымдарды қарастырады. Зерттеу әдістемесі кешенді тәсілдерді қамтиды. Бұл әдістерге мұрағаттардан, ғылыми басылымдардан және цифрлық ресурстардан жобалар мен иллюстрациялық материалдарды (мысалы, сызбалар, фотосуреттер және жоспарлар) жинау; 20 ғасырда Алматыда салынған ғимараттар мен қала ортасының элементтеріне далалық зерттеулер жүргізу; сондай-ақ қорытындыларды жалпылау арқылы хронологиялық, композициялық және салыстырмалы талдаулар жасау кіреді. Зерттеу 20 ғасырдағы Алматы сәулетінің мәдени ерекшелігі Кеңес Одағында кең таралған, бірақ Қазақстанның аймақтық контекстіне бейімделген сәулет тенденцияларынан пайда болғанын көрсетті. Социалистік экономика жағдайында Алматының сәулет өнері дәстүрлі мотивтерді қайта интерпретациялап, салынған орта мен жергілікті мәдени мұра арасындағы байланысты орнатуға ұмтылды. 21 ғасырда мәдени бірегейлікті түсіну қаланың тартымды бейнесін қалыптастыру үшін аса маңызды. Бұл фактор әлеуметтік-мәдени және экономикалық қайта құру стратегияларын әзірлеуде негізгі рөл атқарады, сондай-ақ инвестициялар мен туризмді тартуда маңызды рөл ойнайды.*

Түйін сөздер: *Алматы сәулеті, Қазақстанның аймақтық сәулеті, аймақтық бірегейлік, мәдени бірегейлік.*

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НАУЧНАЯ СТАТЬЯ

АРХИТЕКТУРА АЛМАТЫ XX ВЕКА: В ПОИСКАХ КУЛЬТУРНОЙ ИДЕНТИЧНОСТИ

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Аннотация. *В данной статье представлены результаты исследования, посвященного выявлению источников идентичности Алматы, сформировавшихся в разные годы на основе различных архитектурных концепций. Наиболее активным развитием архитектуры города отмечен советский период его истории. Объектами исследования являются сложившаяся городская среда, здания и сооружения исторической части города Алматы. Методология исследования основана на комплексном подходе. В частности, в работе над статьей использовался ряд методов: сбор проектов и иллюстративных материалов (чертежи, фотографии, рисунки), представленных в архивах, научных публикациях и электронных ресурсах; натурное обследование зданий и фрагментов городской среды, возведенных в Алматы в XX веке; хронологический, композиционный и сравнительный анализ и обобщение результатов. Исследование показало, что источником культурной идентичности архитектуры Алматы в XX веке являлся комплекс сочетаний архитектурных течений, характерных для всего Советского Союза, но получивших локальное преломление в региональных условиях Казахстана. Архитектура Алматы в условиях социалистической экономики в определенных пределах интерпретировала традиционные мотивы, устанавливающие связь между архитектурой и культурой народа, проживающего на данной территории. В XXI веке изучение культурной идентичности – важный фактор создания привлекательного облика города, и может быть использовано для развития стратегий социокультурных, экономических преобразований, привлечения инвестиций и туристов.*

Ключевые слова: *архитектура Алматы, региональная архитектура Казахстана, региональная идентичность, культурная идентичность.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

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БЛАГОДАРНОСТИ / ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось в рамках грантового финансирования Комитета науки Министерства науки и высшего образования Республики Казахстан IRN AP19680138 “Региональная идентичность как фактор устойчивого развития архитектуры независимого Казахстана в условиях глобализации”.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

Architecture as a reflection of the ideas and values of society is an integral part of the cultural identity of any nation. In the twentieth century, in an era of significant changes, architectural solutions became not only a way to reflect technological progress, but also a tool for expressing the values of society. The idea of cultural identity has become a key aspect influencing the formation of urban space and architectural solutions. This was especially evident in the architecture of cities, where traditions and innovative approaches collided and intertwined, creating a unique look and visual heritage.

Kazakhstan holds a special place in the world of architecture due to its rich cultural heritage, which is closely linked to the history and traditions of this country. In the twentieth century, Kazakhstan experienced several significant historical events, including the Soviet period and independence. In recent decades, significant changes have taken place in the country, including in architecture, emphasizing not only its modern development, but also the preservation and respect for national values and traditions.

It is known that cultural identity is formed on values, relevant norms, traditions and is identified with the material heritage of a given society, concentrated in priceless architectural monuments, the study of which will reveal the potential for a methodology for determining identity in architecture **(Erikson, 1996)**.

Almaty, formerly Alma Ata, the capital of Kazakhstan, is the cultural and historical center of the region. The city, inhabited since ancient times, has undergone many transformations throughout its rich history, intensive construction, which gave the settlement its unique appearance. During the twentieth century, the city turned from a modest commercial settlement into a major educational, economic and political center of the country, and became an important symbol of its cultural heritage. The dynamics of the architectural development of this city during the twentieth century are closely linked to historical events, socio-cultural trends, economic transformations and the aspirations of the local population to preserve their unique identity. The article provides a detailed analysis of the architectural objects of the twentieth century of Almaty, demonstrating the directions of the search for the identity of this unique city.

2 LITERATURE REVIEW

The work devoted to identifying the sources of Almaty's identity is based on valuable and convincing research by Soviet and Kazakh scientists. The results of the analysis and study of the problems of architecture of Kazakhstan and the city of Almaty were highlighted in the works of Kazakhstani researchers of the period of Independence of the country, such as Abilov A.Zh., Abdrassilova G.S., Azimov I.M., Basenov T.K., Glaudinov B.A., Ibraeva K.T., Isabaev GA., Kamalova G.M., Kuspangaliev B.U., Ordabaev A.B., Tatygulov A.Sh., Tuyakbayeva B.T. and many others.

The subject under consideration is widely represented in the works of archaeologists and historians who explored Almaty in the pre-war and post-war years. In the book "The Past of the Alma-Ata district", A.N. Bernshtam presented the initial stage of the city's history, the issues of its composition and cultural and historical ties, the peculiarities of the sedentary and nomadic population of southern Kazakhstan and Semirechye, including Almaty **(Bernshtam, 1948)**.

Valuable information about the architectural heritage of the city of Almaty, with a step-by-step analysis of the origin and development of the historical core of the settlement, is revealed in the work of Tuyakbaeva B.T. **(Tuyakbaeva, 2008)**. The detailed illustrated book by Kapanov A.K. and Baimagambetov S.K. highlights complete information about the construction and architecture of the city during the Soviet period **(Kapanov & Baimagambetov, 2013)**. Extensive information about the origin of architecture in Kazakhstan since antiquity and its development during the Soviet period is contained in the works of B.A. Glaudinov, who studied the inclusion of traditional elements of Kazakh architecture in modern projects to maintain cultural ties **(Glaudinov, 1974.)**.

The works of E.G. Malinovskaya, aimed at studying and preserving the architectural heritage of the modern national architectural school of Kazakhstan, contain an analysis of the architecture of the 1920s and 1950s and its relationship with national traditions, the rationale for creating their own "national style" **(Malinovskaya, 2017).**

The works of modern researchers present an extensive overview of the topic of architecture in Almaty and its connection with cultural identity, covering both historical aspects and current challenges and development prospects. The article by Ordabaev A.B. "The history of architecture of the city of Almaty" **(Ordabaev, 2018)** examines the evolution of the architecture of the city, from ancient times to the present. Special attention is paid to the influence of historical events and cultural traditions on the formation of the architectural appearance of the city and its cultural identity.

The work of G.M. Kamalova examines the problems of preserving historical heritage in the context of the development of modern architecture of the city, analyzes examples of both successful and unsuccessful reconstruction of monuments (Kamalova & Sailauova, 2022). The influence of the architectural image on the cultural identity of the city of Almaty and modern trends in architecture are considered in the article X. Truspekova's "Architecture of Almaty and issues of identity" **(Truspekova, 2016)**, where, based on the analysis of architecture from different historical periods, the author explores the issues of perception by residents of new architectural projects. Today, we can note the active conduct of a number of studies by Kazakhstani scientists on the topic of regional identity **(Abdrassilova & Danibekova, 2021, Kozbagarova et al., Baitenov, et al., 2019, Abdrassilova & Murzagaliyeva, 2020, Abdrassilova & Murzagaliyeva 2018)**.

3 MATERIALS AND METHODS

The materials for the study were books, articles on a given topic, projects and illustrative materials (drawings, photographs, drawings) presented in scientific publications and electronic resources; a full-scale survey of buildings erected in Almaty in the twentieth century. The research methodology is based on an integrated approach used in art history cases.

4 RESULTS AND DISCUSSIONS

The favorable natural and climatic conditions of the northern slopes of the Trans-Ili Alatau, where the city of Almaty is located, have led to the existence of semi-settled and settled peoples here since ancient times. The products found during archaeological excavations in large numbers at different times on the territory of the city indicate that since the X-VIII centuries BC, tribes leading a nomadic and semi-sedentary lifestyle lived in this territory **(Glaudinov, 1999)**.

Almaty, formerly known as the settlement of the local Almalyk tribes, was an important trading center on the Great Silk Road connecting China and Europe, and the mixing of cultures is reflected in its unique history.

The period of the XIX-XX centuries. In the middle of the XIX century, after the annexation of the region to tsarist Russia, the fortress city of Verniy was founded in the foothills of Alatau as an outpost of the Russian Empire. Since 1867, Verniy has been the center of the Semirechensk region of the Turkestan General Government of the Russian Empire. One of the key aspects of this period is the predominance of the role of merchants in shaping the architectural appearance of the city. At the same time, the development of the extractive industry at the end of the 19th century led to an increase in the population of Verniy and the expansion of its infrastructure through the construction of public buildings and structures such as schools, gymnasiums, orphanages, etc.

Almaty's strategically advantageous location at the intersection of ancient trade routes linking Central Asia with Russia and China attracted merchants, merchants and entrepreneurs, stimulating economic growth and development of the city. Merchants built luxurious houses, shops and mansions reflecting their wealth and social status. Architectural solutions often combined elements of local traditions with the predominance of architectural forms typical of Persian, Turkish and Russian architecture, creating their own unique style.

The architects of the XIX century turned to Art Nouveau, eclecticism, Art Nouveau, and the buildings of Verniy-Almaty of this period was distinguished by its majestic palace facades, which were refined by large windows, high ceilings and often encountered wooden cornices, balconies, architraves, carved decor and ornament. Built mainly from local materials - brick or wood, the structures demonstrated the wealth and status of their owners and are still an important source for studying the history of the city and its cultural heritage (Auezov & Chulakova, 2010).

Figure 1 shows the buildings of the late XIX- early XX centuries, reflecting the style of the era. This is an important layer of the historical and cultural heritage of the city, which includes: merchant I. Gabduvaliev's trading house (1911, architect A. Zenkov, now the Kyzyl-tan store); G. Kolpakovsky city Real School (1890, architect P. Gurde, now Kazrestavratsiya); Vernensky Orphanage (1892, architect P. Gurde, now the Museum of Almaty), etc.

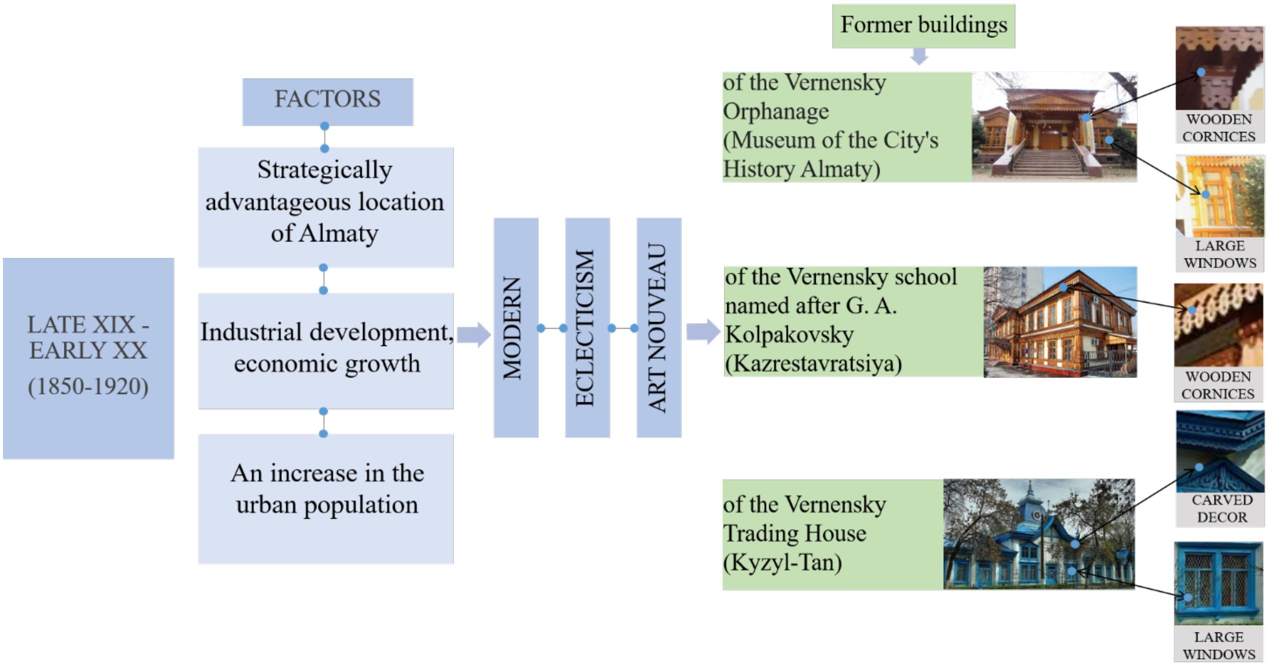

Figure 1 – The formation of originality in the architecture of Verny – Almaty in the late XIX- early XX centuries (author's material)

This period brought a variety of styles and traditions that shaped the current image of the city. The preservation, study of this integral part of cultural heritage and the challenges associated with the adaptation of architectural monuments to modern needs are important for understanding the past and creating a sustainable future for Almaty.

The period of the beginning of the XX century. With the establishment of Soviet power, a period of intensive industrial and cultural development began in the 1920s, which significantly influenced the appearance of Verny, which in 1921 was renamed Alma-Ata. In 1929, after Alma-Ata was declared the capital of Kazakhstan, the city became a place of active construction and modernization. The serious status of the city provided architects from various parts of the Soviet Union with a favorable space for their creative realization, which affected the variety of styles and trends in architecture. During this period, numerous facilities were built here, which served as symbols of the power and prosperity of the Soviet state.

In the first decades of the twentieth century, constructivism and modernism prevailed in the architecture of the city, reflecting the desire for modernity and innovation. Significant examples of the manifestation of this synthesis were the buildings shown in Figure 2: the Central Post Office –

now the House of Communications (1931, architect G. Gerasimov), the Government House of KazASSR – now the Academy of Arts named after T. Zhurgenov (1931 Architect M. Ginzburg, with the participation of F. Milinis), the Club of GPU Workers – now the Uygur the theater (1932, architect V. Burovtsev), built in the style of constructivism. Despite pronounced constructivism, the theme of the "living East" is particularly subtly expressed in the building of the KazASSR Government House: a synthesis of the logic of shaping characteristic of constructivism with the traditions of architecture in Central Asian countries has been achieved - the composition of the image is based on the contrast of the geometry of solid volumes of walls, transparent planes of windows, the presence of deep loggias, an inner courtyard, covered passages connecting separate buildings, etc. **(Auezov & Chulakova, 2010, Glaudinov et al., 1987)**.

Thus, the search for an expressive image personifying the new era of socialism has determined an unconventional approach to incorporating traditional techniques of Central Asian architecture into planning and compositional solutions **(Abdrassilova & Murzagalieva 2018)**.

Since the 1930s, during the reign of "Soviet classicism", simultaneously with the embodiment of the principles of Soviet ideology, architects were tasked with combining modern trends with national culture and traditions. Architectural, planning and imaginative solutions of numerous buildings in Almaty in the 1930s and 1950s were based on traditional techniques or contained elements of national decor. This created a special synthesis between Soviet modernism and national traditions, reflecting the cultural identity of the country in the context of political and social changes.

The result of an intensive search for national identity based on the synthesis of classical European and traditional Central Asian styles can be seen in **Figure 2** - in the architecture of the Kazakh Opera and Ballet Theater named after Abai (1941, architect N. Kruglov, N. Prostakov). The theater building captures an important urban planning node, being its compositional focus. The introduction of national motifs into the overall composition of the building in the form of a redesigned, stylized order and characteristic ornamental elements emphasized the regional affiliation of the theater. This visually connected the building, built according to the canons of classical architecture, with local cultural traditions.

As a result of the study of regional architecture, the period 1930-1950 is seen by scientists from Central Asia and Kazakhstan as: "East plus classics" of the 1930s and 1950s **(Askarov, 1988)**; "Kazakh classics" of the 1940s and 1950s **(Abdrassilova, 2015)**. Through forms and symbols in the architecture of the first half of the twentieth century, the architects expressed their desire to preserve uniqueness and originality, where tradition and innovation merged into a single whole, reflecting the spirit of the times and the cultural heritage of the region.

During the pre-war and post-war decades, there was an active construction of not only unique public buildings, but also industrial facilities. In the 1950s, the development of standard residential building designs was developed, requiring typification and standardization due to the need to introduce large volumes. During this period, projects of single-storey brick houses were developed, the first urban ensembles began to take shape **(Kapanov & Baimagambetov, 2013).** Architectural and urban planning solutions considered the uniqueness of the location in the conditions of mountain-valley circulation. The system of irrigation ditches supplying the city with water (according to the plan of the first general plan of 1869, Verny was supposed to be supplied with water from the Malaya Almatinka River) in the early 1950s supplemented with cast iron intake columns **(Titenev, 2001)**.

The architecture of Almaty in the middle and late twentieth century reflects a period of intense cultural and economic development in the history of the city. In accordance with the socialist course of society, monumental structures reflecting the ideological principles of the existing state system began to prevail in the architecture of Almaty. However, even in these exemplary Soviet buildings, elements of cultural identity can be found. Architectural symbols embodying the history and culture of the people have already become key elements of the urban landscape, capturing epochs and changes. The appeal of traditional construction techniques, the use of national ornaments and decorative motifs, refer to the object to the cultural heritage of the region, not only as architectural monuments, but also as symbols of cultural identity.

After the Second World War, the intensive development of industry and agriculture in the country led to the migration of the population to cities and the expansion of their borders. The urgent need for infrastructure required the construction of a wide range of public buildings - educational institutions, medical institutions, cultural and administrative facilities, as well as new principles of urban planning with an emphasis on ensemble construction **(Glaudinov, 1974, Basenov et al., 1973)**.

This period from the second half to the end of the twentieth century is characterized as a fruitful stage in the work of architects, considering the cultural, historical and environmental context of the "... new way ..." search for regional identity and national identity **(Glaudinov, 1974)**. At the same time, K. Samoilov calls this time "... highly technical and far from mechanical reproduction of old forms and techniques ..." **(Glaudinov & Samoilov 1997)**. Due to the fact that the architecture of famous public buildings in Almaty is characterized by the search for associativity of images and forms, compliance of architectural and planning solutions with the required principles of environmental organization. Kazakh scientist G. Abdrassilova attributes this period to "critical regionalism" **(Abdrassilova, 2015)**.

In the 1950s and 1970s. Alma-Ata, like many other cities of the Soviet Union, underwent an intensive process of modernization, being influenced by social, political and cultural transformations. During this period, architectural solutions not only reflected the principles of socialist aesthetics, but also became symbols of a new cultural identity. Basically, the buildings had the characteristic features of the Stalinist Empire style: monumentality, stylized columns, towers and decor. At the same time, Soviet modernism was actively developing, which was characterized by using modern materials and structures, as well as experiments with forms. The buildings in the Modernist style were more modern and abstract compared to the Stalinist Empire style with simple shapes, convenient for mass production and with moderate decorativeness.

However, to demonstrate that the Soviet government recognized and respected the diversity of cultures of the peoples of the USSR, the architects were given another task – to emphasize the geographical and cultural area, as well as ethnic identity. Thus, in residential buildings (depending on local characteristics), the planning solution could be adapted to the climatic conditions of the region, and in public buildings the influence of the Kazakh tradition was manifested in the details of the decor, in the use of traditional materials and forms.

One of the iconic public buildings of this period is the former building of the Government House of the Kazakh SSR (1957, architect B. Rubanenko, T. Simonov, P. Mamontov, G. Kalish), which plays an important city-forming role and reflects the Soviet style of that time with its architecture. At the beginning of the XXI century, the administrative purpose of the building of the former Government House of the Kazakh SSR was replaced by the function of scientific and educational (now the Kazakh-British Technical University is in the building).

The composition of the main facade of the classical administrative building, corresponding to its purpose, uses a synthesis of the traditional ornament "qoshkar muyiz" in the form of a ram's horn, stylized under the order system. The metrorhythmic composition from the series "qoshkar muyiz" has become the dominant motif in the culture of the steppe peoples, recalling the famous "meander", widespread since the Paleolithic period, including the ancient Greek civilization.

However, the "qoshkar muyiz" ornament is an independent basis of Kazakh culture, conditioned since ancient times by nomadic and semi-nomadic cattle breeding, the conquest of the vast steppe expanses. The way of life and beliefs have left their mark on the nature of the visualization of the Kazakh worldview. Thus, animal products made life easier for him in harsh conditions such as food (meat, milk), clothing and shelter (hide, wool). In this regard, animals, mainly sheep, were equated with deities and depicted with exaggeratedly large horns, which gradually became fundamental in traditional visual art.

Striking examples of the architecture of educational institutions, due to the mixture of classical and national styles, are the central parts of the main buildings of the building of the Women's Pedagogical University (1939, architect V. Bychkov) and the Agrarian University (1954, V. Biryukov) in Almaty. The porticos of the main entrances of the university buildings are built in classic stylistic characteristics and national decor is used: in the piers of the facades of the agrarian university there are multi-faceted paired and single semi-columns with ornamented capitals and developed bases. The arches of the "oriental type" have a complexly ornamented archivolt. The developed cornice has two tires of curly brackets. **Figure 2** shows the facade of the main portal of the Women's Pedagogical University with eastern pointed arches also contains the traditional ornament "qoshkar muyiz".

An important aspect of the architecture of Almaty in the 1950s and 1970s was the further development of the urban environment. New buildings and districts changed the appearance of the city, as well as interacting with existing buildings, creating a unique cultural landscape. This process has also facilitated dialogue between different cultures and traditions, forming a rich and multi-layered cultural heritage of the city. Many buildings erected during this period have become symbols of progress and innovation. New residential complexes, public and cultural centers, as well as industrial facilities reflected the country's desire for economic and cultural development. These buildings not only provided residents with comfort and convenience, but also served as a kind of monument of the era.

In this period, the core of the central part of the city is formed between Zheltoksan and Furmanova streets, where unique public buildings are concentrated. Reconstruction of the northern part of the Central Market is underway (within the boundaries of Gogol Street, Rayymbek Avenue, Ilyich Street and Vesnovka River) with the demolition of dilapidated housing and the construction of residential buildings with panel 5-storey buildings designed considering seismic conditions **(Kapanov & Baimagambetov, 2013)**. The city is developing in a westerly direction - new neighborhoods are beginning to appear, built up with panel residential buildings of mass series **(Tuyakaeva & Murzabayeva, 2019)**. Industry is developing and new industrial facilities are being built.

The 1970s and 1980s were a time of active construction and modernization, with important attention paid not only to economic and social development, but also to the cultural sphere. During this period, structures were erected, which later became significant architectural monuments of that time. In pursuance of the Decree of the legislative bodies of the republic "On the integrated development of main streets, exit highways and the central part of Almaty" (1972), the construction and reconstruction of Seifullin and Abai Avenues, the highway from Rayymbek Avenue to the airport, Zheltoksan str., the central part of the city; at the same time, several of the largest unique buildings and structures were built (Kapanov & Baimagambetov, 2013). An example of a comprehensive reconstruction and development of Dostyk Avenue, connecting the central core of the city with the main southern recreation area in the mountains of the Trans-Ili Alatau, is indicative. The compositional expressiveness of the avenue is achieved by the rhythm of high-rise buildings alternating with developed courdonnaires, landscaped squares and skillful use of relief. High-rise buildings along Dostyk Avenue, in an area of high seismic activity, were built using progressive earthquake-resistant structures.

The growth in the construction of cultural and educational structures, palaces, and hotels favored the appearance of buildings unique in architectural and artistic design, reflecting the social, political, and cultural aspects of the era. These objects not only corresponded to their functional tasks, but also became icons and symbols of modernization and national identity. These include the buildings in Almaty shown in **Figure 2**: The Wedding Palace (1971, architect M. Mendikulov, A. Leppik); circus (1972, architect V. Katsev, I. Slonov); hotel "Kazakhstan" (1977, architect Y. Ratushny, L. Ukhobotov, A. Anchugov, V. Kashtanov); hardware and studio complex (1983, architect A. Korzhempo, M. Ezau, V. Panina); hotel "Otyrar" (1981, S. Kokhanovich, M. Kabylbayev); medical and wellness complex "Arasan" (1983, architect V. Khvan, M. Ospanov); the Republican Palace of Schoolchildren (1984, architect V. Kim, A. Zuev, T. Abilda); the Central State Museum of the Republic of Kazakhstan (1985, architect Y. Ratushny, Z. Mustafina, P. Rzagaliev) and many others.

These architectural structures together form the unique appearance of the city and reflect its history, embodying with their appearance and unique style the period of the Soviet era in the history of the country. Each object uses several techniques, forms and elements of traditional Oriental architecture that complement the expressive image. The combination of elements of Kazakh national culture with modern components represents the desire to preserve and pass on the rich heritage and history of Kazakhstan to future generations.

The synthesis of traditions and modernity in the silhouettes of buildings is manifested in the form of references to the traditional dwelling of Kazakhs – yurts - in the three-dimensional characteristics of the Wedding Palace and circus; stylized forms of the citadel of the feudal city of Central Asia, caravanserai or memorial and cult architecture - in the figurative solutions of the Arasan medical and wellness complex, the Republican Palace of Schoolchildren, The Central State Museum, where domed coverings, arched openings, transitional galleries, towers enhance their regional affiliation and cultural identity.

Components such as ornamental sunscreens on the facades of a few objects, including the Wedding Palace; cornices – Asian "stalactites" on the facade of the hardware and studio complex; Central Asian arches - semicircular forms of balcony fences and the main portal of the Otyrar hotel; the unique antiseismic structural basis of the Kazakhstan hotel also played a key role in the formation of cultural identity the cities of Almaty of the XX century.

Figure 2 – Architecture of Almaty XX – beginning XXI century. (author's material)

In the 1970s and 1980s, the traditional rectangular grid of streets for the city, oriented in the meridional and latitudinal directions, was developed in the western direction in the form of an enlarged grid of new neighborhoods, preserving the continuity of the planning structure.

The attraction of the city of Almaty is its green outfit. The master plan provides for the further development of the system of green spaces by creating parks in floodplains and a forest park in the eastern part of the city. It is becoming urgent to create a continuous interconnected system of green spaces that would effectively affect the improvement of the environment and recreation for the city's population, connecting the city with its unique environment at the foot of the picturesque Trans-Ili Alatau **(Kapanov & Baimagambetov, 2013.)**. In this regard, park lanes and landscaped connections of the latitudinal and meridional directions are organized, which form the basis of the natural and ecological framework.

With the collapse of the Soviet Union in the early 1990s, Almaty felt a wave of political and cultural changes and faced the challenge of preserving and developing its cultural identity in new conditions. It was a time when the country was striving to define its new role on the world stage. This period brought with it the opportunity to freely experiment with new architectural styles and technologies, forms reflecting a variety of cultural influences and trends.

The architecture of the residence of the President of the Republic of Kazakhstan, built in 1995 (architects K. Montakhaev, S. Baymagambetov, O. Tsai) using modern building materials and technologies, indicated the desire of Kazakh society for change. The appeal to modernity and innovations in solving such classical monumental forms as pylons, as well as the use of the principle of contrasting ratios, eventually led to a reflection in the architecture of the 1990s of the cultural changes that took place in Kazakhstan at the beginning of the Independence period.

Attempts to regain one's own identity and culture include an increase in the number of religious buildings in the settlements of the young state. The architecture of the central cathedral mosque in Almaty (1999, architects S. Baymagambetov, J. Sharapiev, K. Zharylgapov) has become a new embodiment of oriental traditions using a dome, portal arch, arched gallery, corner towers and a high minaret. Thus, the revival of religion and religious architecture has become an indicator of the state's desire to preserve cultural identity in conditions of rapid development.

Even though in 1997, the capital of Kazakhstan was moved to Astana, Almaty remains a cultural, scientific, educational, financial and business center, the largest metropolis in the country, which is supported by its status as a city of republican significance **(Decree N 3698, 1997)**.

Intensive construction, reconstruction and urban development over the years of the capital's functions have provided a unique appearance of the city of Almaty. The city has developed interesting urban-planning ensembles and urban-planning nodes: Republic Square, Square named after Abay, buildings in the circus area and the Kazakh Drama Theater, etc. A number of unique objects and structures have been erected: the building of the Abai Opera and Ballet Theater, the building of the Government House (later the Akimat of the city Almaty), the main building of the Academy of Sciences, the complex of the Central Republican Stadium, the complex of the Medeu ice stadium, the building of the Kazakh Drama Theater named after M. Auezov, the Circus, the Wedding Palace, the House of Friendship with Foreign Countries, the complex of therapeutic baths "Arasan", the Palace of Culture of the AKHBK (later the TYUZ named after N.Satz), the Republican Palace of Schoolchildren, the District House of Officers (later the Central House of the Army), the former house of Political Education, buildings of railway stations, air terminals, bus stations, the Palace of the Republic, the Residence of the President, the 25-storey hotel "Kazakhstan", the Dostyk hotel, 5-star hotels "Ankara" (subsequently, the InterContinental Almaty Hotel), Rahat Palace, etc., residential areas of Almaty grew **(Kapanov & Baimagambetov, 2013)**.

In the last decades of the twentieth and early twenty-first centuries, Kazakhstan, like many other countries, actively carried out the construction of modern buildings and complexes. In this context, for the progress and prosperity of the region, it is necessary to preserve historical monuments and traditional architecture as part of the material heritage. The architectural structures of the city of Almaty of the XX century are not only its symbols, but also represent important elements of the heritage of Kazakhstan, which reflect the desire to find a synthesis between traditions and modernity. Taken together, they are an example of how architecture can become an important tool for expressing and strengthening the cultural identity of a society.

5 CONCLUSIONS

The study revealed that the cultural identity of Almaty architecture in the 20th century was formed through a combination of architectural styles inherent in the entire Soviet Union but adapted to the local conditions of Kazakhstan. Within the framework of the socialist economy, the architecture of Almaty to a certain extent rethought traditional motifs, creating a link between architecture and the culture of the local population.

The inclusion of traditional motifs in the design of modern buildings gives the architecture of Kazakhstan a bright individuality and originality, creating a complete regional image. The combination of modern technologies with elements of traditional Kazakh architecture and respect for historical heritage forms a unique architectural environment that can develop and attract the attention of both locals and tourists. Thus:

1. The analysis of theoretical research and practical implementation of architectural objects in Almaty shows that currently the search for cultural identity can be expressed in architecture in several ways:

- visual expression of the territory's connection with the Kazakh national culture (facade decoration, archetypal forms – arches, domes, etc.)

- the formation of new symbols of identity in the architecture of Almaty, which combines reliance on previous experience and the inclusion of modern innovative approaches in shaping.

2. The architectural heritage of the early twentieth century is an important element of the urban culture of Almaty. The buildings of this period remind of the rich history and material heritage of the region, continue to inspire modern architects, residents and visitors of the city. Every building and structure in this city carry a piece of its cultural identity, embodying the richness and diversity of its heritage.

3. Intensive construction, reconstruction and urban development over the years of the capital's functions have provided a unique appearance for the city of Almaty. Interesting urban planning ensembles and urban planning nodes have been formed in the city, residential areas have grown, reflecting the unique spirit, history and atmosphere of this place.

4. The unique location of the city along the foothills of the Trans-Ili Alatau has left its mark on the picturesque appearance of the city, in the silhouette of which the panorama of the mountains plays an important role, this also contributes to the connection with the natural environment, providing it with the image of a "garden city".

5. In the XXI century, Almaty continues its path of searching for cultural identity in architecture. On the one hand, the city is becoming more and more open to modern architectural trends and technologies, on the other hand, there is an interest in national traditions and cultural heritage. The modern architecture of the city reflects a mixture of traditional and modern styles, while maintaining its uniqueness.

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REVIEW ARTICLE

ARCHITECTURE OF EASTERN KAZAKHSTAN (USING THE EXAMPLE OF THE HISTORICAL HERITAGE OF UST-KAMENOGORSK CITY)

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Abstract. *This article examines various aspects of the architectural and urban heritage of the city of Ust-Kamenogorsk from the 18th to the early 20th centuries. A number of architectural monuments of this key city for Eastern Kazakhstan have historical and cultural value for the history of regional architecture. The methodology of the article's research is based on the analysis of valuable, in architectural and artistic terms, historical buildings, as well as on the analysis of academic literature. In the stylistic and artistic orientation of the city's architecture, trends such as the"brick" style, eclecticism with interpretation of "order" styles, and eclecticism with elements of Art Nouveau can be traced. Characteristic feature of Ust-Kamenogorsk was a significant concentration of monuments in the city center, as well as in other cities (Semipalatinsk, Pavlodar), the historical building was dispersed. The architectural image of Ust-Kamenogorsk in the late XIX-early XX century was formed on the basis of the contrast between public buildings and single-story residential buildings, as well as on stylistic unity, the main artistic direction of which was the aforementioned eclecticism with a predominance of buildings in the "brick" style. The buildings and structures of industrial architecture, forming both the facade development of streets and organizing the urban space around them or creating significant urban accents due to their height, were also distinctive.*

Keywords: *fortified line, historical city core, fortress, stylization, urban structure, trading houses.*

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ШЫҒЫС ҚАЗАҚСТАН СӘУЛЕТІ (ӨСКЕМЕН ҚАЛАСЫНЫҢ ТАРИХИ МҰРАСЫНЫҢ МЫСАЛЫНДА (МЫСАЛҒА АЛА ОТЫРЫП)

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Аңдатпа. *Мақалада Өскемен қаласының сәулет-қалалық мұрасының жекелеген аспектілері қарастырылған. XVIII-XX ғасырдың басы. Шығыс Қазақстандағы маңызды қаланың бірқатар сәулет ескерткіштері аймақтық сәулеті тарихи-мәдени құндылыққа ие. Қала сәулетінің стилистикалық және көркемдік бағытын «кірпіш» стилі, «тәртіп» стильдерін түсіндірудегі сәулет бағытымен қатар заманауи элементтерді қамтитын эклектизм сияқты тенденцияларды байқауға болады. Мақаланы зерттеудегі әдістеме сәулеттік және көркемдік жағынан құнды тарихи ғимараттарды тарихи негіздеудегі академиялық әдебиеттерді талдауға негізделген. Күн өткен сайын «инерциялық» қалыптасулар қалалық сәулеттің өзіндік ерекшелігіне ие болды, Өскеменге тән қасиет басқа қалалардағы (Семей, Павлодар) сияқты қала орталығындағы ескерткіштердің айтарлықтай шоғырлануы еді, тарихи ғимараттар шашыраңқы сипатта қалыптасты. 19 ғасырдың соңы мен 20 ғасырдың басындағы Өскемен қаласының сәулеттік келбеті қоғамдық ғимараттар мен бір қабатты тұрғын үйлердің, сонымен қатар стилистикалық емес қауымдастықтың қарама-қайшылығы негізінде қалыптасты, оның негізгі көркемдік бағыты жоғарыда аталған «кірпіш» стильндегі ғимараттардың басымдығы бар эклектизм еді. Өнеркәсіптік сәулет ғимараттары мен құрылыстары көшелердің қасбеттік дамуын құрайтын және олардың айналасындағы қалалық кеңістікті ұйымдастыратын немесе биіктігіне байланысты маңызды қала құрылысы функциясын құрайтын өзіндік ерекшелігімен сипатталады.*

Түйін сөздер: *бекініс желісі, қаланың тарихи өзегі, бекініс, стилизация, қала құрылысы, сауда үйлері.*

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НАУЧНАЯ СТАТЬЯ

АРХИТЕКТУРА ВОСТОЧНОГО КАЗАХСТАНА (НА ПРИМЕРЕ ИСТОРИЧЕСКОГО НАСЛЕДИЯ Г.УСТЬ-КАМЕНОГОРСК)

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Аннотация. *В статье рассматриваются отдельные аспекты архитектурно-градостроительного наследия города Усть-Каменогорска. XVIII-начала XX в.в. Ряд памятников архитектуры данного, ключевого для Восточного Казахстана города имеют историко-культурную ценность для истории региональной архитектуры. Методология в статье исследования основана на анализе ценной в архитектурно-художественном плане исторической застройки, а также на анализе академической литературы. В стилистической и художественной направленности зодчества города прослеживаются такие течения как «кирпичный» стиль, эклектика с интерпретацией «ордерных» стилей, а также эклектика с включением элементов модерна. Характерной чертой Усть-Каменогорска была значительная концентрация памятников в центре города, в то время как в других городах (Семипалатинск, Павлодар), историческая застройка была рассредоточена. Архитектурный облик Усть-Каменогорска в конце XIX-начала XX в.в. формировался на основе контраста общественных зданий и одноэтажной жилой застройки, а также на стилистической общности, основным художественным направлением которой была вышеуказанная эклектика с преобладанием построек «кирпичного» стиля. Своеобразием отличались здания и сооружения промышленной архитектуры, формировавшие как фасадную застройку улиц, так и организующие городское пространство вокруг себя или же создающие за счет высоты значительный градостроительный акцент.*

Ключевые слова: *Иртышская укрепленная линия, историческое ядро города, крепость, стилизаторство, городская структура, торговые дома.*

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

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БЛАГОДАРНОСТИ / ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

Ust-Kamenogorsk was a key city in Eastern Kazakhstan during the late XVIII-early XX centuries. Its urban planning structure was based on a rectangular grid of streets that developed from the original core of the fortress settlement. In the future, the city, which has fortification functions, will be transformed into one of the largest shopping centers in Eastern Kazakhstan. The main direction of the city's development is the north-eastern territory between the rivers Ulba and Irtysh. The formed center of the historical development of the city of Ust-Kamenogorsk has been preserved in the most authentic form in the former shopping malls (on the former Kirov Street), with the representative architecture of that time, the so-called merchant workshops. Currently, the historical development of this street belongs to one of the valuable monuments of the historical architectural heritage of the city.

At the beginning of the XVII century, the eastern borders of Russia, which was formed as a centralized state, approached Kazakhstan. The Empire expanded its Siberian territories in a southerly direction, for which military fortifications were built on the borders. The accession of Kazakhstan to the possessions of Russia was of strategic importance because the Kazakh steppes are "the keys to the gates to all Asian countries" **(Kozlov, 2000)**.

In addition, Peter I became aware that "sand gold is found in abundance somewhere on the Irket River." And there was so much of it that it was mined "during high water with the help of polonas, carpets and cloth." To find these places, as well as to investigate the abuses of the Siberian governor Matvey Gagarin, an expedition was sent, headed by Guard Major I.M. Likharev. On August 12, 1720, a detachment of the Russian army arrived at the place where the Ulba flows into the Irtysh; A new fortress was laid here - Ust-Kamenogorsk, because it was here that the Altai Mountains ("Stone") suddenly ended, then the Irtysh rolled its waters across the plain **(Figure 1)**.

And although the expedition did not find rich placers of sand gold, the Ust-Kamenogorsk fortress appeared on the map of the Russian Empire, "the extreme southern tip of the formed Irtysh line." It was August 12, 1720, that is considered to be the day of the founding of the city of Ust-Kamenogorsk.

The rectangular palisaded fortress with an area of about 1 hectare with a population of 363 people was surrounded by a moat with an earthen rampart, fortified with bastions on which wooden towers were located. Inside there was a wooden church, barracks and administrative buildings.

(a) (b)

Figure – 1 a) The period of the Ust-Kamenogorsk fortress 1720-1765; b) The plan of Ust-Kamenogorsk in 1916 **(Espenbet, 2010)**

2 LITERATURE REVIEW

The historical and architectural scientific base on the history and architecture of Ust-Kamenogorsk is quite extensive, the following sources are used in the study: **Russia (1903); Asian Russia, 1914; Kasymbayev, 1974; Kasymbayev, 1990; Kozlov, 2000; Chernykh, 2004**. In the 1980s -200s, a number of works were republished, which mention historical information about Ust-Kamenogorsk: **Palass, 2000; Gaines, 2004; Finsch, Brem, 1982**. In the 1980s, studies of the architectural heritage of Ust-Kamenogorsk were conducted **(Baitenov et al., 1985)**. The architectural and artistic features of the folk architecture of East Kazakhstan are revealed in the monograph by Baitenov E.M. **(Baitenov, 2004)**. In 1992, a dissertation study appeared, affecting the stylistic features of architecture, including East Kazakhstan in the second half of the XIX-early XX century **(Isabaev, 1992)**, which was published in 2017 in a monograph. In the dissertation research of the author of the article, urban architecture of the XIX-early XX century is considered **(Yespenbet, 2010)**, some other publications are also used. The article uses archival materials (A.S. Yespenbet): Materials of the Central State Historical Archive of the Russian Federation; Materials of the State Archive of the Omsk region of the Russian Federation; Materials of the Central State Archive of the Republic of Kazakhstan.

3 MATERIALS AND METHODS

The following basic materials and methods were used in the work on the article:
- analysis of archival literary sources and museum collections;
- field surveys, including measurements of monuments and photographic fixation;
- architectural and artistic analysis of the historical buildings of the period under consideration as a valuable source for the development of stylistic trends and artistic trends that form the architectural "face" of the city;
- comparison and identification of conceptual approaches in the used artistic techniques in the considered historical buildings.

4 RESULTS AND DISCUSSION

In conclusion, the implications on the studied materials are presented and the results obtained are clarified. The time frame of the research is indicated by the study of the prerequisites for the formation and development of Ust-Kamenogorsk from the end of the XVIII century to the beginning of the twentieth century.

According to the reconstruction plan of 1766, the fortress is developing in three directions (except for the east) and covers an area of 7 hectares. Having absorbed the forstate, the settlement became the core of the formation of the residential territory and its social center. Gradually, the fortress grew into a town where cattle were sold and exchanged, wool and leather were traded. **(Karpenko, 2002)**.

After the annexation of Central Asia and Kazakhstan to the Russian Empire, the importance of fortified centers weakened. Now Ust-Kamenogorsk was already developing as a trading center and a transshipment base for the Altai mining industry. Administratively, it was considered only a "minor city" of the Tomsk province and only in 1869 it became a county town of Semipalatinsk province, the center of the Altai gold industry (there were over 100 gold mines in the county).

The achievements of Russian architecture, expressed in a number of progressive principles of urban planning, could not but be reflected in the general plan of Ust-Kamenogorsk. The principle of "regularity"-the new organization of urban development - implied compliance with a system that required uniformity of layout, geometric correctness of building a city plan, compliance with the established sizes of squares, streets, building heights, building boundaries. The city, born in the era of Peter the Great, had characteristic urban planning features of its time - clear functional zoning, regular street layout and relatively consistent development. An important feature of the primary architectural and planning structure of Ust-Kamenogorsk is the fragmentation of the city into separate residential areas (Levoberezhny, Tsentralny and Zaulbinsky). In 1845, the construction project of the former fortress was approved, which was essentially the first master **plan (History of the Kazakh SSR, 1979)**. There was an undeveloped territory of the former cemetery in the center. The placement of a church, shops, offices, and a manege in this area became the basis for the formation of the first urban center. Unlike the regular layouts of other Russian cities located on the banks of rivers or the sea, as a rule, it was created on the shore of a reservoir, the central square of Ust-Kamenogorsk was formed away from the river, in the geometric center of urban development. This happened because the city was systematically flooded by flood waters of the Irtysh and Ulba rivers, and the coastline was most prone to flooding and erosion. In addition, public buildings did not gravitate towards the river, because River navigation was poorly developed in the Ust-Kamenogorsk area. And finally, strategic considerations affected the central location of the city square - the desire to protect the center from external attack.

The shopping areas of the city were often located on the sites of former cemeteries. At the intersection of Senny Lane and Bolshaya Street (today Ordzhonikidze and Ushanov Streets), on the site of the cemetery, a square for the sale of hay and firewood appeared (now it is the main square of the city). There was once a Muslim cemetery on the site of the modern central market.

Later, in addition to the main residential area of the old city, rural settlements were also formed on the right bank of the Ulba: the villages of Dolgaya, Biryukovka, the villages of Komendantka, Staraya Zashchita, and on the left bank of the Irtysh - Zarechnaya Sloboda. Thus, Ust-Kamenogorsk has already developed in three main areas: the Central one, located between the Irtysh and Ulba rivers, Zaulbinsky, on the right bank and in the Zairtysh district - on the left bank of the Irtysh. The established primary architectural and planning structure of Ust-Kamenogorsk formed the basis for subsequent urban development projects **(Aurov, 1988)**.

Roads between the main cities played an important role in shaping the structure of the city. Freeing themselves from the rigid grid of streets outside the city, they smoothly described all the features of the suburban landscape, diverging in different directions, subsequently forming the main urban thoroughfares. Fragments of today's Bazhanov, Voroshilov streets (now Shakarim Avenue), Lenin Avenue were once one road to Semipalatinsk. There is practically nothing left of the road to Bukhtarma Fortress, but it was in this direction that a whole system of parks and squares arose. In accordance with the relief, the road to Bukhtarma turned steeply to the east, skirting the dried-up bayou and the forest area. The presence of a bend and an array led to the emergence of a park here (now named after Dzhambul).

At the end of the 19th and the beginning of the 20th century, Ust-Kamenogorsk experienced its first economic boom. From 1861 to 1913, its population grew fivefold (3332 and 17980 people, respectively), mainly due to the influx of immigrants. The main direction of the city's development was still the north-eastern one - the territory of Mesopotamia. At that time, riverbeds and tributaries had a more developed system and, together with the relief, were a landscape limiting factor. Since 1868 on the right bank of the Ulba, along the roads to Semipalatinsk and along the Bukhtarma highway to Sogra, a new residential formation is being formed - "Zarechny Khutor", which later became a large residential territory. From 1859 to 1917, the increase in urban areas amounted to 319 hectares, and all land developed for development amounted to 376 hectares. By the 1920s, the city center was fully formed - Sobornaya and shopping squares, where public and commercial buildings were located (today it is a park named after him. Kirov). Communication with the left bank of the Irtysh River was carried out by several ferry crossings. The promotion of Russian economic interests deep into Kazakhstan has influenced the development of cities of commercial, administrative and industrial importance. Some fortresses have become centers of lively trade in the 1760s, 1770s.

The most common was vertical zoning - the first floor for shops and the residential second (the house of merchant Rafikov, etc.). In the organization of the urban environment, two compositional planning techniques of commercial buildings are distinguished: linear and angular. With these layouts of retail facilities, mirror symmetry of facades or symmetry of rhythms is often observed (The "Meloman" Store.)

The main goal of the customer was the attractiveness of his retail facility and, consequently, its high-quality visual assessment. The mirror symmetry of the facade is designed for frontal perception, which is rarely feasible, the symmetry of the rhythms of the wall is comprehended in movement along them. The angular location of the retail facilities made it possible to use both techniques. The beveled corner of the store was the frontal element and often the axial center of the entire volume, the corner facades were designed using portable symmetry.

A characteristic feature of the commercial buildings of the late nineteenth century in the cities of Siberia in Northern and Eastern Kazakhstan was the connection of residential, commercial and government premises in one building. As a result, many of the buildings had the same compositional and functional schemes. The composition of the first commercial floors, facing the street with large storefront windows, was visually opposed to the rest of the building and the surrounding urban environment as a whole, a typical example of such a layout is the house of merchant Rafikov on Gorky Street **(Figure 2)**.

Merchant Rafikov's house and the shop were built in the late nineteenth and early twentieth centuries (Kirov str., 48, 50), in the central part of the city.

Figure 2 – *Rafikov merchant's house and shop.* Photo by E.M. Baitenov.

The building is two-storeyed (the store is located on the ground floor), rectangular in plan, made of brick. The main facade facing the Kirov Park is of the greatest interest. The facade is divided vertically into two parts by an inter-floor draft only slightly entering the side facade, horizontally the division takes place into four sections. At the ground floor level, on the first and third sections on the left, there are window openings covered with arched arches with decorative keystone, in the second section projecting two floors there is an entrance opening, in the fourth (last) – an arched passage into the courtyard. The ground floor windows have double-leaf shutters. At the second floor level, there is one window opening in the first three sections, and two in the fourth which is a wider one. The windows are covered with semicircular arches in archivolts protruding from the wall plane and decorative projections on both sides of the opening symbolizing rusticated pilasters. There is a rectangular panel under each of the windows.

In general, on the facade, the first three sections that make up the symmetrical composition are separated from the fourth by a pilaster, which is an analog of the corner pilaster of the left part of the facade at the second floor level, has rectangular projections and belts. Pilasters on their bases have decorative overhead pedestals. The crowning cornice of the building is a stepped overhanging rod supported by "flattened" brackets. The intermediate cornice is simpler, but also has an overhang and "rests" on a number of "arched" stalactite brackets.

Adjacent to the building is a one-story extension, made in the same style. The inter-floor thrust of the store facade continues on the facade of a one-story building, dividing it into two parts (lower and upper) and at the same time connecting the facades of both buildings.

In the lower part of the facade of the one-storey building there are entrance (2) and window openings, the upper part is decorative, the main motif of this "ribbon" are two large niches covered with arched arches rising above the crowning cornice. Moreover, these two dominants mark the place of entry. The piers between us are filled with rectangular panels with an X-shaped groove between them.

A very interesting technique has been used twice in the architecture of the bookstore building. For the first time in solving the angle, the pilaster does not protrude on the side facade, but the plinth, intermediate cornice, belts and "capital" on the side facade "go in" as if they were there, while forcing the eye to "finish" the body of the pilasters. In the second case, the window openings of the second floor seem to be limited on both sides by rusticated blades. But in fact there are no blades, there are only protrusions, the orientation of which makes us already mentally assume the existence of blades. This principle of "presence-absence" indicates a high degree of style refinement. The facades of the buildings under consideration continue the line of the corner building, currently plastered and whitewashed, but apparently also made in the "brick" style. It seems advisable to "clean" the mentioned buildings from plaster, which in general creates the opportunity to reconstruct the complex of historical buildings, which will form the space of a significant section of the block adjacent to the park.

In the organization of the urban environment, two compositional and planning techniques of commercial buildings are distinguished: linear and angular. "With these layouts of retail facilities, mirror symmetry of facades or symmetry of rhythms is often observed." An example of a linear character in the historical area of Ust-Kamenogorsk can be the building of Kirova Street with shopping malls, now the Meloman store. The corner composition is represented by former merchant shops, currently the Saule store **(Figure 3)**.

Merchant shop of Savva Semenov (1901) in Ust-Kamenogorsk (currently the “Saule” store) was built at the end of the XIX – beginning. XX century, located in the old central part of the city on the.Kirov Street, 52 and the exhibition hall of the Ethnographic Museum. The "Shop on the corner" was developed with the rise of trade and the competitiveness of the local merchants. "There is a need to develop new techniques and forms of placement and construction of retail facilities that ensure the greatest efficiency.

Figure 3 – Saule store (former merchant store of Savva Semenov). Photo by E.M. Baitenov.

The building is brick, L-shaped in plan, one-storey. The entrance to the building is organized from an angle, for which the corner section is "cut off" at 45 °. This cut-off section of the facade is framed by rusticated pilasters in the form of extensions of the pilasters of the upper part protruding above the roof, which are the support for the arched completion.

The facades of the building have wide rectangular window openings with U-shaped (П-shaped) rusticated framing. Rusticated pilasters are located in the piers. At the base, the building has a protruding plinth, and at the top it is covered by a profiled cornice with a number of overhead arches typical of shopping malls.

The front facade of the store facing the square in front of the October cinema is deaf: its corners are framed by rusticated pilasters continuing above the roof in the form of square tops with four pitched roofs crowned with decorative lanterns. Currently, the described end facade is covered with a kiosk and posters. It seems advisable to place them in such a way as to close the new extension to the cinema, thereby opening the front facade of the store, which in general will have a favorable effect on the development of the street. The store building was rebuilt, in particular, the window openings were changed. The building is a typical commercial building for the city of the late XIX – early XX centuries and forms part of the historical core of the city, making out the corner of the block and sets the characteristic scale of the building. The technical condition of the building is satisfactory. The decorative character of the architecture gives it an artistic interest as well.

Merchants tried to build their shops in the busiest places of the city, that is, at the intersection of streets. Thus, the corner section of the intersection determined the layout composition of many commercial buildings in the cities of the province. The main goal of the customer was the attractiveness of his retail facility and, consequently, its high-quality visual assessment. If the mirror symmetry of the facade is designed for frontal perception, which is rarely feasible, then the symmetry of the rhythms of the wall is comprehended in movement along them. The angular location of the retail facilities made it possible to use both techniques. The beveled corner of the store was the frontal element and often the axial center of the entire volume, the corner facades were designed using portable symmetry.

Merchant Kozhevnikov's store (Altai Restaurant) **(Figure 4)**, built in 1914 (59 M.Gorky Street).

Figure 4 - Altai Restaurant (former shop of merchant Kozhevnikov). Photo by E.M. Baitenov.

The building is brick, square in plan, has a pitched roof made of roofing iron, two facades facing intersecting streets are most developed, the main entrance is solved from the corner. The facades have window openings with a protruding frame with arched ends, protruding window sills. The planes of the tympanums have a central decorative spot with two currency-shaped figures on both sides. The piers are decorated with recessed rectangular panels. The entrance vestibule is arranged in a corner section cut off at 45° to the intersecting facades. The double-floor door is enclosed in a decorative profiled U-shaped frame. The porch is open on three sides. There is a protruding plinth at the base; a crowning cornice runs along the top of the building, consisting of a number of "decorative crackers fused at the top and bottom". The corners of the entrance part and the protruding areas on the facades are marked by square roof turrets in the plan. However, these turrets, having no beginning on the facade (cf. the building of the printing house), both in style and color (the facades of the restaurant are multicolored) fall out of the general character of the building, this alienation is emphasized by the line of the cornice.

The building is typical in architecture for the beginning of the XX century. with a peculiar mixture of shapes and details and their interpretation (cornice solution). An extraordinary solution to the facade surface of the building is characteristic, the search for a new one using the techniques of the Art Nouveau style. The architectural solution of the building lacks expressiveness, but as a typical building in scale and architecture, it is deservedly taken under protection with a local category of protection

In addition to trade, gold mining, local industry, and shipping are developing in the region, which contributed to the development of capital construction: residential buildings, public buildings, merchant warehouses, and workshops. The buildings bear the imprint of the Russian "brick" style. Shopping malls stretched in length, shops with identical windows and doors, limit the central rectangular market square, inside which long counters are located **(Baitenov, 1985)**.

Figure 5 - Cinema "October" (former cinema "Echo"). Photo by E.M. Baitenov.

The Echo Cinema (cinematograph), **(Figure 5)**. in Ust-Kamenogorsk, it was built on the initiative of the political exile O. Kostyurin in 1909-1911 (Kirov str., 54). In 1918, the building housed the headquarters of the Red Guard detachment of the Soviet Department. From the first days, the State Department abolished the police, its functions were transferred to the Red Guard, there were about 30 people in the detachment, who were scattered on the second floor. Since 1921, the name "Echo" has been renamed the cinema "October".

The building is an organic part of a low-rise historical building, somewhat distinguished from the facade building by its "semi-island" character of the location. The building is brick, two-storey, square in plan, with a gable roof. The facade facing Kirova Street has a strictly symmetrical composition of three sections – the central and two laterals, vertically the facade is divided into parts according to the floors. In the central section of the first floor there is an entrance opening, a low porch leads to it, on both sides of it, large window openings are in the side sections. With a fairly fine grid of bindings. There is a full-width window above the entrance.

The central section is "clamped" by massive square pilasters on pedestals, similar and even more massive three-quarter pilasters with complicated capitals, the corners of the building are flanked at the ground floor level.

The second floor has been worked out in more detail, the central section has a balcony with a small extension, supported by pilasters of the lower floor. The outer corners of the balcony are decorated with round columns "detached" from the walls to the entire height of the floor, bearing the roof over the balcony and resting on the pilasters of the first floor. The columns of the second floor have capitals and separate belts from the trunk and roof extensions in the form of tops connected by a decorative wall. The balcony is crowned with a finial of metal strips in the form of a figure with a keeled outline. A doorway with a round window above it leads to the balcony. The side sections of the facade of the second floor also have one similar window on the first floor but having a lower height. The windows are enclosed in U-shaped ramps, the piers adjacent to the central sections have pilasters. The corners of the second floor are decorated with square columns rising above the roof. The side facade facing the "square" is much simpler, with the exception of three window openings, it is smooth and attracts attention only with its gable silhouette.

In 1958, the great hall was reconstructed, and the small hall was built in the same year. The building is currently being renovated. The security category is local, the boundaries of the security zone have not been established, the building is used for its intended purpose. The modern annex to the cinema, located between the old cinema building and the former merchant's store, currently "Saule", completely falls out of the historical development.

The cinema building is typical of the architecture of the late XIX – early XX centuries. This also applies to the characterization of the composition as a whole, where there is a search for a bright individual image of a public building with a strong accentuation of the entrance, with the device of large window openings, as well as to the interpretation of individual forms and details, which are characterized by stylization features of medieval architecture, plastic expressiveness.

The Echo cinema, the ethnographic museum (formerly the Mariinsky College); the buildings of the shopping malls on Kirova Street, the former Inkov pharmacy and the brewery office (the original functional purpose is unknown) need reconstructive measures to restore the original architectural image. The administrative building on Kirova Street (Tokhtarova Street), the former trading shops on Gorky Street, the state bank building and the building of the former fire station require a special solution to the question of reconstruction methods, since the degree of their restructuring is very significant.

The losses incurred by the historical complex, as well as the presence of late-period buildings, do not allow us to talk about complete restoration or conservation of the historical center. However, to restore and consolidate the compositional significance of the historical urban core, to preserve the scale and image of the building front, some reconstructive measures are possible. For example, considering the physical deterioration and historical and architectural value of the shops on the street. Kirov, during the restoration work on this historical area, the method of "hidden reconstruction" using elements of "recreation" was applied. This is an unpretentious chain of single-storey buildings in architecture, currently it is a kind of fence perk, broken on the site of the main market square, preserving the scale of the surrounding historical buildings.

When designing security zones, a certain approach has been developed to identify their boundaries. Along the streets, where the influence of the monument and its visual connections are most significant, the security zone has fairly wide boundaries, while on the intra-block territory it is limited to the monument area. Modern economic conditions are characterized by a commercial approach to the use of buildings, especially in the historical zone, as in places of active social and business life of the city, which leads to the development of the relevant territories. Such actions entail a functional and planning transformation not only of historical buildings, but also of the surrounding space. This is manifested in the expansion and development of historically established spaces and giving them new modern functions. The organization of the architectural space of the historical zone of the city should be focused on the use of the territory in accordance with the modern functional structure.

Traditional elements of urban architecture - historical streets, squares - do not change their usual appearance, but the real space of human functioning does not close within these boundaries. It develops from the inside, permeating buildings and neighborhoods, forms additional internal connections, platforms, passages are woven into a rigid canvas of architectural stereotypes of the old city fixed in the mind of the citizen.

A continuation of the urban environment is a shopping and pedestrian zone; therefore it requires an architectural and spatial organization that combines interior elements with the character of a shopping street. It is necessary to preserve the scale of buildings and space, and the corresponding construction of the tectonics of the facade plane of new buildings. The subject arrangement and improvement of the internal space of pedestrian streets should have elements of accompanying and seasonal maintenance, a wide range of small architectural forms, various types of visual information, signs, advertising, special paving, recreation areas, lighting and landscaping. This area should be painlessly reconstructed with minimal disruption of the main function. Comparing the data from the passports of architectural monuments in the central part of Ust-Kamenogorsk, it is possible to identify some architectural techniques characteristic of historical buildings as a whole. The buildings are located along the streets. The feeling of elongation is confused by rusticated pilasters dividing the facades into sections. During the construction, the technique of decorative brickwork was used, the so-called brick or "merchant" style: cornices of complex profile, curved design of window and door openings, arcature belts, such motifs of patterned relief masonry as crackers, flies, brackets, runners, etc. The color of the buildings was created by the natural color of natural building materials. It was mostly wood and brick (usually red, sometimes plastered). "The palette, which originated from natural materials, later becomes the norm, expresses a sign of style." A characteristic coloristic feature of the building is two-tone, light figured details against the background of red brick walls.

Therefore, during the reconstructive events of the historical environment, a color solution in neutral pastel tones is possible, harmoniously combined with the natural and traditionally formed color scheme. Such a relationship will be one of the favorable conditions for a person. Since "Everything created by nature is considered harmonious: natural colors, their combinations ..." Because often, precisely because of the lack of such harmony, citizens try to get out to the protected corners of nature in order to fully relax. "The city is tiring, not being able to replace wildlife for a person." In addition, "... the idea of coloristic subordination to the natural environment has deep historical roots. For centuries, man has cultivated the natural landscape and integrated architecture into the natural environment. Architectural and natural integrity was natural in people's minds, and buildings were seen as an extension of the landscape."

Two buildings of O.F.Kostyurin's mechanical workshops **(Figure 6)**, erected at the beginning of the twentieth century, 1900-1907, in Ust-Kamenogorsk are located on Kirova str., 45.

The first one houses the Znanie Society. The building is built of brick, two storeys high. The facade facing Kirova Street on the first and second floors has three window openings, on the ground floor they are blocked by arched arches with decorative archivolts having a protruding keystone alternating protruding and sinking sections. The window openings of the second floor are rectangular in outline (the middle opening is wide, the side ones are narrow), above them there are three superimposed adjacent arch arches resting on decorative brick brackets, the middle arch is wider than the side ones and is located higher. Panels with a round figure in the center are arranged under the window openings. The building has an intermediate (floor-to-floor) and crowning cornices, the first one is solved as a draft with a number of crackers at the bottom. The crowning cornice consists of a number of decorative brackets.

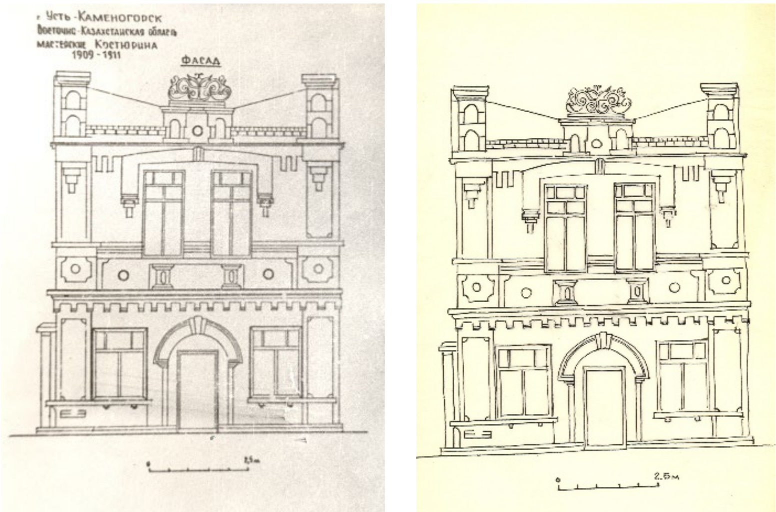

Figure 6 – Two buildings of O.F. Kostyurin's mechanical workshops (Baitenov et al., 1985).

Pilasters are arranged in the corners, which have a continuation above the cornice, there is also an attic with two turrets in the center and a wall with a sagging crown between them. On both sides, an extension on each side adjoins the described volume. On the left side, the one-story extension has a window opening, covered with a bow arch, facing Kirova Street, the corner is decorated with a shovel. On the right side, the annex has an entrance opening, the second floor of the annex is wooden.

The facade of the second building, facing Kirov Street, architecturally resembles the facade of the mechanical workshops of Kostyurin, located nearby. However, there are differences. The building also has two floors, although there are no extensions. The first floor is plastered and whitewashed and has an entrance door with a semicircular overhead arch in the center, there are two window openings on both sides of the door. The second floor also has two window openings, which are located in the central part of the facade surface and have the appearance of a large paired opening framed by a wide arch with brackets.

The placement of buildings in the block is original. They face the front line of the street with narrow end facades, and the buildings themselves go into the depths of the block, in the manner of medieval urban development.

The front end facades are also original from architectural side, they are typical in architecture for the late nineteenth and early twentieth centuries, with the search for new means of expression, with giving the buildings a bright personality.

5 CONCLUSION

In the architectural heritage of Ust-Kamenogorsk, a number of architectural techniques characteristic of the historical development of the XIX- early XX centuries, can be distinguished. The buildings are located along the streets. The "linear" character of the building is "broken up" by rusticated pilasters dividing the facades into sections. During the construction, the technique of decorative brickwork was used, the so-called brick or "merchant" style: cornices of complex profile, curved design of window and door openings, arcature belts, such motifs of patterned relief masonry as crackers, fly, brackets, runner, etc. The color of the buildings was created by the natural color of natural building materials. It was mostly wood and brick (usually red, sometimes plastered). "The palette, which originated from natural materials, later becomes the norm, expresses a sign of style." A characteristic coloristic feature of the building is two-color: light figured details against the background of red brick walls. An analysis of public buildings created in Ust-Kamenogorsk during this period shows that their architecture, as in Russia in the second half of the 19th century, was dominated by stylization, and since the 80s of the 19th century. 20th century. modernity arises. In the architecture of the Echo Cinema (1909-1911), two buildings of the mechanical workshops of O. Kostyurin can see that the slogan of modernity "freedom from the template" is akin to the principles of shaping architecture of the Middle Ages, the principles of expediency and strict connection with the specific conditions of place and time. The method of using "exemplary" facades made it possible to carry out the main task in the formation and construction of cities -to achieve the integrity and originality of the building.

Ust-Kamenogorsk, in the course of its formation and development, is transformed from a fortification urban planning formation into a commercial city when the urban fabric goes beyond the boundaries of the "fortress city". Being formed in the natural forest-steppe landscape between the rivers Irtysh and Ulba, the city becomes a significant city in Eastern Kazakhstan. The city's street and road network was formed by a rectangular grid of streets. The city center was built up with administrative and commercial buildings, which are influenced by the artistic and stylistic trends of the metropolis -from classicism, the end of the XVIII century. eclecticism of the nineteenth century, before the belated "brick" style of the late nineteenth and early twentieth centuries, with elements of emerging Art Nouveau with regional features of "modernized eclecticism".

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RESEARCH ARTICLE

URBAN PLANNING ANALYSIS OF THE NEIGHBORHOOD IN ASTANA CITY

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Abstract. *The authors investigated urban planning challenges in Astana by examining design documents, conducting a field survey of the territory, and conducting a sociological survey. Based on the analysis of the data obtained, four distinct groups of problems have been identified: those related to urban planning, which are linked to the growth of the urban population and the development of transportation infrastructure; those resulting from deviations from regulations and the use of unreasonably standardized coefficients in local design; those related to scientific and technical issues, which arise from the optimization of construction and installation work and lead to uncomfortable conditions; and environmental problems that arise from the reduction of green spaces. All identified problems affect the level of social comfort in the living environment. An analysis of the emergence of these problems reveals a weakness in urban design. In a detailed planning project, architectural schematicity and instability lead to the fact that individual infill developments can edit primary urban planning decisions according to the number of floors, configuration of the residential complex, functional affiliation of the site, development of transport schemes, etc. Consequently, recommendations have been put forth to forego infill development and instead prioritize neighborhood development and the necessity of establishing local planning authorities.*

Keywords: *residential development, masterplan, detailed planning project, infill development.*

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АСТАНА ҚАЛАСЫНДАҒЫ АУДАННЫҢ ҚАЛА ҚҰРЫЛЫСЫН ТАЛДАУ

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Аңдатпа. *Авторлар жобалық құжаттаманы зерделеу, аумақты далалық зерттеу және социологиялық зерттеу жүргізу арқылы Астана қаласының қала құрылысы мәселелерін зерттеді. Алынған мәліметтерді талдау негізінде проблемалардың төрт бөлек тобы анықталды: қала халқының өсуімен және көлік инфрақұрылымының дамуымен байланысты қала құрылысы; нормативтерден ауытқумен және жергілікті жобалауда негізсіз нормаланған коэффициенттерді қолданумен байланысты; құрылыс-монтаж жұмыстарын оңтайландыру кезінде туындайтын және ыңғайсыз жағдайларға әкелетін ғылыми-техникалық мәселелерге байланысты; жасыл аумақтардың қысқаруынан туындайтын экологиялық. Барлық анықталған проблемалар өмір сүру ортасындағы әлеуметтік жайлылық деңгейіне әсер етеді. Осы проблемалардың пайда болуын талдау қала құрылысының әлсіз жақтарын көрсетеді. Егжей-тегжейлі жоспарлау жобасында сәулеттік эскиздік пен тұрақсыздық жеке дамудың қабаттар санына, тұрғын үй кешенінің конфигурациясына, учаскенің функционалдығына, көлік схемаларын әзірлеуге және т. Осыған байланысты ықшамаудандарды дамытуға басымдық бере отырып, толтыру құрылысынан бас тарту және жергілікті жоспарлау органдарын құру қажеттігі туралы ұсыныстар берілді.*

Түйін сөздер: *тұрғын үй құрылысы, бас жоспар, егжей-тегжейлі жоспарлау жобасы, толтыру құрылысы.*

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ГРАДОСТРОИТЕЛЬНЫЙ АНАЛИЗ МИКРОРАЙОНА В ГОРОДЕ АСТАНА

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Аннотация. *Авторы исследовали проблемы градостроительства в Астане, изучив проектную документацию, проведя полевое обследование территории и социологический опрос. На основе анализа полученных данных были выделены четыре отдельные группы проблем: градостроительные, связанные с ростом городского населения и развитием транспортной инфраструктуры; связанные с отступлениями от нормативов и использованием необоснованно нормированных коэффициентов при проектировании на местах; связанные с научно-техническими вопросами, возникающие при оптимизации строительно-монтажных работ и приводящие к некомфортным условиям; экологические, возникающие из-за сокращения зеленых насаждений. Все выявленные проблемы влияют на уровень социального комфорта в жилой среде. Анализ возникновения этих проблем выявляет слабые места в городском дизайне. В проекте детального планирования архитектурная схематичность и нестабильность приводят к тому, что индивидуальная застройка может редактировать первичные градостроительные решения по этажности, конфигурации жилого комплекса, функциональной принадлежности участка, развитию транспортных схем и т.д. В связи с этим были выдвинуты рекомендации отказаться от точечной застройки, отдав предпочтение развитию микрорайонов и необходимости создания местных органов планирования.*

Ключевые слова: *жилая застройка, мастер-план, проект детальной планировки, точечная застройка.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

The city is a functional and spatial environment comprising integrated planning elements; residential, public, and industrial areas; buildings and structures; green spaces; and public open spaces. The main structural component of the city is the residential neighborhood **(Kain and Quigley, 1970)**. When designing a residential micro-district, the project's main task is to create an urban environment for the residential area **(Konsti-Laakso and Tero Rantala 2019)**. This should consider all the engineering, technical, social, domestic, architectural, and planning requirements. The design should be characterized by high-quality architectural and spatial composition, meeting the convenience requirements for living and the population's life.

Following the economic downturn, Kazakhstan experienced revitalization of architectural and urban planning activities. The transfer of the republic's capital to Astana and the city's associated intensive reconstruction and development provided new impetus to this sphere. The master plan for the new capital was developed through international competition that involved prominent architects from Europe, Australia, Japan, and Kazakhstan. However, the plan must consider several indicators crucial for creating a comfortable living environment. This oversight became apparent because of Astana's rapid population growth and expansion.

This study aimed to identify normative inconsistencies in urban planning documents at different levels. The authors conducted a field survey of one of the city's micro-districts and compared the findings with city officials' detailed planning plans.

2 LITERATURE REVIEW

Domestic scientists have studied problems with the formation of urban elements and methods of their interaction. For example, in the article "Features of the Social Infrastructure Formation of Astana City," the authors analyzed the current state of the city's social infrastructure and showed that this element of urban development at the district and local levels affects the population's living conditions. At the same time, the authors do not study design solutions of regional significance and do not consider the close interaction of the social infrastructure with the residential area **(Sarsembayeva et al., 2023)**.

In the work "Development of the Architecture of Residential Buildings from the Beginning of XX to XXI Century (By the Example of Astana)," the group of authors shows the features of the construction of residential buildings, as well as their formation in the course of the search for new architectural, planning, volumetric and urban solutions in the context of socio-economic transformations in the development of society. However, this work focuses on examining small complexes, leaving aside the issues of their interaction with each other and other urban elements **(Toishiyeva et al., 2023)**.

It should be noted that the scientific community often highlights the need to use underground spaces. In an article titled "Planning an Adaptive Reuse Development of Underutilized Urban Underground Infrastructures: A Case Study of Qingdao, China," the authors stated that urban underground infrastructure is vital to urban sustainability **(Qiao, 2023)**.

Thus, this study differs from existing works in its consistent analysis of urban spaces, from design solutions to their actual implementation, a comparative analysis of theoretical material and the results of a field survey, and a wide range of studies on urban elements.

3 MATERIALS AND METHODS

3.1 Study design

To achieve this research objective, this study used a mixed-methods research design based on a combination of data collection and analysis requirements. In particular, the authors considered the peculiarities of the combinatorics of the elements of qualitative and quantitative approaches within the framework of one study.

3.2 *Document analysis*

Thematic materials were collected during the research process, and scientific research, literary sources, archival, and design documentation in urban planning were analyzed. These materials form the basis for research in the search for urban planning problems.

3.3 Survey

To investigate the existing construction and regulatory documentation regarding applied coefficients in designing local areas and determining parking spaces, a survey of 410 people was conducted. Public opinion was assessed in 50 residential complexes under different urban planning scenarios, varying in housing classification, residential density, and functional structures. The survey comprised 12 questions that generated an impartial depiction of the feasibility of specific standards. During the population survey, face-to-face interviews were employed; respondents completed questionnaires individually or as part of a group discussion. Data analysis of the sociological survey uncovered patterns for each queried item.

3.4 Field survey

The study employed a field survey method to investigate the city area's architectural and urban planning solutions under examination. The study covered over 15 urban planning areas, streets, and public spaces. The collected data were arranged in a comparative table.

3.5 Graphical analysis

This method was utilized to undertake a comparative analysis of design documents and field surveys, forming a table that consistently highlights urban planning issues.

4 RESULTS AND DISCUSSION

The population of Astana has steadily increased because of its diverse political and socioeconomic conditions. According to an expert forecast, the urban population is estimated to reach approximately 3 million by 2050, which is approximately 12% of the nation's total population **(Mamedov 2022)**.

As the population expands, the number of urban development initiatives and the city's territory increases. Consequently, new architectural and urban planning documents and projects have emerged. One of the principal urban planning documents is the master settlement plan, a general urban planning document at the local level that establishes the priorities, directions, and strategy for a settlement's integrated urban development; the primary functional use of its territories; the primary parameters for engineering, transport, and social infrastructure development; and the conditions necessary to form a safe and favorable living environment.

The master plan of the settlement was developed following the main directions of the state urban planning policy, considering the socio-economic planning and forecasts of the development of the country and its administrative-territorial units, existing international, national, regional, local, territorial, and sectoral programs.

The urban environment parameters, such as the anticipated population size and socio-demographic structure, are determined through the master plan of the settlement. The plan considers suburban areas while establishing directions and boundaries for territorial development. It also proposes functional zoning and territory planning, territorial organization, and parameters for developing residential, industrial, social engineering, transport, and other infrastructure. The plan also prioritizes and reserves development areas for populated and suburban regions, ensures safety, and creates a comfortable living environment, while protecting natural objects, complexes, and historical and cultural values.After the development of the master plan for the city, the subsequent stage of urban planning commences—the detailed planning project (hereafter referred to as the DPP) - which is an urban planning endeavor conceived for specific subdivisions of territories and functional zones within settlements, as well as areas positioned outside of settlements. DPP and development projects were developed in accordance with the settlement's master plan. This plan is established under the planning structure elements outlined in the master plans, town planning regulations, and the concept of unified architectural style. Additionally, these projects are based on the planning structure elements and town planning regulations outlined in the Rules of the Organization established in the master plan of settlement development. The DPP comprises graphic materials depicting the layout of the planned territory within the city system, organization of the road network and transportation, vertical planning and engineering preparation of the territory, engineering support, conceptual development, urban zoning plan, red-line layout plan, reference plan, and cross-sectional profiles of streets. Furthermore, the DPP aims to address the challenge of creating accessible conditions for individuals with limited mobility to access social and other amenities without hindrances.

Once the DPP has been approved, an infill development project (the final design stage) begins. An infill development project is a project with individual architectural and urban design solutions that is conducted considering the DPP and the existing or planned environment. These projects are located on designated urban sites issued by government agencies and their design must be based on the DPP.

To identify urban planning issues, a site in Astana was chosen in the area encompassing Charles de Gaulle, A. Tokpanova streets, and Tauelsizdik and B. Momyshuly avenues. The site was selected for its potential to reveal weaknesses in the current planning strategies. Historically, the site was situated on the outskirts of the city and consisted of one-story garages. Nonetheless, owing to the steady expansion of the capital, it has been repositioned as an urban hub with thriving social amenities and a triathlon park providing a recreational area for visitors. Consequently, the rapid progression of the area marked its landscape.

During the field survey of a selected site, clusters of issues with four distinct categories were recognized: urban planning, normative, environmental, and scientific-technical. It is important to note that these issues impact social well-being, and many of them can affect multiple groups of people.

The urban planning category encompasses issues related to the decline in available residential areas in cities caused by the ongoing urbanization process. This necessity dictates that we augment development intensity by increasing density **(Kornilova & Saekova 2018)**.

Additionally, there are queries concerning architectural and urban planning concepts, as well as the functional equipment of this location. Challenges arise concerning compliance with urban planning regulations and addressing the impact of infill development on the surroundings.

Field analysis indicated the need for architectural, stylistic, and urban planning concepts. The DPP requires accents and ideas for urban planning. The primary content of this urban planning document is displayed through loosely arranged architectural volumes, without perspective formation. The residential developments currently under construction or have been completed do not align with the established DPP regarding the number of stories **(Figures 1; Figure 2)**, nor do they comply with the plan layout and the required distance from the red line and building line.

A comparison of DPP and field survey analyses revealed a reduction in recreational areas. In some cases, a residential complex is located in areas designated as green areas **(Figure 1; Photo 4)**; in others, the built-in premises of the complex are located in public green spaces **(Figure 1; Photo 5)**. Each site was designed as a functionally independent urban element. However, there is only one five-story office building in this area **(Figure 1; Photo 6)**, and social infrastructure facilities such as schools and kindergartens still need to be built. In contrast, many residential complexes have been constructed **(Figure 1; Photo 7)**, while others are under construction. The DPP also mentions residential developments featuring kindergartens but omits details regarding the type of preschool institution and number of groups. Meanwhile, a field survey revealed the absence of preschool education organizations within the specified residential complex.

The absence of coordinated planning, wherein an architect of a residential complex fails to consider the architectural designs of another construction site, results in inconsistent vertical markings

(Figure 1; Photo 8), as well as the emergence of fences and retaining walls, eventually leading to the creation of an abandoned area **(Figure 1; Photo 9)**.

There was a low level of pedestrian accessibility comfort, as shown in Photos 10 and 11 **(Figure 1)**, for both completed and under-construction objects in the study area. This is because of the need for sidewalks and inconvenient movement caused by parking or construction fencing. These fences should be positioned along the red line instead of encroaching on sidewalk boundaries.

The normative group comprised issues related to the deviation of actual decisions from the existing construction regulatory framework. Under the general provisions of Building Regulations 3.01-01Ac-2007:

- The distances between residential buildings, parking lots, entrances, and exits should follow the specifications listed in Table 13.25. To comply with this standard, there should be at least 10 m between open and ramp-type surface parking lots depending on their capacity. However, this standard is often not met in this area, as shown in Photo 12 **(Figure 1)**.

According to Table 6.5, the minimum provision of green areas in a residential group, micro-district, or residential area should be met. The table indicates that the number of green spaces in the surrounding areas, specifically unconstructed land within the confines of the red lines, should be at least 5 m^2 per person. Images of the adjacent regions show a negligible segment of the green zones, which span less than 30 m^2 **(Figure 1; Photo 13)**.

- paragraph 6.0.3: When planning and constructing residential areas, pedestrian access to public green spaces such as squares, boulevards, and gardens should be at most 400 m. Currently, there are no green spaces in the area.

- paragraph 6.1.9: The green spaces adjacent to areas for children to play and adults to relax should adhere to the minimum standards in tables 6.4 and 6.5. Areas designated for games and recreation should be designed at a rate of 0.5-0.7 m^2 per person. The distance between the windows of the houses and the boundaries of recreational areas should be a minimum of 10 and 12 m for games. It is recommended that the placement of sports grounds is designed at a rate of 0.8-0.9 m^2/person, considering the area of sports grounds in built-in and built-in-attached parts of buildings that are at a minimum of 0.4-0.45 m^2/person, while ensuring the minimum standard of green spaces in adjacent areas. It is easier to verify these prerequisites using the necessary design documentation. Nevertheless, based on the number of flats, we can infer that the territory's area does not fulfill these requirements.

The current state is alarming in numerous cities - residential constructions morph into solid asphalt blocks, functioning as parking spaces for multiple private vehicles **(Yanovskaya & Merenkov 2023)**.

The provision coefficient for parking spaces was routinely adjusted in this regard. According to Order No.32-NK issued on March 1, 2023, normative requires further information by adding the availability of parking spaces for one apartment in the parking lot as follows: for class I–2, class II–1, class III–0.5, and class IV–0.5. Failure to consider the number of rooms or living spaces when determining this coefficient would result in an underestimated number of parking spaces in the design. Based on a sociological survey, most residents in class III and IV residential complexes own cars. Furthermore, large families residing in apartments with three or more rooms have two vehicles. Additionally, elite residential complexes allocated the same coefficient of two car spaces for one-room to six-room apartments.

Environmental issues are closely related to the placement and quantity of green spaces. The primary sources of noise pollution in urban areas are transportation, industry, construction, roads, loading and unloading machinery, attractions, stadiums, children's play areas, and sports grounds. Approximately 30%–40% of the global urban population lives in conditions of acoustic discomfort **(Chelnokov et al., 2015)**. Acoustic discomfort can result in various diseases, including psychoneurological, cardiovascular, and hearing impairment. Furthermore, it can cause a decline in individual performance **(Potaev 2014)**. Thus, in the area being reviewed, no sanitary protection zone exists between the residential complexes and the construction market **(Figure 2; Photo 14)**. As described in the DPP, road landscaping is symbolic because it mainly consists of small lawn areas without trees **(Figures 2; Photo 15)**.

Photo 1. Failure of the urban planning to comply with the DPP and the construction site

Photo 2. Unmanaged blend of developed and undeveloped zones

Photo 3. Non-compliance with height regulations outlined in the DPP

Photo 5. Increased provision of built-in spaces in place of recreational areas

Photo 6. Scope of business function

Photo 7. Construction of social infrastructure facilities

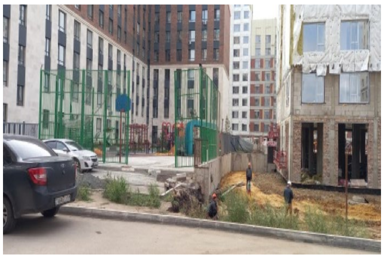

Photo 8. Difference in vertical marks

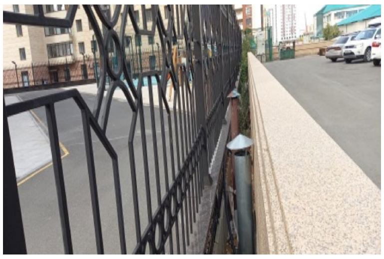

Photo 9. Residential developments are segmented from each other, with distinct boundaries and limited physical connections

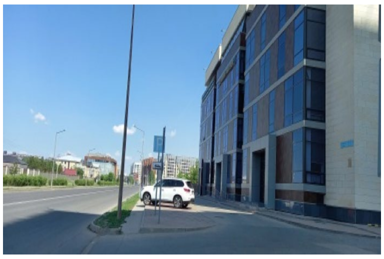

Photo 10. Parking spaces pose a hindrance to pedestrians

Photo 11. Pedestrian accessibility and station condition

Photo 12. Parking spaces are located near the complex

Photo 13. Adjacent area to the residential complex

Figure 1 – Searching for urban planning problems (author's material).

Transport is a fundamental component of a city's functional framework. It facilitates the movement of people and goods throughout the city and serves as a reliable indicator of economic and social status and growth **(Chelnokov et al., 2015)**.

Transport is a crucial element in modern urban areas, as it serves two primary functions: facilitating efficient movement within city limits and connecting the municipality with adjacent territories. Since transport enables the exchange of human, material, energy, and other assets across different areas of the region, it is the cornerstone of infrastructural development within settlements. Transportation flows ensure that settlements are supplied with the necessary provisions and distribute labor throughout the urban environment **(Roy, 2023)**.

Despite the undeniable need for transportation routes, they must be designed logically. Duplication of roads to each complex and paved car park reduces the natural areas that can be used for green spaces **(Figure 2; Photo 16)**.

The close proximity of high-rise residential buildings can significantly worsen sanitary and hygienic conditions, such as inadequate ventilation and reduced sunlight exposure. For instance, in Photo 17, a 25-story building under construction is located adjacent to a 9-story block, with a mere 19-meter separation, which may also impact the psychological well-being of the occupants.

According to experts from the World Health Organization (WHO), environmental factors are responsible for 23% of all disease cases and 25% of cancer cases, with two-thirds of those affecting childhood morbidity. Furthermore, unfavorable environmental conditions lead to 3 million children under five being affected annually.

The engineering and technical challenges category encompasses problems related to complex construction solutions, primarily underground work and specialized equipment for parking facilities and systems. The differences in vertical road elevations result in the formation of ramps, stairs, and the flooding of low-lying areas due to ineffective stormwater drainage operations. Additionally, the increased utilization of underground space for parking has led to the creation of large ramps and asphalt courtyards. However, the current standards must guide the use of underground space, which is ultimately determined by the construction client's requirements specified in the design brief.

The comprehensive assessment revealed disparities between the proposed architectural and urban planning solutions and those implemented in reality. Specifically, incorporating additional residential buildings and floors resulted in escalated population density and the consequent compression of the area, leading to diminished recreational facilities and imposing an additional burden on social and transport infrastructure.

Inadequate development of the area, as construction of a fresh facility starts near an existing residential complex, results in deteriorating sanitary and hygienic conditions for inhabitants due to dust, dirt, noise, and construction and installation work near the house **(Diez Roux & Mair 2010)**. It should also be highlighted that there is a need for more social infrastructure amenities, like preschool and educational facilities, to be established at municipal expense.

The identified structures are intended to be at the district’s heart. The surrounding area is heavily populated with no city facilities under construction. This will lead to adverse future living conditions.

Deviation from prescribed norms in design, construction, and installation work adversely affects the overall comfort level of urban development facilities. Simultaneously, compliance with the present construction regulatory framework for local areas is challenging and uneconomical for customers in smaller regions due to requirements such as the landscape area, sports grounds per person, and indentation of residential buildings from sports areas. In this regard, these areas are expected to be inadequately planned and, in some instances, significantly reduced in size. In addition, the predefined formulas for calculating parking occupancy still need to be completed and fail to factor in the current environment.

The absence of proper sanitary protection zones and spaces for leisure activities is primarily attributed to the inadequate availability of regulatory documents and authorities governing the construction and environmental sectors. Any region, excluding areas with asphalt concrete pavement, may be deemed suitable for recreational purposes, while grassy zones without trees may serve as recreational and hygiene zones. Multiple access scenarios were devised for particular urban planning objects and elements to establish a comfortable transportation environment. However, these scenarios can negatively affect the environment.

In modern conditions, there is a need to construct additional zones within residential structures **(Pickett & Pearl 2001)**. Parts of these zones, such as parking, utility, and storage areas, do not require natural light. Hence, there is a requirement to actively encourage underground growth and to position such zones below ground level.

Many individual projects lead to many social problems associated with a lack of green spaces, inconvenient use of pedestrian walkways, and residential areas.

Thus, urban planning problems can be traced back to the master plan, which defines the development direction. This document adopts a global approach using traditional urban planning methods to structure cities; however, this approach results in the categorizing of urban areas into functional and residential blocks organized by number of floors. Modern urban planning trends emphasize multifunctionality and compactness, where each district is self-sufficient in functionality and residential complexes comprise multi-story blocks **(Levy 2016; Webster et al., 2005)**.

Photo 14. There is insufficient provision of an area designated for sanitary protection

Photo 15. Green spaces near the road

Photo 16. Duplication of passages

Photo 17. The incline leading from the main thoroughfare is angled towards the perimeter of the housing development

Photo 18. Underground space is not used

Photo 19. Parking shortage

Photo 20. Increase of asphalt-concrete surfaces

Photo 21. Artificial turf and fenced areas

Photo 22. Instead of the initially planned 9 floors, according to the DPP, a residential complex with 9-16 storeys will be constructed

Photo 23. Combination of architectural styles

Photo 24. The distance between apartment blocks is less than 20 meters

Photo 25. A residential complex comprising integrated facilities and a nursery

Figure 2 – Searching for urban planning problems (author's material).

The detailed planning project presents a challenge: architectural schematics at the district level establish boundaries between each site, resulting in urban fragmentation and incoherence of the elements within a given area.

Then comes the problem of infill development, an isolated object in urban planning that is developed individually. At this stage, the environmental weakness of the design solutions is particularly noticeable, as well as their tendency to independence due to their own "fence," yard, road, essential facilities (shops), etc.

It is also necessary to note the need for more current building regulations in urban planning and the design of residential complexes. Due to the lack of clear definitions of terms and their components, architectural and urban planning schemes explain their practical application—the validity of the applied coefficients and certain distances and areas.

5 CONCLUSIONS

Based on the analysis of the identified problems, proposals are made to improve the urban environment as follows:

(1) Revision of the primary methods of urban planning and, consequently, of the structure and purpose of the master plan, in which equivalent blocks will appear and objects of special urban significance (shopping and entertainment complexes, parks, etc.) will be equally distributed;

(2) Combining a DPP and infill development into a more extensive area action plan or neighborhood plan, i.e., a Development Plan Document that should be displayed on the master plan of the city of Astana. A Neighborhood Development Plan or Area Action Plan is a comprehensive architectural and urban planning project for an entire city area, with all the necessary social infrastructure except for specialized urban facilities. This solution allows for the coherent development of the urban area, as well as the architectural and urban connection of all elements of the project, which improves the social and environmental aspects of living;

(3) Adjusting the current building regulations in the field of urban planning, which will make it possible to create an algorithm for the formation of a new type of urban development and to determine the minimum indicators of the degree of comfort of the living environment;

(4) Create an urban regulation model that monitors the compliance of design decisions with relevant standards and their implementation.

Each proposal requires a separate study that will gradually determine the principles of architectural and urban design in neighborhood development.

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RESEARCH ARTICLE

MODERN EDUCATIONAL SPACE AS A RESULT OF RECONSTRUCTION SCHOOL BUILDINGS

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Abstract. *The article deals with the important topic of reconstruction of existing school buildings. School plays an important role in the life of every person, and the creation of a comfortable educational space is an important task for architects and designers. The main problems considered in the article are the shortage of pupil places in schools, as well as the discrepancy between the architectural and planning structure of schools and the requirements of modern education. In the introduction the questions related to the infrastructure of the school building are considered, that in the existing today schools it is difficult to organize the educational process that will meet the requirements of modern education. The main issues of reconstruction were studied: such as elimination of physical deterioration of the building, the impact of reconstruction on the change of the educational process. In the main part of the article a plan of reconstruction of a typical school building is proposed. The developed steps will help to create comfortable conditions for learning in existing schools, as well as to adapt the space of schools to the requirements of modern educational programs. In the context of state programs considered in the paper, the measures taken by the state to solve the existing problems are presented. State programs provide for the construction of new school buildings based on public-private partnership, but do not exclude the possibility of reconstruction of the existing stock. The conclusion describes the main conclusions of the conducted research, which suggest that the reconstruction of school buildings can be one of the possible steps to solve two major problems. The authors believe that changing the internal space of existing schools can contribute to the development of motivation among students, improve the level of education, and develop various abilities of students.*

Keywords: *School, reconstruction, modern education, school building typology, educational trends, life-long education, informatization of education.*

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МЕКТЕП ҒИМАРАТТАРЫН ҚАЙТА ҚҰРУ НӘТИЖЕСІНДЕГІ ҚАЗІРГІ БІЛІМ КЕҢІСТІГІ

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Аңдатпа. *Мақала қолданыстағы мектеп ғимараттарын қайта құрудың маңызды тақырыбын қарастырады. Мектеп әр адамның өмірінде маңызды рөл атқарады, ал жайлы білім беру кеңістігін құру сәулетшілер мен дизайнерлер үшін маңызды міндет болып табылады. Мақалада қарастырылған негізгі мәселелер-оқушылар орындарының жетіспеушілігі мектеп, сондай-ақ мектептердің сәулеттік-жоспарлау құрылымы мен заманауи білім беру талаптарының сәйкес келмеуі. Кіріспеде мектеп ғимаратының инфрақұрылымына байланысты Қазіргі мектептерде қазіргі білім беру талаптарына жауап беретін оқу процесін ұйымдастыру қиын екендігі туралы мәселелер қарастырылған. Қайта құрудың негізгі мәселелері зерттелді: ғимараттың физикалық тозуын жою, қайта құрудың білім беру процесінің өзгеруіне әсері. Мақаланың негізгі бөлігінде типтік мектеп ғимаратын қайта құру жоспары ұсынылған. Әзірленген қадамдар қолданыстағы мектептерде оқуға ыңғайлы жағдай жасауға, сондай-ақ мектептер кеңістігін заманауи білім беру бағдарламаларының талаптарына бейімдеуге көмектеседі. Жұмыста қаралған Мемлекеттік бағдарламалар контекстінде мемлекет қолда бар проблемаларды шешу үшін қолданатын шаралар ұсынылған. Мемлекеттік бағдарламалар мемлекеттік-жекешелік әріптестік негізінде жаңа мектеп ғимараттарын салуды көздейді, бірақ қолданыстағы қорды қайта құру мүмкіндігін жоққа шығармайды. Қорытындыда мектеп ғимараттарын қайта құру екі негізгі мәселені шешетін ықтимал қадамдардың бірі болуы мүмкін деген зерттеудің негізгі қорытындылары сипатталған. Авторлар қолданыстағы мектептердің ішкі кеңістігін өзгерту оқушылардың мотивациясын дамытуға, білім деңгейін арттыруға, оқушылардың әртүрлі қабілеттерін дамытуға ықпал етеді деп санайды.*

Түйін сөздер: *Мектеп, қайта құру, заманауи білім беру, мектеп ғимаратының типологиясы, білім беру тенденциялары, үздіксіз білім беру, білім беруді ақпараттандыру.*

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НАУЧНАЯ СТАТЬЯ

СОВРЕМЕННОЕ ОБРАЗОВАТЕЛЬНОЕ ПРОСТРАНСТВО КАК РЕЗУЛЬТАТ РЕКОНСТРУКЦИИ ШКОЛЬНЫХ ЗДАНИЙ

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Аннотация. *Статья рассматривает такую важную тему, как реконструкция существующих школьных зданий. Школа играет важную роль в жизни каждого человека, а создание комфортного образовательного пространства, является важной задачей для архитекторов и проектировщиков. Основные проблемы, рассмотренные в статье – это нехватка ученических мест в школе, а также несоответствие архитектурно-планировочной структуры школ и требований современного образования. Во введении рассмотрены вопросы, связанные с инфраструктурой школьного здания, заключающиеся о том, что в существующих сегодня школах сложно организовать учебный процесс, который будет отвечать требованиям современного образования. Были изучены основные вопросы реконструкции, такие как устранение физического износа здания и влияние реконструкции на изменение образовательного процесса. В основной части статьи предложен план реконструкции типового школьного здания. Разработанные шаги помогут создать комфортные условия для обучения в существующих школах, а также адаптировать пространство школ под требования современных образовательных программ. В контексте государственных программ, рассмотренных в работе, представлены меры, предпринимаемые государством для решения существующих проблем. Государственные программы предусматривают строительство новых школьных зданий на основе государственного-частного партнерства, но не исключают возможности проведения реконструкции существующего фонда. В заключении описаны основные выводы проведенного исследования, которые говорят о том, что реконструкция школьных зданий может стать одним из возможных шагов, решающих две основные проблемы. Авторы считают, что изменение внутреннего пространства существующих школ может способствовать развитию мотивации среди учащихся, повысит уровень образования, создаст условия для развития различных способностей у учащихся.*

Ключевые слова: *Школа, реконструкция, современное образование, типология школьного здания, образовательные тенденции, непрерывное образование, информатизация образования.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді. Автор зерттеу барысында консультациялық көмек көрсеткен Халықаралық білім беру корпорациясының (ҚазБСҚА кампусы) әріптестеріне алғысын білдіреді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования. Автор выражает благодарность коллегам Международной Образовательной корпорации (кампус КазГАСА), оказавшим консультационную помощь при проведении исследования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

One of the main functions of humanity is to educate and train the new generation, on which the future generally depends. To solve this very important task, professional teachers and educators have always worked to realize the right of every child to education.

One of the world's leading trends in the development of modern education is the transition to continuous, open education, which forms the basis of the information society and is built on the principles of open information space.

The most significant trends in modern education are globalization, informatization, humanitarization, and humanization of the educational process.

Globalization of education is the process of expanding the external and internal boundaries of education. In other words, it is a process of interaction and integration of different educational systems, methods and technologies.

Informatization of education means the process of introduction of information and communication technologies in education and their influence on the process of teaching and education of schoolchildren. The tasks of education remain unchanged, but the technologies are changing. In modern education, the teaching of disciplines in the field of informatization should be conducted as a continuous multi–purpose program, taking into account both individual and social requirements.

Humanization is the realization of the worldview principle, which is based on respect for people, care for them, and belief in their great potential for self–improvement. According to Humanization, human welfare is the ultimate goal of society.

A humanization process in education is a consequence of the process of humanization. The curriculum necessarily includes disciplines of the general cultural plan. Humanitarization of modern education is designed to solve two main problems: educational and social. Education, as a social institution, is designed to provide modern society with qualified specialists.

According to statistical data for June 1, 2023, the deficit of places in general education schools of Almaty is 27 thousand. Today the lack of places in schools is called the most urgent problem in the field of education. One of the reasons for this deficit is considered to be the rate of migration (internal and external) in Almaty. On average, the number of children increases in the megapolis by 12–14 thousand annually.

But, it should be noted that the shortage of places in schools did not arise today. Kazakhstan has already faced this problem about 15 years ago. Since 2007, the program “100 Schools, 100 Hospitals” was adopted, which operated on the basis of public–private partnership. During its implementation it was planned to build 106 new schools, but the program was not fully implemented. In 2013, the Parliament noted the low degree of implementation of the program. In 2020, 100 schools were built in Kazakhstan, and construction continues now. In 2022, the state program “Comfortable School” was adopted. The program is aimed at eliminating emergency schools, so–called “three–shift schools”, as well as at eliminating the lack of pupil places. In addition to the construction of new schools, the existing problems of non–compliance of the infrastructure of existing educational institutions with modern requirements and the lack of pupil places can be solved through reconstruction.

Reconstruction is a complex approach to changing a school building, it is a complex process that involves specialists from different fields. In their works the issues of reconstruction are considered by such scientists as **Mironyuk (2005)**, **Magula (2000)**, **Stepanov (1983)**.

2 LITERATURE REVIEW

It is necessary to change approaches to the formation of a modern school building under the influence of various factors and transformation processes in education. Studies of school building typology issues have been conducted by many scientists, such as: E.B. Dvorkina, V.I. Ezhov, V.I. Zherdev, S.G. Zmeul, A.V. Zudin, S.Y. Kuznetsov, S.G. Leibovich, E.V. Pimenova, G.D. Platonov, T.A. Slavina, V.I. Stepanov, V.V. Smirnov, N.B. Fedorova, A.I. Chaldymov and others. Considerable attention is also given to urban planning issues of school buildings design in the works of scientists A.A. Borovkov, T.M. Bragina, V.E. Bykov, G.A. Gradov, A.V. Mahrovskaya, B.M. Poluya, V.V. Smirnov, V.I. Stepanov.

For the purposes of solving the problem of lack of places in schools of Almaty city and Kazakhstan as a whole, the national project in the field of education “Comfortable School”, approved by the resolution of the Government of the Republic of Kazakhstan on November 30, 2022, has been developed. The main goal of the project is to eliminate emergency educational facilities, three–shift education and shortage of student places in secondary education facilities. In addition, one of the possible options to solve the issue of insufficient number of places in the existing schools of our city can be their reconstruction.

In Almaty city today there are 212 state–owned schools and another 98 privately owned schools. The total enrollment is 320,453 students. Basically, all these schools are built according to standard designs, and according to the shape of the plan they can be divided into several groups. In their shape, the buildings resemble the letters of the Russian alphabet: H, P, G, Sh, Zh.

In 1964, the most widespread type of school building was approved, popularly called “Airplane”. School type 65-426/1 was designed by the Moscow Institute of Typical and Experimental Design under the direction of A. Avrusov. The architectural composition includes two buildings connected by a passage, which in the upper perspective resembles the wings of an airplane, which became the reason for its popular name **Figure 1**.

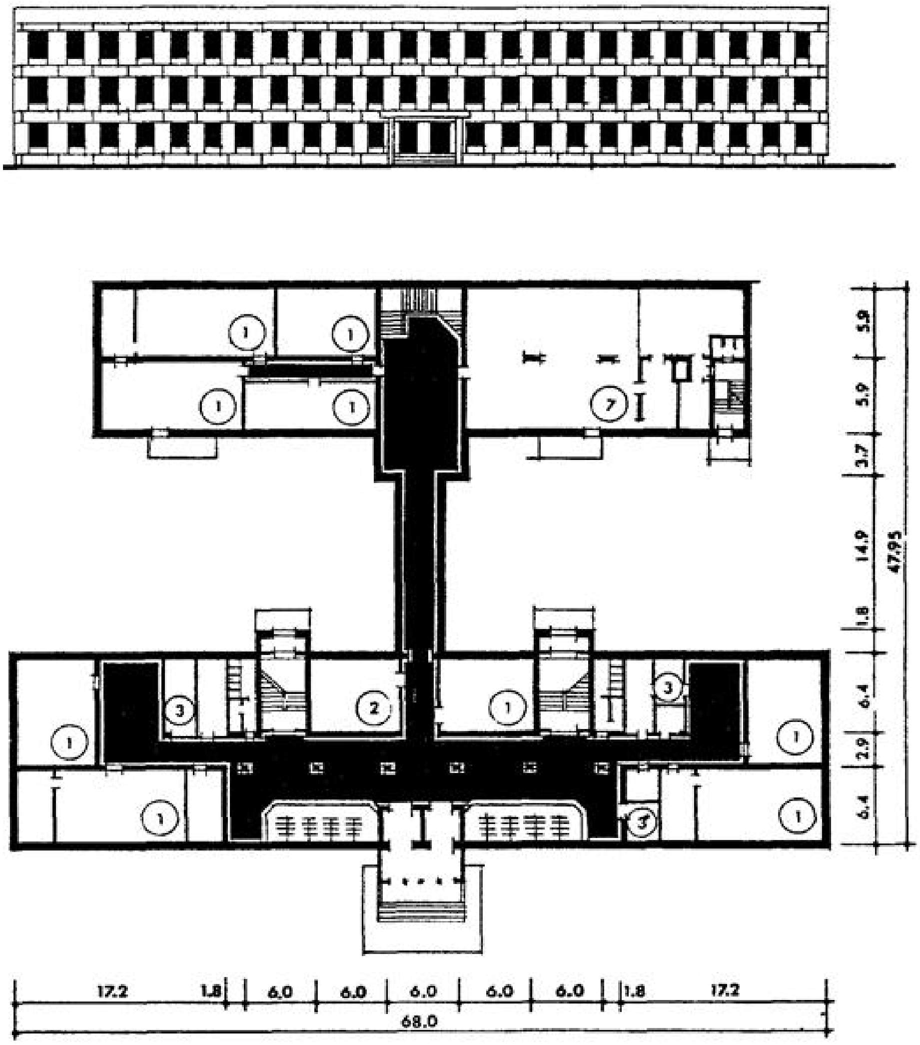

Figure 1 – Typical project of school building 65–426/1 (**Past school buildings: typical designs, 2009**).

During research of school buildings in Almaty and their typology, it can be concluded that the most popular are schools built according to the standard project 65–426/1 **(Figure 2)**. This is an H–shaped building designed for 960 students, shown on this research is reflected in the article "Current Trends in Education and the Architecture of the Modern School".

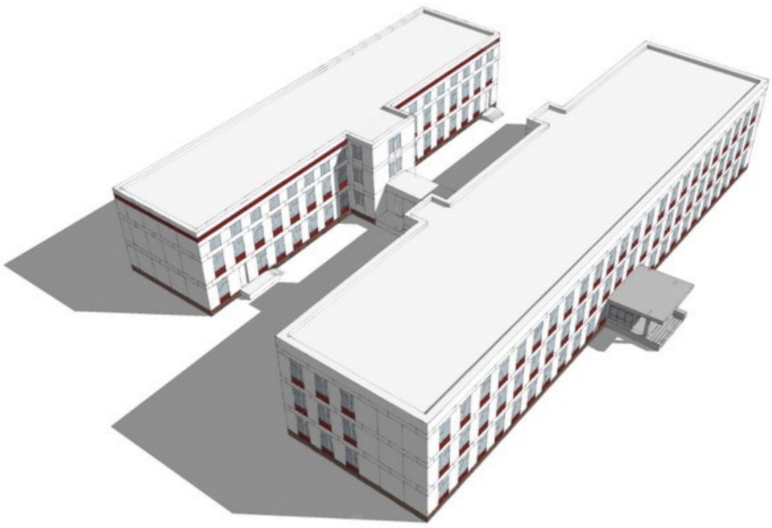

Figure 2 – 3D model of School type 65-426/1
(Past school buildings: typical designs, 2009)

3 MATERIALS AND METHODS

The actuality of this issue is very high. First of all, there is a clear deficit of pupil places in schools throughout Kazakhstan, as well as existing today schools built on standard designs 50 and more years ago need major repairs, and therefore can be reorganized through reconstruction and redevelopment projects. For example, in the summer of 2023, 260 schools across the country began major renovations, but only 194 of them completed renovations by the start of the school year. It can be noted that there is an interesting opportunity for architects to reorganize school buildings and improve the learning environment through various means of architecture.

The main method applied in this study is descriptive, it includes to varying degrees the interpretation, comparison and generalization of various publicly available information.

The research analyzed the actual condition of existing school buildings in Almaty, reviewed government programs such as "100 Schools, 100 Hospitals" and "Comfortable School" to address the shortage of school buildings and student places, as well as the issues of mismatch between schools and education requirements.

4 RESULTS AND DISCUSSIONS

Reconstruction can be a real step towards solving the problem of shortage of places in the city schools, as follows from the data given earlier, and will also allow to bring the planning organization of school buildings in line with modern educational trends. I propose to consider proposals for the reconstruction of one of the typical schools, multi–purpose gymnasium №34, located at Brusilovsky Street, Almaty, corner of Balotnikov Street, which is shown in **Figure 3**. This school was built and opened as a secondary school in 1983, the status of a gymnasium was awarded later in 1998. The gymnasium building is gallery type, with most classrooms oriented towards the south. The school consists of two and three–storey blocks. This school was built taking into account all norms and requirements of that time, but today a number of shortcomings can be noted. For example, the lack of classrooms, recreational and school–wide spaces, laboratories aimed at the implementation of programs in science, engineering and technology, robotics. These are the most important problems that can be solved through reconstruction, among others.

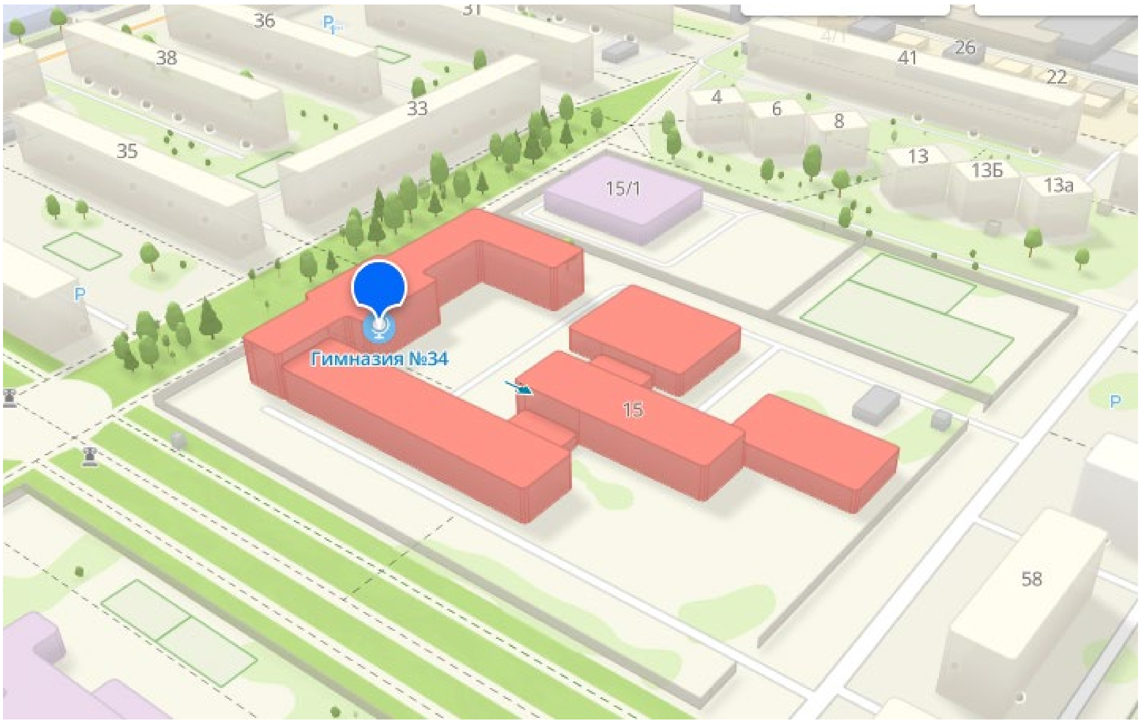

Figure 3 – Multi–purpose gymnasium №34. 8.Google maps. **(Past school buildings: typical designs, 2009)**

The project proposed for reconstruction includes several basic steps that can be applied in the subsequent reconstruction of this type of school buildings:

1. Connection of blocks A, B and C by organizing an inner courtyard (open or closed) to increase the organization of areas and perimeter of consecrated spaces used for the organization of additional premises: recreations, communications, galleries, passages, etc.

Enclosed courtyard is created in which a conservatory will be organized, in the adjoining room it is recommended to create a living corner. There are several types of conservatories: freestanding, attached to a building and integrated conservatories.

Many researchers prove in their works the beneficial effects of so-called biophilic spaces in buildings. The main principles of creating internal green spaces are the integration of nature and man, the development of a sense of harmony with nature, the use of greenery to maintain the physical and moral health of man. All these issues are widely disclosed in the works of researchers **Butabekova (2022), Ryan et al. (2014), Hanc, et al. (2018), Krundyshev (2014), Akhmedov (2017), Poznyak (2009), Kupriyanov et al. (2023)** and others.

Modern trends in the field of education are becoming the subject of numerous studies in the field of education, attracting the attention of scientists **Erik D.C. (2019), Lamekhova, N.V. (2022), Komarova I.I. (2018, 2020), Çalik F. et al. (2014), Vereshchagina E. (2021), Gorubshov A.A. (2022), Ostroverkh O.S. (2021), Klochko A.R. and Topaeva P.A. (2021)**

2. Removal of the corridor as a means of communication by demolishing the partitions between the classrooms on the north side and the corridor (Block B) in order to transform the resulting space into a multi–purpose space for recreation, games, “lines”, location of individual closets (lockers) and additional sanitary facilities.

For the reconstruction of the multi–purpose gymnasium № 34, it is proposed to demolish the partitions between the classes in the junior block on the northern side. In this way, additional free space will be created.

3. Extending the length of the existing building by organizing an extension to increase the number of classrooms and, consequently, the area of multipurpose space and organizing an additional exit.

For the reconstruction of the multi–purpose gymnasium №34 this cannot be done because of site constraints, but in many other cases it will be one of the possible options.

4. Construction of an extension of complex configuration on the north side of the multipurpose space in order to organize a winter garden and other green spaces for recreation, rooms for parents, psychologist, speech therapist and others.

For the reconstruction of the multi–purpose gymnasium №34, such a space can be created in the junior school block by adding a hexagonal projection on the northern façade. The resulting free space can have several purposes, including serving as an alternative to the assembly hall for the junior high school, as previously there was no separate hall for them.

5. Organization of an independent area in the elementary school lunchroom by extending the depth of the existing building (Block A) and organizing a passageway.

6. Relocation of chemistry, physics, biology classrooms with the organization of laboratories to the upper floors and to free up space in order to create an organized laboratory block, which will help to implement programs in science and engineering and technical areas

7. Addition of a separate new Block E to increase the number of classrooms for high school students.

Block E is attached to the south side of the main building.

8. Active introduction of color into the interior of the school.

The results of the proposed reconstruction project can be seen in **Figures 4 and 5**.

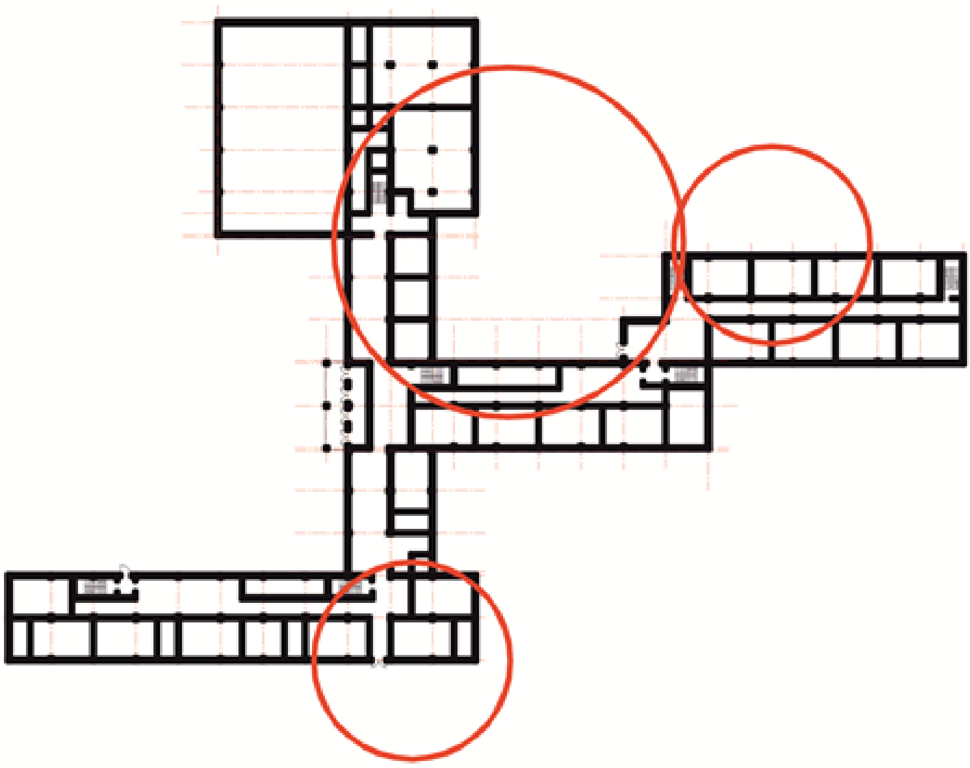

Figure 4 – Plan before reconstruction (author's material)

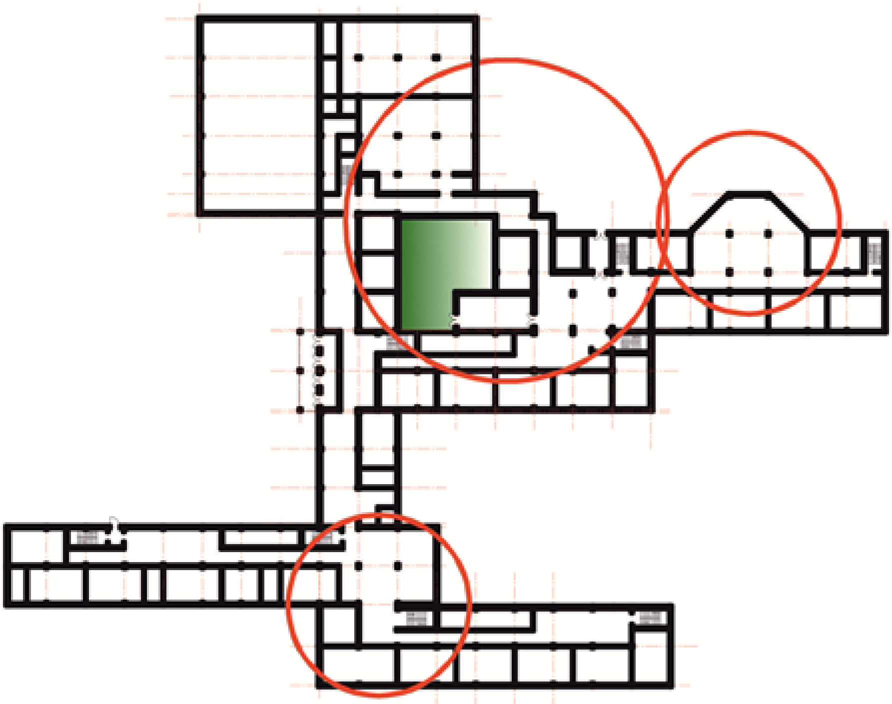

Figure 5 – Plan after reconstruction (author's material)

5 CONCLUSIONS

The aspects studied in this article show that reconstruction can solve complex architectural problems of an existing school. Reconstruction of school buildings is an opportunity not only to transform the space, but also to influence the educational process itself. It allows to adapt the school space to the requirements of modern education and society, it can also allow to increase the classroom capacity of schools, which will reduce the shortage of student places. Besides, with the help of reconstruction it is possible to improve conditions for students and teachers, to create a modern educational space taking into account modern technologies. The result of the reconstruction project is not just a school building, but an educational space designed to be comfortable and meet modern educational needs.

According to the results of the research conducted, we can draw the following conclusions:

1. State programs that are intended to reduce the deficit of pupil places in schools and improve conditions for students and teachers in the context of the requirements of modern education are not implemented in full compliance with their plan;
2. These steps proposed for the reconstruction of the school building can be implemented in a fairly short period of time in order to solve the existing problems in the sphere of general school education;
3. The following step–by–step recommendations can be developed for the reconstruction of other typical general education schools based on architectural assessment that takes into account the volumetric and planning parameters of school buildings.

As a result, it should be noted that the reconstruction of a school building is not only a solution to the problem of physical or moral obsolescence of the facility, but also an investment in the future of our children. With the help of the steps proposed in the article for the reconstruction of the existing gymnasium, it is possible to create a space where students can receive a comfortable and quality education and prepare for the challenges of the modern world.

We can conclude that school building renovation can be an integral part of improving modern education. With the help of reconstruction, it is possible to provide conditions for the formation of future innovators and leaders in existing school buildings.

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RESEARCH ARTICLE

MODERN EDUCATIONAL STRATEGIES AND SCHOOL ARCHITECTURE: MUTUAL INFLUENCE AND SYNCRETISM

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Abstract. *The article deals with the interaction between architecture and education, the influence of various factors on the creation of modern educational institutions. It is important that modern educational trends are also able to influence the formation of planning organization and volume-spatial solution of a modern school building. The world practice of life-long education is considered and how it is implemented in architectural practice in our country. The article reflects the currently popular teaching strategies: design studio model, environmental learning, taxonomy of goals, work evaluation model and the model that takes into account the needs of groups of people with special educational needs. Based on the study of existing experience, a major principle in the concept of school building design is identified: the interaction between the context, the content of the learning process and the learning process itself. A number of trends and transformations of architectural and planning solutions of school buildings have been identified. On the basis of the studied material the effective variant of the model of learning space is revealed, the taxonomy of formation of learning space of a modern school building is defined. As a result of the study, three main concepts of forming a modern school building that meets the requirements of modern education are defined.*

Keywords: *educational strategies, learning environment, learning material, taxonomy, syncretism.*

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ҚАЗІРГІ БІЛІМ БЕРУ СТРАТЕГИЯЛАРЫ ЖӘНЕ МЕКТЕП АРХИТЕКТУРАСЫ: ӨЗАРА ӘСЕР ЖӘНЕ СИНКРЕТИЗМ

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Аңдатпа. *Мақалада сәулет пен білімнің өзара әрекеттесу мәселелері, заманауи білім беру мекемелерін құруға әртүрлі факторлардың әсері қарастырылған. Заманауи білім беру тенденциялары заманауи мектеп ғимаратының жоспарлау ұйымы мен көлемдік-кеңістіктік шешімін қалыптастыруға да әсер ете алатыны маңызды. Өмір бойы білім берудің әлемдік тәжірибесі қарастырылып, оның біздің елімізде сәулет тәжірибесіне қалай енгізіліп жатқаны қарастырылады. Мақалада бүгінгі таңдағы танымал оқыту стратегиялары көрсетілген: дизайн студиясының моделі, экологиялық оқыту, мақсаттар таксономиясы, жұмысты бағалау моделі және ерекше білім беру қажеттіліктері бар адамдар топтарының қажеттіліктерін ескеретін модель. Қолданыстағы тәжірибені зерделеу негізінде мектеп ғимараттарын жобалау концепциясындағы негізгі қағидалардың бірі анықталды: контексттің өзара әрекеттесуі, оқу процесінің мазмұны және оқу процесінің өзі. Мектеп ғимараттарының сәулеттік-жоспарлау шешімдеріндегі бірқатар тенденциялар мен өзгерістер анықталды. Зерттелген материал негізінде оқыту кеңістігі моделінің тиімді нұсқасы анықталып, заманауи мектеп ғимаратының оқу кеңістігін қалыптастыру таксономиясы анықталды. Зерттеу нәтижесінде заманауи білім беру талаптарына жауап беретін заманауи мектеп ғимаратын қалыптастырудың үш негізгі тұжырымдамасы анықталды.*

Түйін сөздер: *Білім беру стратегиялары, оқу ортасы, оқу материалы, таксономия, синкретизм*

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НАУЧНАЯ СТАТЬЯ

СОВРЕМЕННЫЕ ОБРАЗОВАТЕЛЬНЫЕ СТРАТЕГИИ И АРХИТЕКТУРА ШКОЛЫ: ВЗАИМОВЛИЯНИЕ И СИНКРЕТИЗМ

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Аннотация. *В статье рассматриваются вопросы взаимодействия архитектуры и образования, влияние различных факторов на создание современных образовательных учреждений. Важным является то, что современные образовательные тенденции тоже способны влиять на формирование планировочной организации и объёмного-пространственного решения современного школьного здания. Рассмотрена мировая практика обучения в течение всей жизни- life-long education и как она внедряется в архитектурную практику в нашей стране. В статье отражены популярные на сегодняшний день стратегии обучения: модель дизайн-студии, средовое обучение, таксономия целей, модель оценки работ и модель, учитывающая потребности групп людей с особыми образовательными потребностями. На основе изучения существующего опыта выявлен один из главных принципов в концепции проектирования школьных зданий: взаимодействие контекста, содержание учебного процесса и самого процесса обучения. Выявлен ряд тенденций и трансформаций архитектурно-планировочных решений школьных зданий. На основе изученного материала выявлен эффективный вариант модели учебного пространства, определена таксономия формирования обучающего пространства современного школьного здания. Как результат исследования определены три основные концепта формирования современного школьного здания, отвечающего требованиям современного образования.*

Ключевые слова: *Образовательные стратегии, обучающая среда, обучающий материал, таксономия, синкретизм*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді. Автор зерттеу барысында консультациялық көмек көрсеткен Халықаралық білім беру корпорациясының (ҚазБСҚА кампусы) әріптестеріне алғысын білдіреді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ / ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования. Автор выражает благодарность коллегам Международной Образовательной корпорации (кампус КазГАСА), оказавшим консультационную помощь при проведении исследования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

The interaction between architecture and education has been developing for centuries and has a mutual character. Deep centuries-old traditions of building educational institutions, formed in regions with different natural, climatic and socio-cultural conditions, led to the formation of a variety of volumetric and spatial structures of educational facilities. Today the question of adequacy of generally accepted variants of compositional and planning solutions of existing schools and those active changes that are taking place in the education system both all over the world and in our country becomes relevant.

It is time to transform our traditional view of learning and create a new learning environment that is relevant to educators, administrators, and most importantly, learners of all ages. Active collaboration among architects, educators, parents, administrators, and other interested community members can play a very important role in this process. The question of what architects can do to support education and what educators can contribute to the design process are now becoming important as part of the implementation of co-design principles. Is it possible to create an interactive environment that serves as a "three-dimensional textbook" for learners? What elements of architectural space can drive the learner's desire and drive to learn? What architectural techniques, landscaping elements, design objects, and principles of environmental organization can become catalysts for self-learning processes?

2 LITERATURE REVIEW

The world practice of education for the whole life of a people, life-long education, is being introduced in our country as well, as it has come to be understood that education for the purpose of maintaining physical, mental and emotional health of a person is important for the effective and successful development of society as a whole. That is why for designing a modern school it becomes fundamentally important to study new educational systems, sometimes quite different from the early traditional ones. It is necessary to formulate a philosophy of education, create a taxonomy of learning experiences and performance goals, define children's rights to development, and create valid forms of analysis and evaluation. The process of the architectural design of a modern educational facility inevitably poses the challenges of a deep understanding of the learning system.

Trends in modern education are the subject of research by many scientists. In their dissertations these issues were considered by: **Kraig (2000), Bessarabova (2006), Volodin (2011), Volkova (2004), Vyazemsky (2004), Lim (2006), Marina (2003), Machekhina (2021), Statkova (2005), Shultseva (2009), Yatsenko (2021)**. Trends in modern education are the subject of research by many scientists. In their dissertations these issues were considered by: **Akulova (2004), Antonova (2012), Pankova (2004), Savinova (2021), Sosnin (2014), Belogrudova (2008), Shcheblanova (2016), Osorina (2007), Khaperskaya (2020), Khomuttsova (2005)**, and the influence of outer factors on the educational process was considered in the works of **Antipkina (2020), Bikbaeva (2021), Drozdov (2022), Makotrova (2021), Remorenko (2019)**.

3 MATERIALS AND METHODS

Despite the fact that the early methods of school building design, which were tested in capital sociological studies, have proven themselves, when developing new solutions it is necessary to ask the question again: what do schoolchildren need for successful learning? This is not an idle question, and it is caused by the change of the educational paradigm towards individualization of methods, bringing them closer to the technologies of play and creativity, where there is no single correct answer, but there are options for solving problems. And most often, as in the professional activities of adult people, it is the learner's ability to respond flexibly and effectively to emerging challenges that is assessed. Obviously, learning spaces should support the learner's enthusiasm for inquiry. At

the same time, it is clear that all learners are different and everyone has different ways of forming perceptions and processing information. This is supported by the results of well-known studies of information processing and developmental stages of children **Piaget (2004)** theory of multiple intelligence **Gardner (2004)** adopted as a basis for new learning strategies. Accordingly, new learning processes provide an active view of the learner, which is now being considered in the design of school buildings. Some of the learning strategies developed to date, depicted in **Figure 1**, are:
- design studio model (design technologies);
- environmental learning;
- taxonomy of objectives;
- a model for assessing learners' work;
- a model that takes into account the needs of different groups of learners.

Figure 1 – Modern learning strategies (authors' material)

Each of the strategies in its own way teaches certain skills, the ability to seek and find information and master the process of problem solving, i.e. it allows to solve the main tasks of the educational process.

Cooperation between the context, content of the learning process and the learning process is the main principle in the concept of school building design by researcher **Ostroverkh and Tikhomirova (2021)**. In this case, the context is understood as the learning environment **(Figure 2)**: artificial, natural, cultural, which is an active “learning material”.

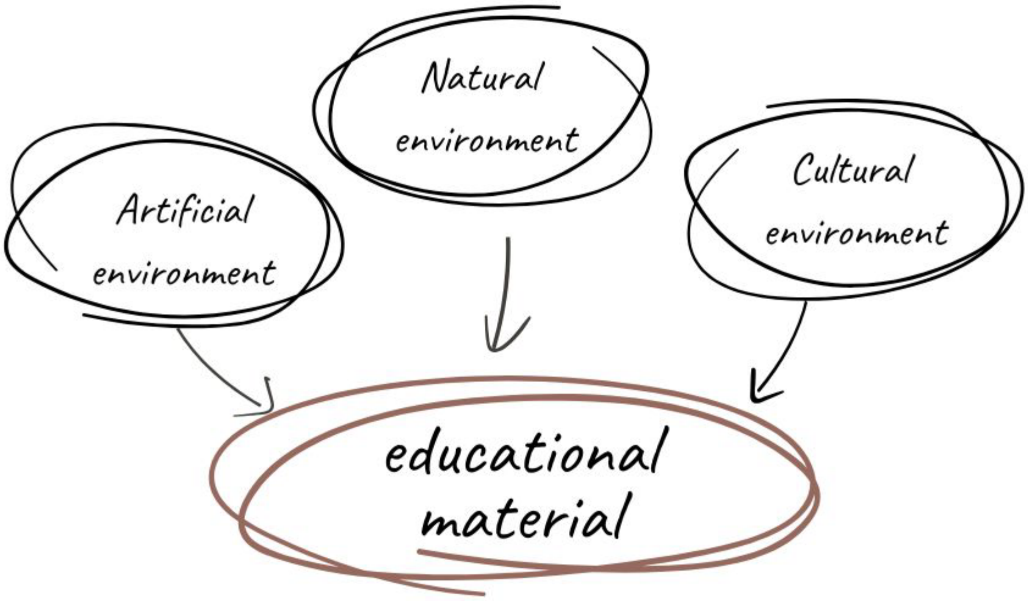

Figure 2 – Learning environment (authors' material)

The whole area of the school, in summary, should teach, and the learning environment, in turn, should take into account the ethnic, regional, cultural characteristics of the local community. The content of learning should strive for common links between disciplines, as the mind learns in an integrated and holistic way by making connections. Interdisciplinary thinking is also the goal of **Kazinik (2010)** innovative schooling methodology in which common themes are chosen for all disciplines. For example, the topic of Water: its characteristics in physics, properties in chemistry, importance in biology, civilizations of rivers, seas and oceans in history and geography, marinists and watercolor techniques in drawing, swimming in physical education, water in works of lyrics, prose and music, water economy in economics and social studies, etc. Such an integrated approach to study can reveal for a learner the phenomenon of Water from all sides and help to internalize its peculiarities as a holistic phenomenon. That is, it is not a passive, but an active process that requires a different organization of school building space.

As a result, the context and content of the learning process influence the organization of the learning process and, accordingly, can influence the layout of the school building and the organization of its territory.

The school territory has the function of a learning space, and the more diverse and complex its structure and content, the more "stimuli" for students, the more active and fulfilling the learning process can become.

4 RESULTS AND DISCUSSIONS

Studying the international experience **Samoilova and Chislova (2017)**, it can be concluded that a number of trends in the transformation of architectural and planning solutions of modern schools stand out:

1. Block functional zoning: administrative, sports and leisure facilities form an external, road-facing block, while in the back of the site are located the actual educational blocks for junior, middle and senior schools. The blocks can be connected by courtyards, warm or open passages, or a large recreational facility common to the whole school (library, assembly hall, design studio, workshop);

2. A central (in the compositional, functional and structural sense) creative space for both general and collective, as well as private and isolated types of learning activities. Most often for this purpose the hall type of layout is used, which is also an active learning space for schoolchildren. The hall type of layout can solve the problem of possible transformation of this space depending on any

changes in the future. Transformation of the space can be realized through the use of partitions, furniture, mobile equipment;

3. Flexibility of the planning scheme, especially if certain zones and blocks of the school become public socio-cultural facilities accessible to the local community. Connections between zones and blocks can be made, among other things, through the organization of courtyards-recreations, warm passages, information facilities (for example, a library). The combination of open and closed, accessible and isolated zones and spaces for play and learning activities is characteristic of many alternative schools in foreign countries. It is assumed that such diversity stimulates the free organization of students' activities, which, in turn, is intended to stimulate their sense of responsibility;

4. Using new technologies: energy-saving, possibly energy-efficient, which can have an economic effect. In addition, these technologies can also become educational material for students, and not only for schoolchildren, but for the whole community;

5. Actively using green architecture techniques, incorporating elements of landscape architecture into the interior and exterior (depending on the natural and climatic conditions of the area), which again can become a potential information and training platform;

6. The informational content of recreational, communication and educational spaces has educational properties: texture, color combinations, fonts of inscriptions, i.e. well-considered interior design has an active impact on learners and community members.

It is important to understand that the school can become a social and community center for the entire community of the residential neighborhood in which it is located. It can turn from a self-contained object into a living communicative space for the formation of social and cultural diversity. For safety reasons, it is possible to provide for the autonomous use of individual objects in the school building. Russian researchers distinguish different degrees of planning flexibility: “flexible”, “moderately flexible” and “inflexible”, implying a corresponding variety of layout, configuration of premises, and transformation possibilities. They note that “from these parts it is possible to make up schools and complexes for completely different learning systems and a wide range of uses” **(Samoilova and Chislova (2017) p. 216)**.

One of the effective ways to model a learning space, in our opinion, is a design studio. In itself, the design approach to create anything involves solving a specific problem and developing the skill of independent thinking and decision-making. In this way it is possible to teach students to think, i.e. the emphasis shifts not to the result, but to the process, which can show the connection between children's learning and the world around them. The learning space of the design studio should have the following characteristics:

– room should have a significant area (at least 72 square meters) for free placement and arrangement of equipment, as well as for possible transformation; the latter can be provided with light transformable furniture;

– the studio should be equipped with large horizontal planes for group and individual classes;

– there should be a separate utility room or space in the room itself for storing work in progress, models and maquettes, personal belongings and materials;

– it is necessary to provide vertical surfaces for general discussion of design solutions, “smart walls” for brainstorming, presentations, discussions;

– it is recommended to have a connection with the outside world, i.e. access to the patio, green walls, plants.

Modern trends in the field of education become the object of numerous studies in the field of education, attracting the attention of scientists **Baktybaev (2017), Musaeva and Avliyakulov (2017), Rasuleva et al. (2021), Kultysheva (2018), Bukina et al. (2021), Pirnazarova and Hakimova M. (2023), Smakova (2020), Tran and Phan (2020), Erik (2019), Akhmadov (2023), Petrosyan (2022)**. Another model of learning space can be the urban educational environment proper, i.e. some object that allows studying different phenomena from different sides. It can be museums, planetariums, galleries, exhibitions, botanical gardens, as well as natural environment. To involve the urban space as a learning environment, it is effective to define an objective for the whole school year, which can be solved through both in-school technologies and by involving the urban environment surrounding the school in close and distant accessibility. This approach allows organizing learning around big ideas and problems that are relevant to the learners themselves. This makes it possible to adapt the curriculum taking into account the hypotheses and assumptions of students, making them involved and, therefore, responsible for decision-making, and developing their independence. Foreign experience shows that the introduction of such educational technologies contributes to the improvement of learning outcomes and pride in personal and group achievements, reduction of discipline problems and student engagement.

Research of the influence architecture has had on educational activities has been carried out by **Kuvaeva (2011), Skripkina and Tarasova (2021), Ermakov (2022), Klochko and Topaeva (2021), Lamekhova (2022), Domolazova (2021)**.

As a result, architecture teaches through the following factors:

– Visual/spatial: diversity of spaces, decoration (sculpture, wall graphics);

– Physical/kinesthetic: fitness tracks, gym, dance studios, manipulation tools;

– Musical/rhythmic: acoustics, music classrooms, performance spaces;

– Inter-personal: transformable and movable furniture, collaborative workspaces, large horizontal work surfaces as opposed to individual desks, indoor and outdoor meeting spaces, conference rooms;

– Intra-personal: outdoor seating areas, study nooks, private areas, quiet rooms;

– Natural: habitats, recycling sites, nature trails, green architecture.

Another important factor that can have an impact on architectural decisions is the assessment system or the so-called Ann Taylor Associates (ATA) taxonomy. This taxonomy can be used to teach any subject or concept in any learning situation and at all age levels. Even very young children, whose abilities are often underestimated by adults, can benefit from an active, experiential approach. Teachers can apply taxonomy as a system, a scheme of thought, or a teaching strategy. Architects can use it to identify the types of activities children do in educational settings and to plan spaces that support these activities.

The six-step process depicted in Picture 3, or taxonomy, involves the following steps:

I. Observation and multisensory discovery:
   1) Using the senses (sight, hearing, smell, taste, touch);
   2) Recording what is observed using a variety of media (drawing, writing, videotaping, entering data into a computer).

II. Data collection:
   1) Counting;
   2) Measuring;
   3) Mapping;
   4) Questioning and interviewing;
   5) Sorting, classifying and comparing.

III. Generation of concepts and literacy in all disciplines:
   1) Visual-spatial and verbal thinking, literacy and language (concrete to abstract);
   2) Generation of concepts and literacy across disciplines (math, science, art, language, foreign language, social studies, environmental studies, technology/digital literacy, health and physical education);
   3) Family literacy, emergent literacy, multilingualism to empower global citizens;
   4) Exploring, reading and understanding ideas.

IV. Creative problem solving (based on the scientific method, but applicable to all disciplines):
   1) Identify the problem or task;
   2) Generating a hypothesis;
   3) Testing the hypothesis by exposing the objects;
   4) Summarizing and analyzing findings;

5) Using inductive and deductive reasoning;
6) Testing: conformity to or deviation from the hypothesis;
7) Choosing whether to start over or build on what has been learned.

V. Grading:
1) Making critical aesthetic judgments;
2) Decision making;
3) Self-determination and self-motivation;
4) Working with other people, understanding different points of view and teamwork;
5) Cultural pluralism;
6) External Evaluation.

VI. Management:
1) Eco-literacy, ecological wisdom, non-linear and systemic thinking;
2) Respect and care for the built, natural and cultural environment;
3) Cultivating a symbiotic relationship with the environment and a sense of ownership;
4) Using a global ethic (sustainability as a moral issue);
5) Taking responsibility for the consequences of one's actions (freedom, not regulations);
6) Thinking outside yourself.

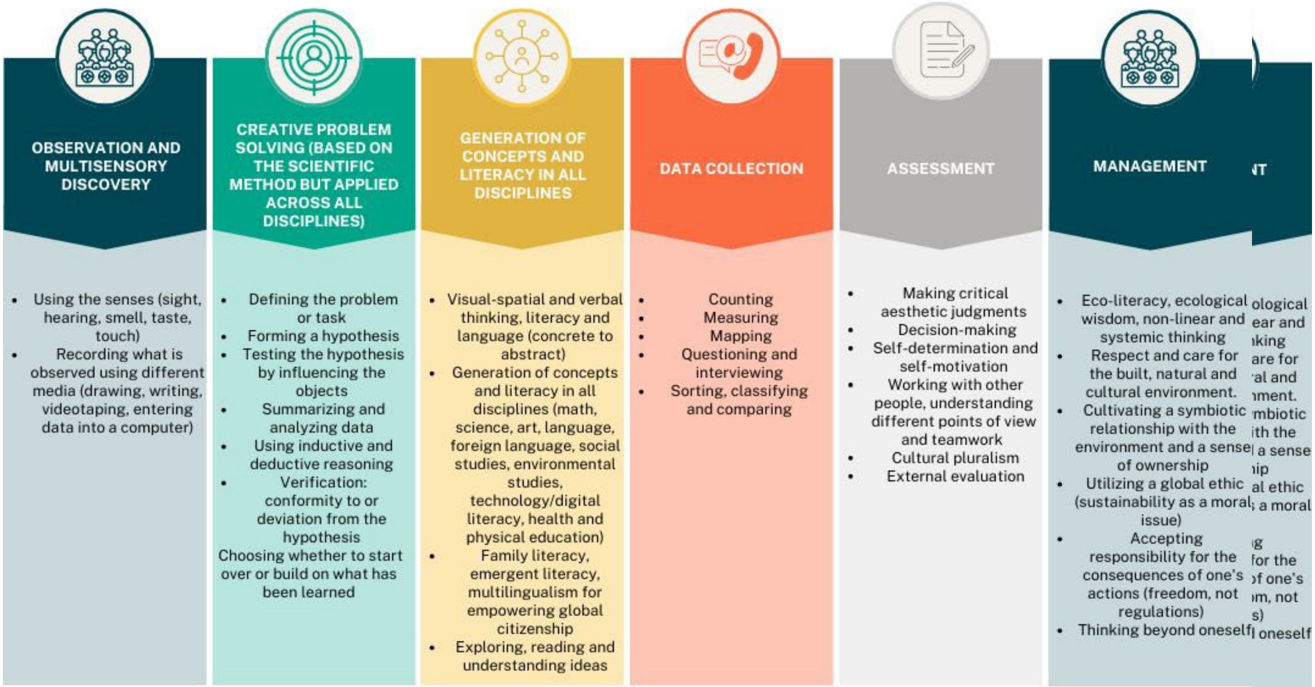

Figure 3 – Taxonomy and its components (authors' material).

Taxonomy can help identify questioning strategies for teaching and curriculum development. Educators and architects can also use taxonomies when planning school buildings. To get feedback, designers can start with simple questions aimed at developing observation skills and then move on to questions that require students or stakeholders to identify the decision-making process Higher-level learning opportunities can be programmed into the school building design, and architects and educators can eventually use the taxonomy to evaluate the learning environment once it is in use. Does the finished environment have room for multisensory learning, creative problem solving, and management? Does the environment promote imaginative thinking? These and many other questions can be answered by applying the taxonomy methodology.

5 CONCLUSIONS

In summary, we can talk about at least three concepts of the formation of a modern school building for modern education, these are:

1. Context or "Where are we learning?": local geophysical environment (built, natural and cultural environments); thematic learning; systems thinking; sustainable worldview; cultural environment as a learning tool.
2. Content or "What are we learning?": subject disciplines; multidisciplinary concepts; elements of architecture; art and design; project-based portfolio assessment.
3. Learning processes or "How are we learning": rights of development for all children (body, mind, spirit); theory of multiple intellects; ATA taxonomy, including governance; practical learning; applied technology; project-based assessment.

We can identify a few general principles that guide the design of schools of the future: (1) Learner-centered learning; (2) Personalization of the environment; (3) Group and teamwork and spaces for communication; (4) Program adaptability; (5) Connection with the community; (6) Aesthetics; (7) Safety.

The organization of effective, attractive, comfortable, inclusive architecture of a school building implies, in our opinion, the following principal decisions:

– organizing different public spaces: corridors and public spaces that symbolize interconnectedness within the school community provide coherence and meaning, which increases motivation;

– safety can be ensured by different architectural techniques: planning, lighting, use of digital technologies;

– space diversity: a variety of places with different shapes, colors and lighting, nooks and crannies;

– changing expositions: changing and interacting with the environment stimulates brain development;

– integration of different zones, multiple - multifunctionality and cross-fertilization of ideas are the main goals;

– flexibility as a factor in sustainable school building architecture.

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RESEARCHARTICLE

SOCIO-ECONOMIC ASPECTS AS A FACTOR IN INCREASING THE LEVEL OF COMFORT IN PRESCHOOL INSTITUTIONS

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Abstract. *The aim of the work is to determine the socio-economic aspects that influence the level of comfort of preschool institutions in the regional conditions of Northern Kazakhstan. In the process of conducting the study, the following issues were resolved: the main interest groups of the parent committee were identified; the principles of forming new conditions for children's stay in preschool institutions were identified; the main aspects of changes in education were identified. Architecture and social relevance are used to examine the current state of affairs in general. The primary categories of tasks assigned to contemporary preschool educational institutions are used to identify and study the primary typological series of these kinds of institutions. Preschool educational institutions of all kinds need to have their designs seriously reconsidered. Preschool education in its earlier form is in severe decline due to the shift in departmental to municipal subordination of preschool institutions, the nation's crisis, and the extremely low financial status of the populace. The former daycare centers are no longer lucrative. It's not often that new preschools are built. The general informatization of society and the population's growing educational potential, which is centered on expanding the amount of knowledge that a modern person possesses, dictate the urgent need for preschool education services to be provided to children on a mass scale.*

Keywords: *functional need, social survey, questionnaire, regionalization, conditions, needs, preschool institutions.*

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ӘЛЕУМЕТТІК-ЭКОНОМИКАЛЫҚАСПЕКТІЛЕР МЕКТЕПКЕ ДЕЙІНГІМЕКЕМЕЛЕРДІҢЖАЙЛЫЛЫҚДЕҢГЕЙІНАРТТЫРУ ФАКТОРЫРЕТІНДЕ

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Аңдатпа. *Жұмыстың мақсаты Солтүстік Қазақстанның өңірлік жағдайында мектепке дейінгі мекемелердің жайлылық деңгейіне әсер ететін әлеуметтік-экономикалық аспектілерді анықтау болып табылады.Зерттеу барысында келесі мәселелер шешілді: ата-аналар комитетінің негізгі қызығушылық топтары анықталды; балалардың мектепке дейінгі мекемелерде болуының жаңа жағдайларын қалыптастыру принциптері анықталды; білім берудегі өзгерістердің негізгі аспектілері анықталды. Сәулет және әлеуметтік маңыздылық жалпы істердің қазіргі жағдайын зерттеу үшін қолданылады. Қазіргі мектепке дейінгі білім беру мекемелеріне жүктелген міндеттердің негізгі категориялары осы мекемелердің негізгі типологиялық қатарларын анықтау және зерттеу үшін қолданылады. Барлық түрдегі мектепке дейінгі білім беру мекемелері өз жобаларын елеулі түрде қайта қарауды қажет етеді. Мектепке дейінгі білім беру, оның бұрынғы түрінде, мектепке дейінгі мекемелердің ведомстволық бағыныстылығының муниципалитетке ауысуына, елдің дағдарысына және халықтың өте төмен материалдық жағдайына байланысты терең құлдырауда. Бұрынғы балабақшалар енді пайда әкелмейді. Жаңа мектепке дейінгі мекемелер жиі салынбайды. Қоғамды жалпыға бірдей ақпараттандыру, қазіргі заманғы адамның білім көлемін кеңейтуге бағытталған халықтың өсіп келе жатқан білім беру әлеуеті балаларға мектепке дейінгі білім беру қызметтерін жаппай ұсынудың шұғыл қажеттілігін тудырады.*

Түйін сөздер: *функционалдық қажеттілік, әлеуметтік сауалнама, сауалнама, аймақтандыру, шарттар, қажеттіліктер, мектепке дейінг імекемелер.*

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НАУЧНАЯ СТАТЬЯ

СОЦИАЛЬНО-ЭКОНОМИЧЕСКИЕ АСПЕКТЫ КАК ФАКТОР ПОВЫШЕНИЯ УРОВНЯ КОМФОРТНОСТИ ДОШКОЛЬНЫХ УЧРЕЖДЕНИЙ

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Аннотация. *Целью работы является определение социально-экономических аспектов, влияющих на уровень комфортности дошкольных учреждений в региональных условиях Северного Казахстана. В процессе проведения исследования были решены следующие вопросы: выявлены основные группы интересов родительского комитета; выявлены принципы формирования новых условий пребывания детей в дошкольных учреждениях; выявлены основные аспекты изменений в образовании. Архитектура и социальная значимость используются для изучения современного состояния дел в целом. Основные категории задач, возлагаемых на современные дошкольные образовательные учреждения, используются для выявления и изучения основных типологических рядов этих видов учреждений. Дошкольные образовательные учреждения всех видов нуждаются в серьезном пересмотре своих проектов. Дошкольное образование в его прежнем виде находится в глубоком упадке из-за перехода ведомственной подчиненности дошкольных учреждений в муниципальную, кризиса страны и крайне низкого материального положения населения. Бывшие детские сады уже не приносят прибыли. Новые дошкольные учреждения строятся нечасто. Всеобщая информатизация общества, растущий образовательный потенциал населения, ориентированный на расширение объема знаний современного человека, диктуют острую необходимость в массовом предоставлении детям услуг дошкольного образования.*

Ключевые слова:. *функциональная потребность, социальный опрос, анкетирование, регионализация, условия, потребности, дошкольные учреждения.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

The urgency of current issues arising from the implementation of a wide range of programs and methods, various forms of work with children in the conditions of the old material base, in buildings that do not meet the modern requirements of the pedagogical process, is now visible thanks to the development of preschool education. In this case, the issue of assessing the architectural quality of the preschool education environment is particularly relevant, since the dynamics of scientific and technical progress, improvement of the educational process, and expansion of social requirements are not taken into account.

At present, preschool educational institutions in our country lack the material base necessary to comply with modern design and construction technologies in the following areas:

- the existing architecture of preschool educational institutions is inadequate to the needs of modern society and many social groups of consumers, including parents, teachers and students;
- currently, the architecture of preschool educational institutions does not meet modern standards; for example, the introduction of scientific and technical means is not provided, there is no possibility to organize a set of materials necessary for the pedagogical process;
- types of activities (leisure, educational games, modern educational activities).

It should be emphasized that in order to activate the development of educational institutions in the territory of the Republic of Kazakhstan as a whole and Northern Kazakhstan in particular, a comprehensive program for the development of preschool educational institutions is needed.

2 LITERATURE REVIEW

The article "Aspects of Formation of Architectural Environment for Preschool Education", which was published in the news of universities "Arkhitekton"**(Lamekhova, 2019)**, considers the development of modern architecture of preschool institutions, identifies current problems and suggests ways to solve them based on the main stages of design. A number of architectural techniques and methods have been developed and presented, some of which are new to domestic practice and include elements that create a playground in the summer and ideal conditions for installing an ice slide in the winter, as well as the modernization and implementation of individual architectural elements (slopes, ramps, straight and spiral tubular slides) to ensure a variety of play spaces and improve fire safety of preschool educational institutions in Russia.

In researches Potapova T.V. **(Potapova, 2004)** reveals, that modern requirements for the development of the network of architecture of buildings of preschool educational institutions include: an increase in the number of typological series that meet the requirements for increasing the availability of social services in the city; an increase in the number of functions in preschool educational institutions necessary for the all-round harmonious development of the child, family recreation, providing qualified assistance to parents in raising children; improving the architectural aesthetics of buildings of preschool educational institutions by developing a set of compositional techniques and means that help maintain a positive emotional mood of pupils.

According to the L.P. Bannikova`s **(Bannikova, 2007)** considerations, the general informatization of society and the growing educational potential of the population, aimed at expanding the volume of knowledge of a modern person, dictate an urgent need to provide preschool education services to children on a massive scale.

In researches A.V. Efimov **(Efimov, 2005)** reveals, that a modern person needs new knowledge and skills to solve technical and intellectual problems of everyday life due to changing social conditions, complication of economic and production processes, the need for continuous development and self-improvement throughout life.

Taking into account modern requirements for the architectural environment of preschool education and its prospective development, it becomes relevant to forecast and develop a comprehensive model of the building of a preschool educational institution, taking into account the parameters of compliance with functional and planning flexibility, constructive rationality, individuality and uniqueness of the architectural appearance, as shows A.A. Kuznetsova **(Kuznetsova, 2012)** in her report. The purpose of the study is to develop methods, strategies and principles for structuring the architectural space of modern preschool institutions, based on scientific data.

The dissertation **(Miklyaeva, 2011)**, a child's development and the maintenance and improvement of his mental health greatly depend on the preschool and primary school levels being implemented as levels of a unified system. A kid typically enters the educational system by enrolling in kindergarten, and after completing it, they are introduced to primary school for the first time.

According to N.A. Loginova **(Loginova, 2006)**, environmental events and human behavioral events in the environment are not the same thing. occurrences that take place in a person's life without their consent are referred to as environmental occurrences. Events related to the affirmation or denial of any values are considered human behavioral events.

Arnheim **(Arnheim, 1954)** highlights the unique characteristics of the cognitive process involved in the perception of art. He first stresses that aesthetic perception is an active, creative activity rather than a passive, reflective act. It can be used for constructive purposes, such as creating visual models, in addition to reproducing objects.

The article **(Yakhno, 2022)** considers the main methods of forming play spaces in kindergarten. The role of the architectural environment in the education of the child's personality is considered. The main principles of organizing children's play space and their relationship with the developmental and educational function are given.

Air, soil, and water pollution, as well as the decline in children's health brought on by sedentary lifestyles and high levels of emotional stress, are issues that require an ecological approach to solve in order to provide a safe and health-preserving environment for preschoolers, as shown in report **(Lamekhova, 2019)**

The contemporary issue of visual perception of the urban environment is the focus of Belyaeva E.L.'s work **(Belyaeva, 1977)**. The specificity and conditions of this perception are described, and the theoretical preconditions for researching how architecture is perceived are examined. The city's architectural environment's objectively assessed visual attributes are examined. Art historians and architects are the target audience for this book.

3 MATERIALS AND METHODS

The methodological basis of the study is a comprehensive study of existing preschool institutions in Northern Kazakhstan. The comprehensive nature of the study considers the stages of the work:

- field studies;
- sociological research;
- identification of progressive criteria for the development of preschool institutions.

During the field study, more than 12 preschool institutions were visited with photo recording and collection of statistical material.

Sociological research was conducted in 7 preschool institutions in the form of a survey and questionnaire survey of the population and key specialists. To survey the population and key specialists, two types of questionnaires were developed, including socio-economic aspects of the development of preschool institutions. In total, about 80 people were interviewed, including employees and parents.

The method of identifying progressive criteria for the development of preschool institutions was used at the final stage when determining the main factors influencing the development of educational institutions.

4 RESULTS AND DISCUSSIONS

During the research, a sociological survey was conducted in the following categories of the preschool institution:

- Junior group - for children aged 3 to 4 years.
- Middle group - for children aged 4 to 5 years.
- Senior group - for children aged 5 to 6 years.

Sociological surveys were conducted using the "Questionnaire - Interview", which includes 26 questions. The questionnaire consists of the following sections: information about the family is shown in **Figure 1**, which indicates the number of children for each age group.

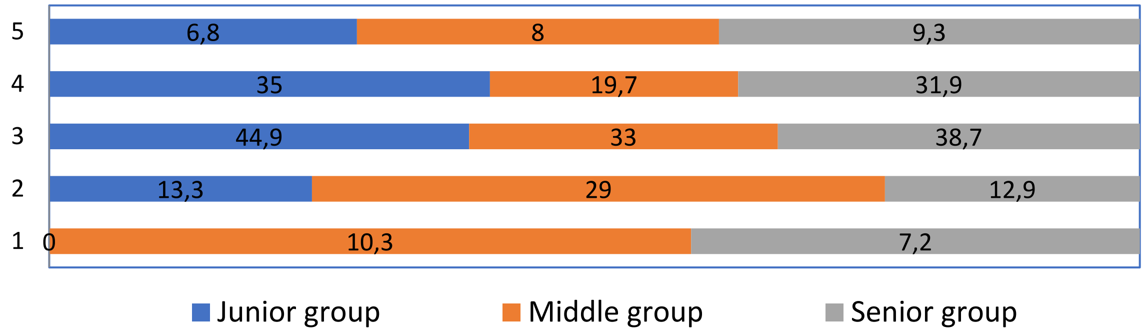

Figure 1 – Familysize (in % of respondents)(author`s material).

When assessing the current situation in preschool institutions in Northern Kazakhstan, it is important to note the dissatisfaction of employees of institutions with the development of the social sphere, as well as the lack of conditions for the implementation of interests related to education, health care, public provision of services and cultural needs - all this entails general qualities. Since **Figure 2** shows the percentages of satisfaction with the conditions of preschool educational institutions, it can be concluded that there are several aspects that require a number of aspects that require a unique approach to solving the shortcomings.

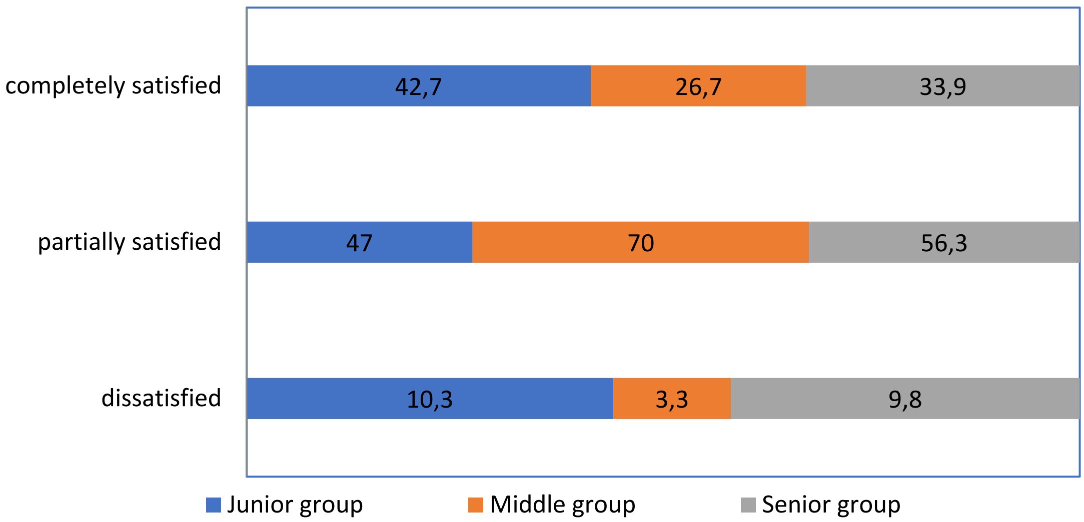

Figure 2 – Degree of satisfaction with the conditions of institutions (in % of respondents) (author`s material).

As a result of the conducted sociological research, several interest groups of preschool workers were identified, the most important of which are:

- social security;
- education, including qualified education;
- satisfaction of cultural needs, recreation and sports;
- medical care.

As a result of the consideration of the factors influencing the development of preschool institutions, it can be concluded that the social factor plays a significant role in its growth. Recreational considerations are becoming increasingly important; the transition to integrated architectural planning forms is becoming increasingly noticeable. As a result, territorial organization does not reflect the current socio-economic situation.

Architectural design solutions for preschool educational institutions are becoming increasingly attractive due to pedestrian accessibility to all city components, acceptable sanitary and hygienic and environmental conditions. All this necessitates the development of an architectural planning structure that reflects all the advantages of urban life, taking into account the density and number of storeys of buildings, as well as the degree of improvement and maintenance of educational centers. **Figure 3** shows the main reasons for dissatisfaction of parents and employees of preschool educational institutions, which require primary attention.

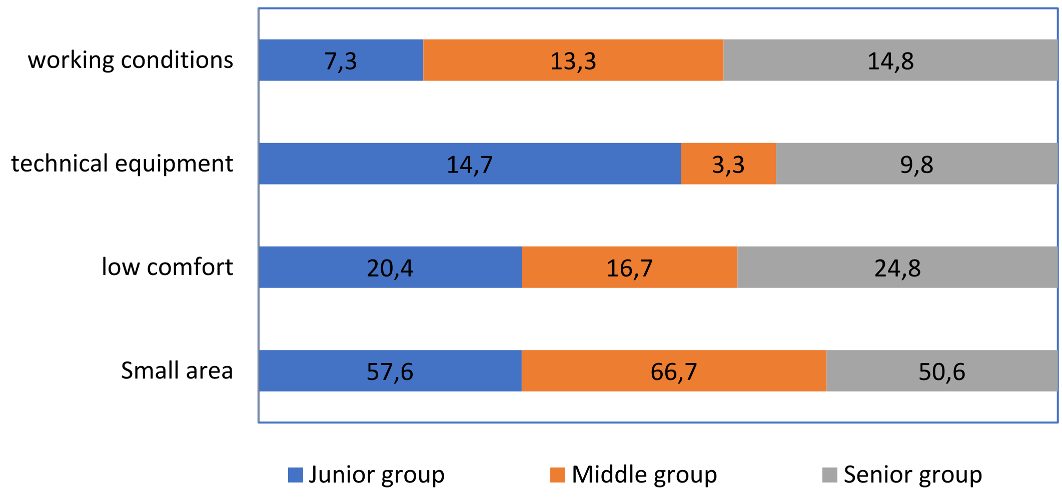

Figure 3 – Reasons for dissatisfactions (in % of respondents) (author`s material).

Based on the results of the conducted research in the form of a sociological survey and the current state of architectural planning solutions for preschool institutions, the following recommendations are proposed to solve the identified problems:

1. To create an architectural environment for a group cell's individual space in accordance with contemporary pedagogical requirements. This will enable the development of a flexible planning structure that considers the primary activities and the unique aspects of preschoolers' psychological development, as shown in report **(Lamekhova, 2011)**.This is possible as long as the interior blends easily transformable, multifunctional elements with a shared semantic integrity.

2. The internal organization of each group member's individual space may include mobile architectural environment components, such as shelves, partitions, sports corners, small architectural forms, natural elements, etc., which can also be colored-highlighted and arranged into groups and activity centers, to enhance the emotional impact of particular emotional zones and to encourage a particular kind of activity. The research **(Lamekhova, 2017)**analyzed the landscape component of kindergartens, which is based on deciduous tree species.

3. Every group or center has a distinct hue: for example, the play center and the physical activity center are brightly colored, signifying that loudness is acceptable. Calm behavior is suggested by the math and book centers' muted pastel tones. Such centers shouldn't be situated adjacent to one another in order to guarantee comfort. The scientific article **(Demidova, 2009)** contains prerequisites, that shelves that are roughly one meter high should be used to divide the centers in order to guarantee both the safety and efficacy of play or educational activities.

4. As shown in dissertation **(Komarova, 2020)**, it is possible to create a unique subject-developing environment for each age group of children by selecting an ideological and thematic concept, organizing the subject environment for each age group of children, and using various figurative and coloristic solutions to form the internal space of preschool institutions' architectural environments.

5. The research of Lamekhova I.V. **(Lamekhova, 2007)** The functions of "educational" architecture, namely the creation of three different types of group cells for three age groups, can be manifested in many ways by modeling the individual space of a group cell using the functional-compositional matrix method and by utilizing a constructive system with a free layout.

5 CONCLUSIONS

Conducted sociological research allowed to conclude that the activities taking place in preschool institutions of Northern Kazakhstan do not fully support the norms and rules.

A creative approach to the development of the architectural structure is currently required, which covers all areas of economic, social and planning aspects.

To improve the architectural environment for preschool education, it is proposed to use the technique of careful elaboration of details and textures of architectural elements of the facade, located in the field of visual and tactile accessibility by creating a section of the facade with special texture characteristics within 2 m from the ground and using different textured coatings and paving in open play areas. Measures to protect against contamination of wall planes and water penetration are carried out due to a tightly adjacent paving plane, the device of a blind area with a lawn covering. The contour of the blind area involves the inclusion of various boundary lines, which helps to improve the aesthetic qualities of the lower tier of the building. Creating a smooth transition from the basement to the first floor allows for the creation of an additional field for creative activity of pupils using economical means (smooth surfaces for drawing, textured coatings for the development of tactile sensations). In addition, it is necessary to note the wide possibilities for concentrating attention by using window openings with different parameters. This technique has not been used in domestic practice before and deserves special attention in order to improve the quality of architecture and develop its didactic properties. The technique of clarity is implemented by using and arranging window elements to carry out experimental.

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RESEARCH ARTICLE

THE ROLE OF DIGITAL TECHNOLOGIES IN THE DEVELOPMENT OF SUSTAINABLE ARCHITECTURE IN KAZAKHSTAN

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Abstract. *In today's world, digital technologies play a crucial role in the development of architecture, particularly in the context of striving for sustainability, which has led to the study of this concept within Kazakhstan. The region stands at the crossroads of tradition and innovation, where the state is advancing the integration of digital innovations into architectural design while preserving its rich cultural heritage. This study examines how digital technologies can contribute to the creation of sustainable and functional architecture in Kazakhstan, highlighting the benefits of artificial intelligence, Building Information Modeling (BIM), 3D printing, as well as virtual and augmented reality. The application of these technologies enables more precise planning and implementation of architectural projects, taking into account the natural and climatic conditions, socio-economic requirements, and cultural-historical context of the region. Special attention is given to analyzing the resource potential of different regions in Kazakhstan, allowing for the optimal use of local resources and the integration of architectural structures into the existing landscape while maintaining their uniqueness and identity. Thus, digital technologies open new opportunities for creating sustainable and efficient architectural solutions that meet modern requirements for comfort and safety while promoting environmental conservation. The study emphasizes the importance of integrating new technologies with cultural and historical aspects to ensure the harmonious development of architecture in Kazakhstan. In conclusion, the authors highlight how digital technologies enhance the quality of architectural projects and contribute significantly to the development of sustainable architecture, advancing the concept of green building that blends innovation with tradition. This approach provides a foundation for the further development of architecture in Kazakhstan aimed at achieving high standards of sustainability and quality of life.*

Keywords: *digital technologies, sustainable architecture, development of Kazakhstan, green technologies, energy efficiency.*

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ҒЫЛЫМИ МАҚАЛА

ҚАЗАҚСТАННЫҢ ТҰРАҚТЫ СӘУЛЕТІН ДАМЫТУДАҒЫ ЦИФРЛЫҚ ТЕХНОЛОГИЯЛАРДЫҢ РӨЛІ

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Аңдатпа. *Қазіргі әлемде цифрлық технологиялар сәулет өнерін дамытуда, әсіресе орнықты дамуға ұмтылу контексінде шешуші рөл атқарады, бұл Қазақстан шеңберінде осы тұжырымдаманы зерделеуге себеп болды. Дәстүр мен жаңашылдықтың қиылысында орналасқан аймақ, мұнда мемлекет өзінің бай мәдени мұрасын сақтай отырып, тек қана емес, сәулеттік дизайнға цифрлық инновацияларды енгізу жолында. Бұл зерттеу жасанды интеллект, ғимараттарды ақпараттық модельдеу (BIM), 3D-басып шығару, сондай-ақ виртуалды және толықтырылған шындықтың артықшылықтарына баса назар аудара отырып, цифрлық технологиялардың Қазақстанның экологиялық және функционалдық сәулеті шеңберінде құруға қалай ықпал ететінін қарастырады. Бұл технологияларды қолдану аймақтың табиғи-климаттық жағдайларын, әлеуметтік-экономикалық талаптарын және мәдени-тарихи контекстін ескере отырып, сәулет жобаларын дәлірек жоспарлауға және іске асыруға мүмкіндік береді. Қазақстанның әртүрлі өңірлерінің ресурстық әлеуетін талдауға ерекше назар аударылады, бұл жергілікті ресурстарды оңтайлы пайдалануға және сәулет объектілерін олардың бірегейлігі мен бірегейлігін сақтай отырып, қолданыстағы ландшафтқа біріктіруге мүмкіндік береді. Осылайша, цифрлық технологиялар жайлылық пен қауіпсіздіктің заманауи талаптарына жауап беріп қана қоймай, қоршаған ортаны сақтауға ықпал ететін тұрақты және тиімді сәулеттік шешімдерді құрудың жаңа мүмкіндіктерін ашады. Зерттеуде мәдени және тарихи аспектілерді ескере отырып, жаңа технологияларды интеграциялаудың маңыздылығы атап өтіледі, бұл Қазақстанда сәулет өнерінің үйлесімді дамуын қамтамасыз етуге мүмкіндік береді. Қорытындылай келе, авторлар цифрлық технологиялар сәулеттік жобалардың сапасын қандай жолмен жақсартатынына назар аударады және тұрақты сәулеттің дамуына айтарлықтай үлес қосады.инновациялар мен дәстүрлерді жан-жақты біріктіретін жасыл құрылыс тұжырымдамасы. Тұжырымдаманың мұндай тәсілі тұрақтылық пен өмір сапасының жоғары стандарттарына қол жеткізуге бағытталған Қазақстандағы сәулет өнерін одан әрі дамыту үшін негіз береді.*

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НАУЧНАЯ СТАТЬЯ

РОЛЬ ЦИФРОВЫХ ТЕХНОЛОГИЙ В РАЗВИТИИ УСТОЙЧИВОЙ АРХИТЕКТУРЫ КАЗАХСТАНА

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Аннотация. *В современном мире цифровые технологии играют ключевую роль в развитии архитектуры, особенно в контексте стремления к устойчивому развитию, в этом стало причиной изучения данной концепции в рамках Казахстана. Регион, находящаяся на перекрестке традиций и новаторства, где государство на пути внедрения цифровых инновации в архитектурное проектирование и не только, сохраняя при этом свое богатое культурное наследие. Это исследование рассматривает, как цифровые технологии могут способствовать созданию в рамках экологичной и функциональной архитектуры Казахстана, делая акцент на преимуществах искусственного интеллекта, информационного моделирования зданий (BIM), 3D-печати, а также виртуальной и дополненной реальности. Применение данных технологий позволяет более точно планировать и реализовывать архитектурные проекты, учитывая природно-климатические условия, социально-экономические требования и культурно-исторический контекст региона. Особое внимание уделяется анализу ресурсного потенциала различных регионов Казахстана, что позволяет оптимально использовать местные ресурсы и интегрировать архитектурные объекты в существующий ландшафт, сохраняя при этом их уникальность и идентичность. Таким образом цифровые технологии открывают новые возможности для создания устойчивых и эффективных архитектурных решений, которые не только отвечают современным требованиям комфорта и безопасности, но и способствуют сохранению окружающей среды. В исследовании подчеркивается важность интеграции новых технологий с учетом культурных и исторических аспектов, что позволяет обеспечить гармоничное развитие архитектуры в Казахстане. В заключении авторы делают акцент на том, что каким путем цифровые технологии улучшают качество архитектурных проектов, и вносят значительный вклад в развитие устойчивой архитектуры, развивая концепция зеленого строительства, которые разносторонне сочетают в себе инновации и традиции. Такой подход концепции предоставляет основу для дальнейшего развития архитектуры в Казахстане, направленного на достижение высоких стандартов устойчивости и качества жизни.*

Ключевые слова:. *цифровые технологии, устойчивая архитектура, развитие Казахстана, зеленые технологии, энергоэффективность.*

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

In Kazakhstan, as in the rest of the world, solutions are needed to address environmental issues and achieve sustainable development. To meet the challenge of sustainability in architecture, the market is increasingly utilizing cutting-edge technologies - ranging from 3D modeling and Building Information Modeling (BIM) to artificial intelligence (AI). These tools help ensure that homes and buildings are not only visually appealing and comfortable but also resource-efficient, conserving energy, water, and other essential resources.

The response to these challenges has been the active integration of digital technologies into architectural practice, representing a modern approach to design and construction. This approach encompasses a broad range of innovative technologies, including AI, BIM, 3D modeling and printing, as well as the use of virtual and augmented reality (VR/AR), aimed at enhancing sustainability and efficiency in architecture. Naturally, transitioning to new technologies is not without challenges. Investments in new equipment, training of specialists, and legislative changes are necessary to ensure these advancements are implemented effectively. However, through these efforts, the construction industry in Kazakhstan is becoming more modern and innovative. Globally, there are numerous examples of successful applications of digital technologies in construction, and Kazakhstan aims to align with these trends.

This study focuses on analyzing the impact of digital technologies on shaping sustainable architecture in Kazakhstan. The “Future Architecture of Kazakhstan” model places significant emphasis on “green” technologies, such as water-saving methods, the use of renewable energy sources, and strategies for improving the energy efficiency of buildings. This underscores the aim to synthesize technological innovation with ecological approaches - a critical pursuit for a country striving to create an environmentally friendly and sustainable architectural environment while preserving its cultural and historical heritage. The study explores the potential of BIM and 3D printing to enhance the accuracy of design solutions and optimize the use of materials and resources. It also evaluates the role of AI in addressing routine tasks and examines the use of VR/AR in the design process and stakeholder interactions. A key part of the analysis is assessing how these technologies contribute to the environmental sustainability of buildings and urban structures, as well as investigating ways to integrate them into architectural planning processes that take into account Kazakhstan’s unique regional conditions.

2 LITERATURE REVIEW

The literature review highlights the contributions of research on digital technologies in the context of cultural-historical and sustainable architecture, as well as their impact on the development of construction in Kazakhstan.

Energy efficiency, as a crucial aspect of sustainable architecture, is discussed in Amory Lovins’ (**Amory, 2011**) work Reinventing Fire: Bold Business Solutions for the New Energy Era, which proposes a comprehensive approach to transitioning to renewable energy sources and implementing energy-efficient technologies across various industries, including architecture.

Research by Issabayev G.A. (**Issabayev, 2020**) introduces the concept of a digital agro-polis for the sustainable development of rural settlements. Hardin and McCool’s (**Hardin & McCool, 2015**) studies emphasize the enhancement of project planning and management through the use of BIM. The application of BIM for the restoration of Notre-Dame de Paris and the preservation of its historical value through the use of traditional materials is illustrated by Guselnikov V.S. and Krupennikov I. (**Guselnikov V. S. & Krupennikov I.).**

Additive technologies, particularly 3D printing in construction, show potential for sustainable development by minimizing waste and utilizing eco-friendly materials, as noted by Kornweitz (**Kornweitz, 2021**). VR and AR technologies, described by Milgram, Takemura, Utsumi, and Kishino (**Milgram, Takemura, Utsumi, Kishino, 2005**), improve design processes and stakeholder engagement, making project visualization more intuitive. Chaillou (**Chaillou, 2020**) and Abacioglu (**Abacioglu, 2020**) explore the application of AI, highlighting new methods of interaction between humans and technology to accelerate the self-organization of the design process.

The importance of preserving cultural heritage is emphasized in the works of Abdrassilova G.S. and Danibekova E.T. (**Abdrassilova & Danibekova, 2021**), as well as Glaudinova M., Galimzhanova A., and Glaudinov B. (**Glaudinova, Galimzhanova A, Glaudinov B. 2021**), and Baitenov E. (**Baitenov, 2023**), who investigate the balance between historical identity and modernity in architecture.

3 MATERIALS AND METHODS

This study employs a combination of interdisciplinary approaches. An analysis of global and local examples of the use of digital technologies, such as BIM, AI, 3D printing, and VR/AR, has been conducted to identify best practices that can be adapted and applied for the development of sustainable architecture in Kazakhstan. The methodology incorporates knowledge from various fields, including digital culture and cultural-historical heritage, which has helped in identifying and structuring key aspects of the content.

4 RESULTS AND DISCUSSION

This section presents the findings of the research dedicated to the role of digital technologies in advancing sustainable architecture in Kazakhstan, focusing on their potential and practical application.

4.1 APPLICATION OF BIM AND 3D TECHNOLOGY

The study revealed that Building Information Modeling (BIM) and 3D modeling technologies play a critical role in architecture and construction in Kazakhstan. These technologies enhance project planning and facilitate better construction management, from the design phase to the building's operational use. They contribute to making buildings more energy-efficient and help reduce waste (**Yitmen, 2021**). However, as with any emerging field, there are challenges. For instance, BIM implementation can be costly, especially for smaller projects that may not justify the investment, potentially increasing overall project expenses (**Hardin & McCool, 2015**).

A prominent example from global practice is the restoration of Notre-Dame de Paris after the fire. Restorers used BIM modeling and advanced technologies to expedite the restoration process while preserving the historical value by employing traditional materials. The use of Autodesk Revit for creating a detailed model of the cathedral **Figure 1**, AutoCAD for drawings, Recap for processing laser scanning data, BIM 360 for collaborative project work, laser 3D scanners, drones, and other associated technologies enabled precise planning and documentation of the work. The project also employed digital twins and IoT to enhance the cathedral's management, which aids in preventing future catastrophes, showcasing a blend of heritage conservation and innovation (**Guselnikov, 2022; Krupennikov, 2023**).

Drawing lessons from these examples, several key approaches can be identified for preserving historically significant structures in regions spanning from the ancient settlement of Otrar and Sygnak to the majestic mausoleums of Aisha-Bibi, Babaji Khatun, and Khoja Ahmed Yasawi. The application of laser scanning and photogrammetry technologies allows for the creation of precise 3D models of these sites. This facilitates the assessment of their condition and aids in planning restoration efforts while considering the architectural and historical specificities.

Virtual modeling using software such as Revit and related programs opens up new opportunities for detailed visual analysis and optimization of the restoration process, ensuring the authenticity and uniqueness of each site. An important aspect is the integration of traditional restoration methods with modern technologies, contributing to the durability and sustainability of structures (**Nabiev et al., 2019**).

The installation of monitoring systems with sensors, including seismometers and thermo-anemometers, to track changes in the condition of structures in real-time allows for the timely detection and prevention of potential damage, which is critical for traditional materials and historically valuable sites.

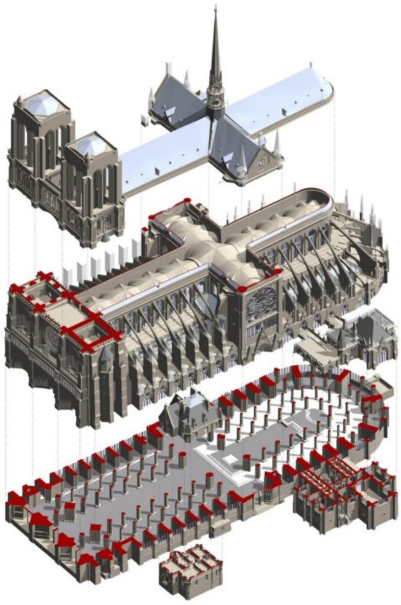

Figure 1 – BIM model of Notre-Dame developed by EPA and Autodesk.
(Retrieved from: URL: http://surl.li/rdsjen)

3D printing offers new methods for using eco-friendly materials, enabling the construction of energy-efficient buildings with unique forms, making construction more accessible, eco-friendly, and economical. However, the adoption of these technologies in Kazakhstan faces challenges such as the high cost of software and equipment, as well as the need for specialist training. Despite this, the prospects for using digital technologies in Kazakhstan's construction industry appear promising due to decreasing technology costs, government support, and increasing awareness of their benefits. One of the first 3D-printed houses was built in Moscow's region by the startup Apis Cor in 2015.

From 2020 to 2022, 3D printing demonstrated its effectiveness and began to spread in construction, attracting significant investments. By 2023, over 1,000 buildings had been 3D printed, and the technology started being used for building settlements, with a regulatory framework developing to support it **Figure 2**, (**Kornweitz, 2022**).

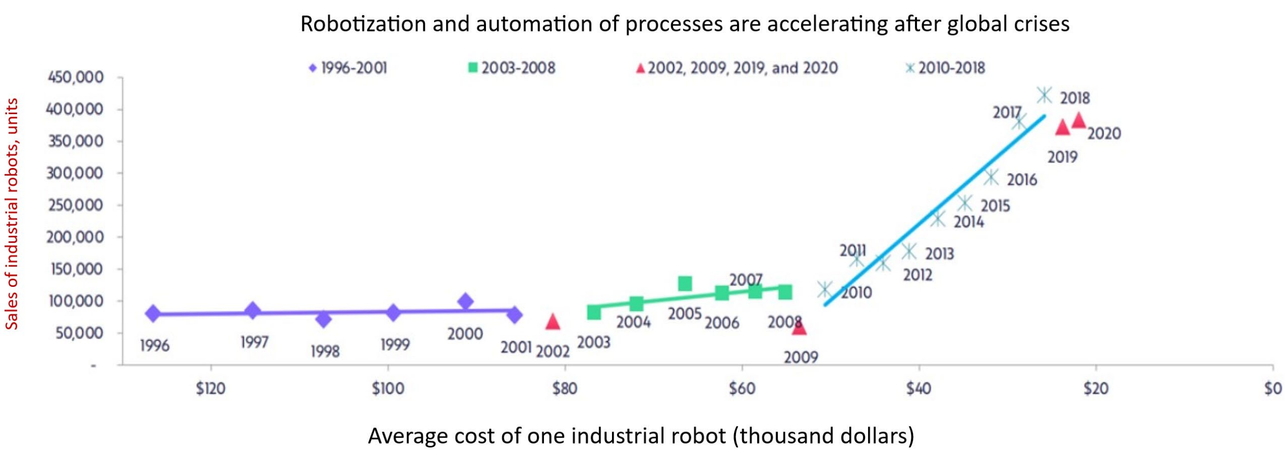

Figure 2 – Statistics on the use of 3D printing. (Retrieved from: URL: http://surl.li/fccgxo)

An example is a two-story house in Germany built using 3D printing. The walls of the house were constructed layer by layer, with a production rate of five minutes per square meter of wall **Figure 3**, (**Kornweitz, 2022**).

Figure 3 – The first residential house created with 3D printing in Germany, 2020. URL: https://habrastorage.org/getpro/habr/upload_files/412/d91/493/412d91493671aaebd2e8feb6079713ab.jpg

3D printing offers new methods for using eco-friendly materials, enabling the construction of energy-efficient buildings with unique forms, making construction more accessible, eco-friendly, and economical. However, 3D printing in construction has its drawbacks, including high costs and technological complexities. It is not always more cost-effective than traditional methods due to the expense of equipment and materials. Challenges include wall quality issues and the need for temperature control during printing. Despite these limitations, the technology has found applications in various areas, including the construction of wind turbine supports. The implementation of 3D printing is slowed by the need for standardization and certification of new materials and methods. Developing these standards takes time, and specialists face the task of adapting the technology and overcoming various barriers.

4.2 INTEGRATION OF VR/AR, ARTIFICIAL INTELLIGENCE, AND INDUSTRY 4.0 PRINCIPLES

Virtual tours of buildings, cities, or historical sites have become popular as a means of engagement and education. Augmented Reality (AR) enables the visualization of future structures within real-world environments, enhancing the understanding of architectural designs. For instance, new VR technologies, such as Apple Vision Pro, offer novel opportunities for studying and preserving cultural heritage. These technologies simplify the creation and interaction with virtual models of archaeological findings, reducing the risk of damage (**Milgram et al., 2005**). Developers employ various tools to create educational materials that promote cultural heritage.

Artificial intelligence (AI) is transforming the field of architecture by automating design processes. AI assists architects in analyzing large datasets to develop innovative projects, enhancing all stages of design and introducing new construction methods and materials (**Chaillou, 2022; pro-tim.ru, 2023**).

In Kazakhstan, archaeological research supported by the "Cultural Heritage" program utilizes modern technologies to study historical sites. Preservation projects for ancient settlements and mausoleums leverage laser scanning and 3D modeling to facilitate documentation and digital restoration. Virtual reconstructions allow for detailed studies of architectural monuments, producing highly accurate digital replicas.

These methods have proven valuable in the restoration of cultural and historical sites in Kazakhstan and in archaeological research, as demonstrated by the example of the Sygnak settlement Figure 4. Partial approaches to the study and restoration of Sygnak have provided insights and sparked interest in the history and culture of the region (Nabiev et al., 2019).

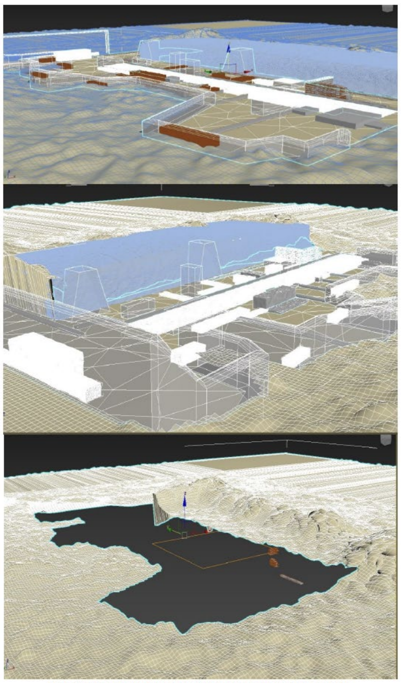

Figure 4 – Models of the virtual reconstruction of the Sygnak settlement (Nabiev et al., 2019).

At the symposium on sustainable construction, Abacioglu T. discussed how Industry 4.0 contributes to building a future where construction is environmentally friendly, economically feasible, and socially responsible. Sustainable development here is viewed as a means to meet current needs without compromising future generations. This involves reducing waste and increasing recycling through new technologies such as 3D printing.

The concept of Industry 4.0 brings innovations to construction through automation and intelligent technologies, making processes more efficient and less harmful to the environment. Abacioglu emphasized the importance of balancing environmental, economic, and social goals and highlighted the need to maintain the human element within technological progress to ensure that construction is not only smart but also sustainable (Abacioglu, 2020).

4.3 SUSTAINABILITY AND CULTURAL HERITAGE: THE «FUTURE ARCHITECTURE OF KAZAKHSTAN» MODEL

The Bronze Age and antiquity left a significant imprint, while the Middle Ages contributed castles and mausoleums that reflect the spirit of their time. Modern ethnographic approaches emphasize the importance of preserving traditional methods and materials while adapting them to contemporary needs. The use of traditional ornaments helps maintain national identity, while modern architecture merges innovation with respect for cultural heritage. The regional characteristics and rich history of Kazakhstan inspire the creation of architecture that embodies the unique nature of the locality.

Natural, climatic, socio-economic, and cultural-historical factors play a key role in shaping architecture. Economic prosperity and social requirements determine building types and materials, while cultural traditions and historical heritage are expressed through styles and designs. The regional characteristics of Kazakhstan, including the unique artistic imagery of each area, give architecture not only functionality but also cultural significance. The southern region, as a center of economic and cultural development since the Middle Ages, maintains its uniqueness in architectural solutions.

The new architecture of Turkestan draws inspiration from historical buildings, such as the mausoleum of Khoja Ahmed Yasawi, creating a unique cityscape that blends tradition and modernity. This approach allows Turkestan to preserve its identity in an increasingly globalized world, offering a fresh perspective on traditional Eastern architecture and highlighting its role as a spiritual center (**Abdrassilova & Danibekova, 2021**).

In Astana, the transformation of the city's architectural landscape combines tradition with modern architectural trends. The concept of "chance" in architecture characterizes the current state of architecture in Kazakhstan, reflecting the process of adapting to change, exploring new forms and styles, and striving to create a new national identity (**Glaudinova et al., 2022**).

Green Technologies. Architecture plays a crucial role in the development of sustainable technologies, such as wind turbines, water conservation, and energy efficiency. Wind energy reduces electricity consumption and enhances the sustainability of buildings. Water conservation has become essential with the introduction of new regulations, such as those in Kazakhstan starting in 2024. In the UAE, "steam fountains" are used to humidify and cool the air to combat heat. Desalination and the use of low-carbon materials make buildings more eco-friendly and resilient.

Sustainable architectural and agricultural projects, both within and beyond Kazakhstan, are being developed based on ecological principles and the latest technologies. Research focuses on methods such as drainage systems and passive heating, which protect buildings from extreme weather conditions and increase energy efficiency. The use of local materials and innovative solutions improves livestock conditions on farms and enhances agricultural sustainability. These examples demonstrate the potential for developing previously unsuitable land for agriculture, maintaining the natural balance, and improving life in small settlements (**Iskhodzhanova & Salimbekova, 2022**).

Within the framework of a sustainable system, the concept of a digital agro-polis aims to create sustainable rural eco-settlements in Eurasia for the cultivation of organic products using modern technologies while minimizing environmental impact. This includes the use of IT systems for resource management, drones for crop monitoring, blockchain technologies for product quality assurance, big data analysis for optimal crop planning, educational programs for local residents, and the use of renewable energy sources, contributing to the economic well-being of rural areas (**Issabayev & Issabayeva, 2020**).

Use of Traditional Building Materials. Kazakhstan produces a wide variety of building materials, including cement, asbestos products, concrete structures, ceramic materials, plastics, roofing materials, facade cladding, and more, including glass and stone products. The architecture of Kazakhstan shows respect for traditional building materials, which reflect the historical and cultural heritage of the country's various regions. These materials not only embody local traditions but are also adapted to climatic conditions, offering natural solutions for ensuring sustainability and comfort **(forbes.kz, 2023**).

Many "green" materials may not meet environmental standards, a practice known as "greenwashing," making it important to verify their compliance with eco-certifications and standards (**Spiegel & Meadows, 2011**). Combining new concrete production technologies with traditional materials enables the construction of more sustainable and energy-efficient buildings. The use of local resources in new concrete formulations reduces environmental impact and preserves ties to tradition. The introduction of non-heated, self-compacting concrete in the production of precast reinforced concrete has reduced electricity consumption from 146 kWh to 125/48 kWh (**Kolesnikova & Alguzhina, 2021**).

In Western Kazakhstan, the use of stone, shell rock, limestone, and clay in construction reflects the region's rich history of creating necropolises, mosques, settlements, and homes capable of withstanding strong winds and sandstorms. These materials provide coolness during hot summer months and retain heat during cold winters.

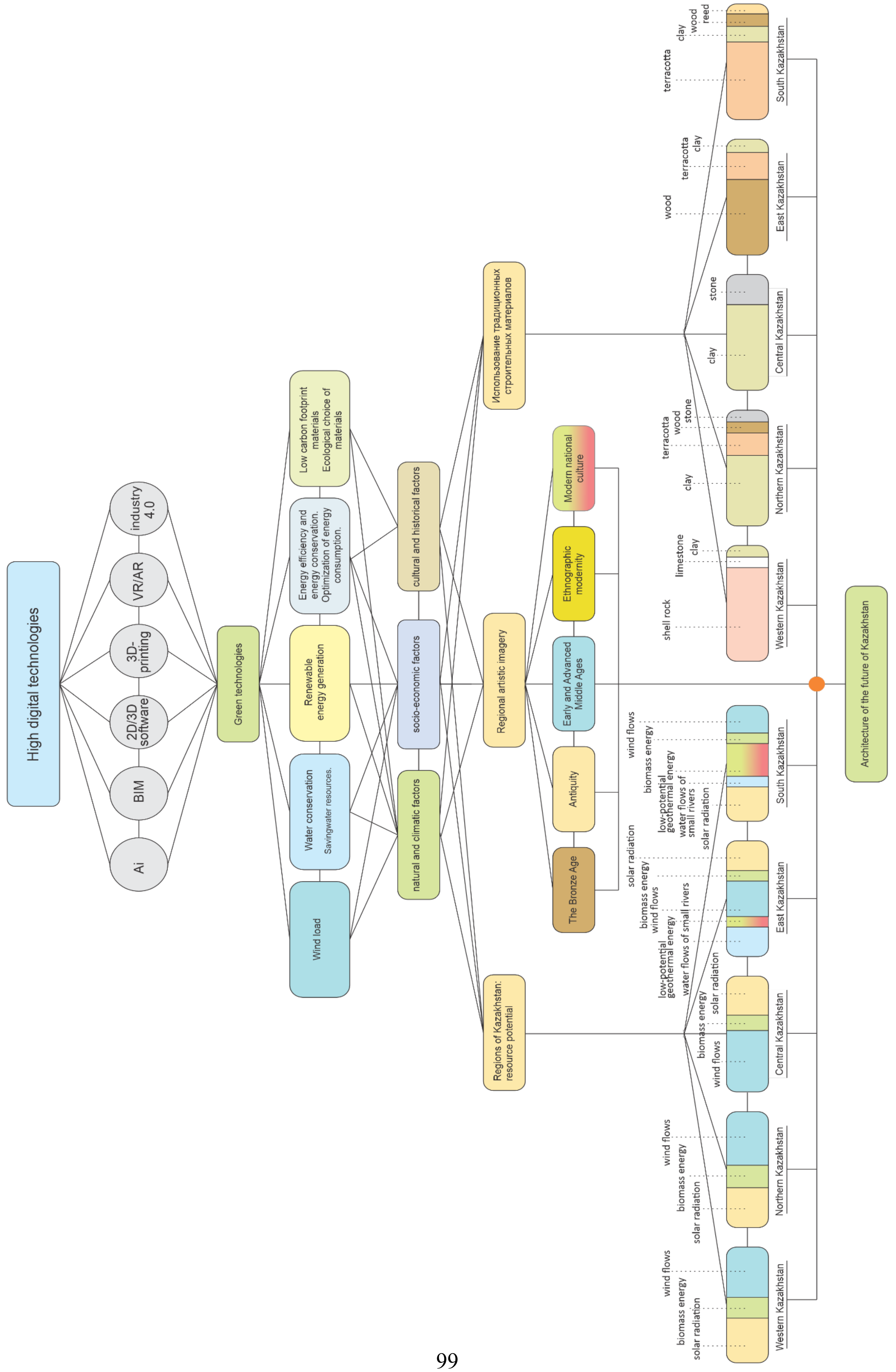

Figure 5 – «Future Architecture of Kazakhstan» Model (Nabivev. 2024).

Northern Kazakhstan, with its harsh winters, has long utilized traditional building materials such as clay, terracotta, wood, and stone to create warm homes capable of withstanding low temperatures.

Central Kazakhstan traditionally uses wood, clay, and stone, reflecting the availability of resources for building warm homes in a continental climate. These materials integrate harmoniously into the region’s landscape.

In Eastern Kazakhstan, where the climate is wetter and colder, wood and stone are preferred for providing reliable protection from wind and precipitation, as well as for retaining indoor warmth.

Southern Kazakhstan predominantly uses terracotta, light-colored clay and stone, wood, and reeds, which effectively absorb sunlight and prevent overheating of buildings during summer. These materials are also highly durable, maintaining their aesthetic qualities for centuries.

The use of traditional building materials in Kazakhstan reflects the centuries-old history and culture of the regions and provides practical solutions for creating comfortable and sustainable housing in diverse climatic conditions.

In the future architecture of Kazakhstan, as shown in **Figure 5**, it is crucial to consider cultural heritage and resilience to change. We must adapt traditions to new technologies so that buildings can withstand climatic and social challenges while preserving the uniqueness of architecture. Innovations must be used wisely so that small changes in design or materials can significantly enhance building sustainability. It is equally important to maintain cultural values, integrating modern and traditional elements into a harmonious whole. Our goal is to create spaces that serve current needs without forgetting the past and future (**Baitenov, 2023**).

5 CONCLUSIONS

The study on digital technologies in architecture demonstrates that the use of BIM and 3D printing enhances project efficiency, reduces waste, and optimizes resource utilization. The application of AI, VR/AR, and Industry 4.0 principles improves design processes and reduces errors, contributing to the overall efficiency of construction. Further implementation and adaptation of these technologies to local conditions and needs will advance the construction industry and improve the quality of the urban environment. Digitalization also plays a crucial role in preserving cultural and historical heritage, allowing for precise documentation and recreation of structures while adapting traditional materials to modern sustainability requirements.

The study recommends the development of educational programs, digital technology standards in architecture, and platforms for experience exchange. It is advised to explore the economic efficiency, social and cultural impacts of these technologies, and the integration of renewable energy sources to achieve sustainability and energy efficiency. The adoption of digital technologies, such as BIM, 3D printing, VR, and AR, has the potential to transform construction, making it more efficient and eco-friendly, while ensuring the preservation of Kazakhstan’s cultural traditions.

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RESEARCH ARTICLE

CREATING SAFE URBAN ENVIRONMENTS THROUGH THREE-DIMENSIONAL DIGITAL MODELS OF CITIES: INSIGHTS FROM KAZAKHSTAN

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Abstract. *Global urbanization and urban population growth emphasize the need for a safe and comfortable urban environment, especially in large cities such as Almaty in Kazakhstan. The fusion of historical architectural ensemble with new development, along with compositional aspects of urban aesthetics, raises urban development issues. Thus, the street-road network and communications vary in the degree of wear and tear and load, which requires logistical support from road and utility services and energy supervision. In addition, the threat of earthquakes and other disasters requires effective evacuation strategies. This article presents the effectiveness of a digital 3D city model as an innovative solution for improving urban safety. The methodology uses the concepts of "protective space", "eye on the street" and "city for people" to establish safety criteria. At the same time, given the relevance, special attention is paid to seismic safety. Using information and communication technologies, this model forms and then continuously updates the basic principles of urban development. Using comparative analysis, photography and morphological mapping, she explores architectural and urban planning strategies for safe spaces at different scales, from individual buildings to neighborhoods. The proposed smart digital model aims to improve urban safety by helping to identify and address safety issues. This approach expands the scope of urban planning methods, stimulates interdisciplinary research to improve the quality of life in cities and contributes to the development of the smart city initiative in Kazakhstan.*

Keywords: *urbanization, safe environment, 3D model, smart city, seismic safety*

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ҒЫЛЫМИ МАҚАЛА

3D ЦИФРЛЫҚ ҚАЛА МҮЛГІЛЕРІН ПАЙДАЛАНҒАН ҚАУІПСІЗ ҚАЛА ОРТАСЫН ҚҰРУ: ҚАЗАҚСТАНДЫҚ ЗЕРТТЕУ

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Аңдатпа. *Жаһандық урбанизация және қала халқының өсуі, әсіресе Қазақстанның Алматы сияқты ірі қалаларында қауіпсіз және жайлы қалалық ортаның қажеттілігін көрсетеді. Тарихи сәулет ансамблінің жаңа дамумен үйлесуі, қала эстетикасының композициялық аспектілерімен қатар, қала құрылысы мәселелерін көтереді. Осылайша, көше-жол желісі мен коммуникациялары тозу және жүктеме дәрежесінде әр түрлі болады, бұл жол және коммуналдық қызметтерден материалдық-техникалық қамтамасыз етуді және энергетикалық қадағалауды қажет етеді. Сонымен қатар, жер сілкінісі мен басқа да апаттар қаупі эвакуацияның тиімді стратегияларын қажет етеді. Бұл мақалада қала қауіпсіздігін арттырудың инновациялық шешімі ретінде цифрлық 3d қала моделінің тиімділігі ұсынылған. Әдістемеде қауіпсіздік критерийлерін белгілеу үшін "қорғаныс кеңістігі", "көшедегі көз" және "адамдарға арналған қала" ұғымдары қолданылады. Бұл ретте өзектілігін ескере отырып, сейсмикалық қауіпсіздікке ерекше назар аударылады. Ақпараттық-коммуникациялық технологияларды қолдана отырып, бұл модель қала құрылысының негізгі принциптерін қалыптастырады, содан кейін үнемі жаңартып отырады. Салыстырмалы талдауды, фотографияны және морфологиялық картаны қолдана отырып, ол жеке ғимараттардан бастап аудандарға дейінгі әртүрлі масштабтағы қауіпсіз кеңістіктерге арналған сәулет және қала құрылысы стратегияларын зерттейді. Ұсынылған ақылды цифрлық модель қауіпсіздік мәселелерін анықтауға және шешуге көмектесу арқылы қалалық қауіпсіздікті жақсартуға бағытталған. Бұл тәсіл қала құрылысы әдістерінің аясын кеңейтеді, қалалардағы өмір сүру сапасын жақсарту бойынша пәнаралық зерттеулерді ынталандырады және Қазақстандағы "ақылды қала" бастамасының дамуына ықпал етеді.*

Түйін сөздер: *урбанизация, қауіпсіз орта, 3D моделі, ақылды қала, сейсмикалық қауіпсіздік*

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НАУЧНАЯ СТАТЬЯ

СОЗДАНИЕ БЕЗОПАСНОЙ ГОРОДСКОЙ СРЕДЫ С ПОМОЩЬЮ ТРЕХМЕРНЫХ ЦИФРОВЫХ МОДЕЛЕЙ ГОРОДОВ: ИССЛЕДОВАНИЯ ИЗ КАЗАХСТАНА

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Аннотация. *Глобальная урбанизация и рост городского населения подчеркивают необходимость создания безопасной и комфортной городской среды, особенно в крупных городах, таких как Алматы в Казахстане. Слияние исторического архитектурного ансамбля с новой застройкой, наряду с композиционными аспектами городской эстетики, поднимает вопросы городского развития. Таким образом, улично-дорожная сеть и коммуникации различаются по степени износа и нагрузки, что требует материально-технической поддержки со стороны дорожных и коммунальных служб, а также энергетического надзора. Кроме того, угроза землетрясений и других стихийных бедствий требует эффективных стратегий эвакуации. В этой статье представлена эффективность цифровой 3D-модели города как инновационного решения для повышения безопасности в городах. В методологии используются концепции "защитного пространства", "глаз с улицы" и "город для людей" для определения критериев безопасности. При этом, учитывая актуальность, особое внимание уделяется сейсмической безопасности. Используя информационно-коммуникационные технологии, эта модель формирует, а затем постоянно обновляет основные принципы городского развития. Используя сравнительный анализ, фотографии и морфологическое картографирование, она исследует архитектурные и градостроительные стратегии создания безопасных пространств в разных масштабах, от отдельных зданий до микрорайонов. Предлагаемая интеллектуальная цифровая модель направлена на повышение безопасности в городах, помогая выявлять и решать проблемы безопасности. Этот подход расширяет сферу применения методов городского планирования, стимулирует междисциплинарные исследования для улучшения качества жизни в городах и способствует развитию инициативы "Умный город" в Казахстане.*

Ключевые слова: *урбанизация, безопасная среда, 3D-модель, умный город, сейсмическая безопасность*

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The authors state that there is no conflict of interest.

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БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

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КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

Architectural and urban planning principles are key to a safe urban environment **(Tolegen, Pomorov, & Issabayev, 2023)**. Today, the transformation and reconstruction of the modern city environment are becoming relevant, taking into account the latest modern technologies and social requirements, with the observance of users' interests at a level that is not as quantitative as qualitative **(Ying, Oosterom, & Fan, 2023, Konbr, & Mamdouh, 2022)**. Almaty is the largest city of Kazakhstan. All major financial and cultural objects are concentrated here, and the beautiful mountain scenery attracts not only residents of Kazakhstan but also tourists **(Tolegen, Imanbayeva, Trofimov, Popov, & Amandykova, 2022)**. The number of citizens especially increases during the school season, in the city, concentrated many higher and secondary educational institutions. These aspects make Almaty a center of attraction for construction companies that deploy active residential and public building construction **(Tolegen, Konbr, Karzhaubayeva, Sadvokasova, Nauryzbayeva, & Amandykova, 2023, Tolegen, Moldabekov, Kosheno, & Mugzhanova, 2018)**. Block or point construction introduces new objects into the existing context, often violating the principles of "neighbourhood".

For example, violation of access control, complete shading of neighboring buildings and violation of insolation requirements, conditional nature of landscaping. The city's most important problem is that Almaty is in the zone of the 9-point earthquake. Therefore, earthquake resistance is one of the main issues in creating a safe urban environment **(Zhaina, Kaltay, Mukhtarova, Beibit, & Amandykova, 2022)**. In addition to the threat of destruction and collision of buildings, there is a problem of a lack of information and orientation for evacuation of people, designated open areas, and temporary facilities that could be installed to serve the population **(Tolegen, Issabayev, Yussupova, Murzalina, & Amandykova, 2022)**. Problems are associated with the infrastructure of residential areas of the post-Soviet period, which still occupy a significant part of the urban area. The unfavorable factors include the presence in the volumetric and spatial solution of residential buildings of blind unviewable ends, poor natural lighting in entrances, lack of comfortable public spaces, etc. Most of these residential properties are rented out and subject to frequent changes of tenants, which increases the problems of lack of social control and creates discomfort for residents and pedestrians. Another important factor in justifying the relevance of this topic is the need for cities in Kazakhstan to comply with international safety indices **(Iskhojanova, Zayats, & Sarttarova, 2022)**.

It should be noted that active construction not only increases the density of the urban environment but also significantly expands the territory of the entire city of Almaty. For example, in the early 2000s, the city's boundaries included eight districts. Nowadays, the territory of Almaty consists of 11 districts. Expanding the urban area leads to the extension of the main street network and the emergence of new ones. The street network is organized according to the historically established Almaty scheme - the road and sidewalk principle. According to this approach, transport is given 2-4 road lanes, and the size of sidewalks is 1 meter. This leads to non-compliance of pedestrian streets to safety requirements, creating comfortable conditions for people and forming visual and aesthetic properties.

Considering all the aspects described above, creating a safe urban environment is the most important issue for the City Hall and among architects, urban planners, urbanists, designers, etc. The creation of a safe urban environment is the most important issue for City Hall. Specialists often organize seminars, competitions, and conferences, where the main task is to search for new ideas and proposals for solving the problems of urban environment safety **(Gholipour, Mahdinejad, Saleh & Sedghpour, 2021)**.

Specialists of seismology, builders, and architects are currently working on the passportization of buildings for seismic resistance. The passportization covered 10,525 objects built before 2001, including residential buildings, social facilities - schools, kindergartens, polyclinics, hospitals, and administrative buildings. It was carried out to examine buildings for earthquake resistance to identify defects and deterioration of structures **(Abdirayim, 2023)**. A third of the 10,525 objects in the city surveyed as part of the passportization do not meet the norms of seismic resistance, and a thousand houses were recognized as dilapidated by experts and recommended to be demolished.

Based on the results of the passportization, electronic passports were created with the surveyed 10,525 objects linked to the electronic map 2 GIS. For each object on the map, there is a photo and information about whether the building is earthquake-resistant or not, what will happen to the building in case of an earthquake in Almaty, and whether there is a place to gather. Old buildings that have been remodeled pose a particular threat.

This trend became widespread in the early 2000s when the first floors of panel houses were reconstructed as stores and pharmacies with separate entrances. To introduce the concept of "city for people" in Almaty, the famous Danish architect and urban design consultant and author of the concept of "city for people", Jan Gale, was invited to Kazakhstan in 2014-2016. The architect gave six lectures in Almaty to representatives of the city authorities, city planning council, architecture students, and builders.

The expert noted that Almaty has huge spaces, large neighborhoods, and sparse development. This creates some discomfort. Many underground and elevated crosswalks do not allow people to use the space of streets to cross without steps on zebra. Catastrophic lack of comfortable space for pedestrians on the streets of the city. Almaty has a unique natural potential - the city is close to nature and has numerous green spaces. Despite these advantages, the main problem of the city is air pollution. The idea of a "city for people" has been partially realized in Almaty. Bicycle lanes and stations for bicycles and scooters have appeared.

Part of the city streets were reconstructed with safety islands. It should also be noted that the city of Almaty currently has a digital three-dimensional model, but its main purpose is economic. Providing general information and the structure of the urban environment to attract investors for the construction of new facilities. Therefore, this study aims to validate the need to create a unified platform that can assess the safety of the urban environment and present possible options for architectural and urban planning solutions.

Based on the studied sources raising the issues of developing a model for organizing the construction of an urban environment, the main security risks should be identified: criminal, infrastructural, environmental and seismic.

The relevance of the study lies in the development of a system of general security and improving the quality of life in the cities of Kazakhstan.

Thus, the purpose of this study is to justify the need to create a single platform that could assess the safety of the urban environment and present possible options for architectural and urban planning solutions. This study is aimed at developing the concept of a digital three-dimensional model of the city as an architectural and urban planning method for creating a safe urban environment.

2 LITERATURE REVIEW

Theoretical aspects of organizing urban environment safety are reflected to a certain extent in scientific works of foreign and domestic scientists. Depending on the stages of urbanization, various theories of architectural urban planning were put forward and tested, types of ensuring safety and organizing life in cities were considered.

In her book, "The Death and Life of Great American Cities", Jane Jacobs **(Jacobs, 1961)** emphasized the importance of "eyes on the street" in keeping urban areas safe. Her theories emphasize the importance of active streets and mixed-use buildings to keep people in constant presence, which helps reduce crime.

Oscar Newman's **(Newman, 1972)**: "defensible space theory, proposed in 1972, asserts that certain architectural and planning decisions can increase safety by strengthening territorial control and creating clear boundaries between public and private spaces".

CPTED (Crime Prevention Through Environmental Design), a concept developed in the 1970s, is based on the idea that architecture, physical planning, and environmental design can influence human behavior and reduce the likelihood of crime. The principles of CPTED include improving visibility and lighting, maintaining order and cleanliness, restricting access, and fostering a sense of community **(Jeffery, 1971, Elsayed, 2024)**.

Kevin Lynch **(Lynch, 1960)**, in his book "The Image of the City", published in 1960, explores how people perceive and orient themselves in urban spaces. The book's main idea is that successful urban design must consider the ease of orientation and understanding of the urban environment by its residents and visitors. Lynch argues that five basic elements are necessary to create an "image of the city" in people's minds: paths (roads, trails), boundaries (delineators of spaces), neighborhoods (distinguishable sections of the city), nodes (focal points such as squares and intersections), and landmarks (notable objects). These elements help people form a stable mental image of the city, making navigating and perceiving the urban environment easier.

Le Corbusier **(Corbusier, 1987)** in his works, including the book " The City of To-morrow and its planning", put forward the ideas of separating urban functions, creating wide avenues and large green spaces, and applying strict geometry in the layout. These ideas aimed to solve the problems of congestion and disorganization in traditional cities, which is relevant to safety issues. Le Corbusier advocated the creation of different levels for pedestrians and vehicular traffic, which was intended to reduce traffic accidents and improve pedestrian safety and comfort.

Many studies developed an integrated approach to planning the urban environment, considering social, economic, and aesthetic aspects of life. He substantiated the need to create multifunctional urban areas that balance residential areas, public spaces, and recreational areas. Recent trends in planning contributed significantly to developing concepts for creating safe and human-centered urban spaces. His approach to urban design centers around improving citizens' quality of life by making urban spaces safer, more comfortable, and more accessible to all categories of people **(Krebs, Mayr, Rezwan, Höftberger, König, Salas, Jong, & Cani, 2023)**.

The book Architectural Design of Earthquake Resistant Buildings by Christopher Arnold and Robert Reitherman emphasizes the importance of integrating architectural and engineering approaches to create safe and aesthetically pleasing buildings. Arnold and Reitherman emphasize a multidisciplinary approach to design, emphasizing the importance of collaboration between architects, civil engineers, and structural engineers **(Arnold, & Reitherman, 1989)**.

Research in the field of urban development shows that at the present stage, focusing on the international level, for Kazakhstan it is relevant to unite individual intellectual cases based on a single platform of a digital three-dimensional model of urban development, using architectural and urban planning principles for solving criminal, environmental, infrastructural and seismic safety.

3 MATERIALS AND METHODS

In the course of the research, collection and study of domestic and foreign experience in architectural urban planning were conducted. Groups of urban environment safety risks were identified and systematized, the basic principles of "protected space" were defined, including in seismic areas. Such forms of design as morphological mapping, three-dimensional modeling, creation of digital twins were proposed. Through the research, certain conclusions were made on the relevance of the transition to an integrated approach to the formation of the "smart city" model.

It is known that recent scientific and technological advances have changed the boundaries of knowledge. They will generate the next wave of breakthrough technologies that significantly impact urban society **(Anselmo, Ferrara, Corgnati, & Boccardo, 2023, Doshibekova, Jurinskaya, Tashpulatov, Zhilisbayeva, Sarttarova, Akbarov, & Kalmakhanova, 2023)**. The development of digital twin technologies has significantly influenced the use of virtual cities and mobility in smart cities. Digital twins provide a platform for developing and testing various systems, algorithms, and mobility policies, which may be employed in creating new safe cities **(Bayer, & Pruckner, 2023)**.

A control system using a digital twin for emergency pedestrian evacuation can improve the overall evacuation efficiency **(Han, Zhao, & Li, 2020)**. Digital twins can make cities more efficient, smarter, sustainable, safer, and inclusive **(Konbr, & Abdelaal, 2022)**. To date, various options for digital twins of cities have been developed. For example, city digital twin systems have already been developed, such as urban transport, disaster management, citizen participation **(Dembski, Wössner, Letzgus, Ruddat, & Yamu, 2020)**, infrastructure management **(Pedersen, Borup, Brink-Kjær, Christiansen, & Mikkelsen, 2021)** or urban planning **(Schrotter, & Hürzeler, 2020)**.

In particular, this is a current problem of digital twins in physical urban infrastructure because they model a wide number of systems that need to be integrated into one tool. City digital twins can drive the development of smart city concept and urban models to a new level. Taking advantage of data collected in smart cities and automatically introducing them into a model of the city and its system, an accurate digital replica is supported that can autonomously interact with the city. Digital twins of cities can not only model, reflect, and interact with the city physical aspect of the city but can also focus on the social and economic aspects.

4 RESULTS AND DISCUSSION

Architectural and urban planning principles of formation are the most important aspects of organizing safe urban environments. For example, since the COVID-19 outbreak, there has been a renewed focus on the links between cities, urban planning, and the pandemic, which has led urban planners and policymakers to question the future of the urban built environment **(Mouratidis, & Yiannakou, 2022)**. Proper planning of projects in the urban environment is how cities enhance outdoor living conditions and urban and public health **(Buffoli, Mangili, Capolongo, & Brambilla, 2022)**. The urban environment influences the lives of urban dwellers in terms of both health and the behaviors they may exhibit, encouraging or discouraging activity and the adoption of good lifestyles **(Faedda, Plaisant, Talu, & Tola, 2022)**. The built environment and mobility system significantly impact people's mobility behavior and activity patterns and, in turn, affect the entire population's health and quality of life **(Giles-Corti, Vernez-Moudon, Reis, Turrell, Dannenberg, Badland, Foster, Lowe, Sallis, & Stevenson, 2016)**. Outdoor spaces allow urban children to engage in physical activities, foster social interactions, and facilitate relaxation **(Reimers, & Knapp, 2017, Hoseeini, Salehinia, Shafaei, & Sedghpour, 2021)**. This significance becomes particularly important in high-density urban environments where the availability of open spaces is often constrained. The efficient design of outdoor open spaces allows the creation of functional and enjoyable recreational areas within the confines of the available space **(Hoseeini, Salehinia, Shafaei, & Sedghpour, 2021, Konbr, Elsayed, & Elboshy, 2023, Tang, & Woolley, 2023)**.

The theoretical concept of the three-dimensional digital model is based on the idea of understanding the city and urban life as a living organism using various self-regulation mechanisms. According to the proposed idea, the digital three-dimensional model integrates indicators that ensure a safe environment in the city of Almaty. The research methodology is based on identifying concepts that use architectural-urban planning methods to create a safe urban environment. These concepts are: "protecting space", "eyes on the street", and "city for people".

Based on the study of research material, the basic principles and systematized criteria for creating a safe urban environment at the level of "building", "yard", "street" and "district" are defined in **Table 1**.

Under the proposed concept, a digital three-dimensional model can identify architectural and urban planning inconsistencies with the above recommendations.

Table 1
Systematization of the safe environment at the levels: building, yard, street, and district based on the principles of "protecting space", "eyes on the street", and "city for people" (authors' materials).

Territoriality	BUILDING	YARD	STREET	DISTRICT
	Buildings of various ages	The distinction between private and public space	High pedestrian trafficking	High building density
Natural observation	Orientation of windows in kitchens and	The only direct path to the building entrance	Avoiding barriers and visibility of entrances	Straight street configuration

	common rooms exits to the courtyard			
Mixed land use	Organization of public spaces for common use	Functional zoning and subject organization of the yard for all groups of people	24-hour street maintenance	Variety of housing types
Broken windows theory	Aesthetically attractive, durable materials	Use of equipment made from quality materials	Organization of streets as equipped public spaces for meetings and communication	Lack of large unused spaces, maintaining order
Access control	Variation in the degree of openness at the boundaries of public spaces	Access control	Real symbolic barriers	Small neighborhoods

As noted above, the territory of Almaty is the most earthquake-prone zone in Kazakhstan. One of the important aspects of seismic safety is the presence of urban open spaces in the urban environment near the residential area. According to this concept, a digital three-dimensional model allows the identification of the required areas of open spaces in each residential area and limits the construction of new facilities in case of violation of the permissible norm.

This digital three-dimensional model reflects the seismic characteristics of each architectural feature. The digital three-dimensional model's programmed program will reflect the seismic deterioration of buildings, emergency buildings, etc **(Table 2)**.

Table 2
Requirements for organizing a safe environment in seismic areas: building, yard, street, district (authors' materials).

Building	**Configuration of vertical building ledges**	**Configuration of incoming corners**	**Possibility of collision with neighboring buildings**	**Building configurations**	**Potential weaknesses in construction**	**Building response to ground movement**
Yard	Communication systems, such as loudspeakers or information boards, can help organize and carry out evacuations and provide vital information during and after an earthquake.	Designation of safety zones in courtyard spaces	Lighting systems are functional in case of power failures, and the presence of information signs indicates the direction to safety zones and evacuation exits.	All landscaping elements must be securely fastened, including trees, benches, playgrounds, and art objects.	Assess the probability of damage or collapse of buildings during a real earthquake.	Paths and exits from courtyard spaces must be clear of obstacles to ensure unhindered evacuation of people. Regular inspection and maintenance of these paths are essential.
Street	Resistance to seismic influences. Quality of materials and technologies used	Streets must be equipped with an effective drainage system to prevent flooding after earthquakes	Separation of traffic and people in case of evacuation	Transformation into evacuation routes.	Lighting systems and safety signs that can operate even during a power outage.	Evacuation zones are designated accessible to all residents in the event of seismic activity.
District	Designating open, safe spaces for people to gather during an earthquake	Designation of open spaces for the placement of temporary objects	Optimization of the location of infrastructure facilities and development areas	Develop risk-decreasing strategies	Areas of the region most vulnerable to earthquakes	Information about soil types

Based on the compiled criteria, **(Table 1, Table 2)** on the example of one district of the city, a comparative analysis of compliance with the principles of "protecting space", "eyes on the street", and "city for people" was carried out.

In the 2010 s, the smart city concept (i.e., a city where the administration and citizens cooperate with new technologies to make the city more efficient, intelligent, sustainable, safer, inclusive, and democratic) was popularized, and cities were sensorized **(Ferré-Bigorra, Casals, & Gangolells, 2022)**. Nevertheless, current approaches cannot usually directly interact with the city urban digital twins, which can potentially change this and drive the smart city concept and urban models to the next level. By taking advantage of the data that are gathered in smart cities and automatically introducing them into the city model and its systems, an accurate digital replica capable of autonomously interacting with the city is maintained.

This study draws attention to consider architectural and urban planning methods as key factors in organizing a safe urban environment in a smart city system. At the present stage, the concept of "smart city" has become widespread as a new dimension of the use of digital technologies to create a comfortable infrastructure and improve the quality of life of people in cities by creating safe urban environments **(Tolegen, Moldabekov, Kosheno, & Mugzhanova, 2018)**.

The main protective means are electronic or mechanical video surveillance systems, access control, strengthening of building structures, etc. Sometimes, they replace compliance with the requirements of the spatial planning characteristics of buildings and architectural and urban planning principles of forming a safe urban environment, which fade into the background.

The emphasis on the maximum use of information technology tools to ensure security in the urban environment, without paying due attention to architectural and urban planning techniques, leads to high financial costs when used.

According to the proposed concept, a digital three-dimensional model can identify architectural and urban planning inconsistencies with the above recommendations. Social dwellings and houses of cheap market segments have a particularly low security potential. However, expensive commercial complexes often do not use elementary spatial planning solutions to increase security, relying on security guards and surveillance cameras.

Modern residential areas are often built on point or block principles and are divided into "economy", "comfort", "business," and "elite" class residential complexes. Residential complexes, "economy", and "comfort" practically repeat the model of neighborhoods built in the post-Soviet period. Therefore, such problems as the presence of blind ends of buildings. There are no distinctions by zone and degrees of privacy; the public space begins right outside the apartment's threshold.

As noted above, the territory of Almaty is the most earthquake-prone zone in Kazakhstan, where construction of more than 9 floors was not allowed. Currently, the city has a huge number of buildings with more than 16 floors. Seismology specialists, builders, and architects are currently working on the certification of buildings for seismic resistance.

"There are technologies to test houses for seismic resistance. After the frame is built, a special simulator is put on the roof of the building, which rocks the building. However, the machine rocks the building from above, while the earthquake happens from below, so testing is incorrect. In reality, the shocks come from below; the foundations are at the bottom, not at the top" **(Oliynyk, Amandykova, Konbr, Eldardiry, Iskhojanova, & Zhaina, 2023)**. It is necessary to apply new technologies in construction and legislate it. A seismic isolator is a "pad" between the foundation and the columns. It does not allow seismic loads to be transferred from the foundation to the frame of the building," believes a representative of the Union of Builders of Kazakhstan.

Today, Building Information Modeling also plays an important role in the seismic design process. BIM modeling allows the creation of a digital model of a building, including its structure, materials, and systems, which helps visualize and analyze the earthquake behavior of the building. In addition, various scenarios, including seismic events, can be previewed using augmented reality elements to evaluate and predict their impact on the building. Additionally, this allows appropriate modifications and improvements at the design stage to ensure optimal seismic stability.

An important functional feature of the proposed numerical model is its ability to test the seismic performance of buildings, demonstrate possible building collapse options, and calculate the hazardous area of collapse.

Even though the city is located in an earthquake-prone zone, the analysis shows that the architectural spaces under consideration do not meet the criteria for creating a safe urban environment **(Figure 1 – 8)**.

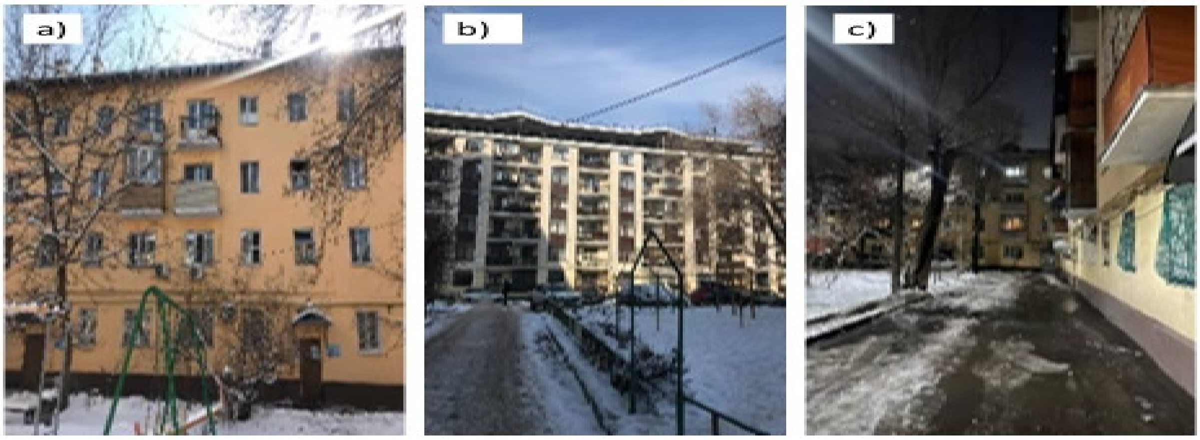

Figure 1 – Results compliance with the principles of "space protection, "eyes on the street": (a, b) Buildings of various ages; (c) Orientation of windows in kitchens and common rooms, exits to the courtyard (authors' materials).

Figure 2 – (a) Organization of public spaces for common use; (b) Aesthetically attractive durable materials; (c) Variation in the degree of openness at the boundaries of public spaces (authors' materials).

Figure 3 – Results of courtyard spaces correspondence with the principles of "space protection, "eyes on the street," and "city for people": (a) The distinction between private and public space; (b) The only direct path to the

building entrance; (c) Functional zoning and subject organization of the yard for all groups of people (authors' materials).

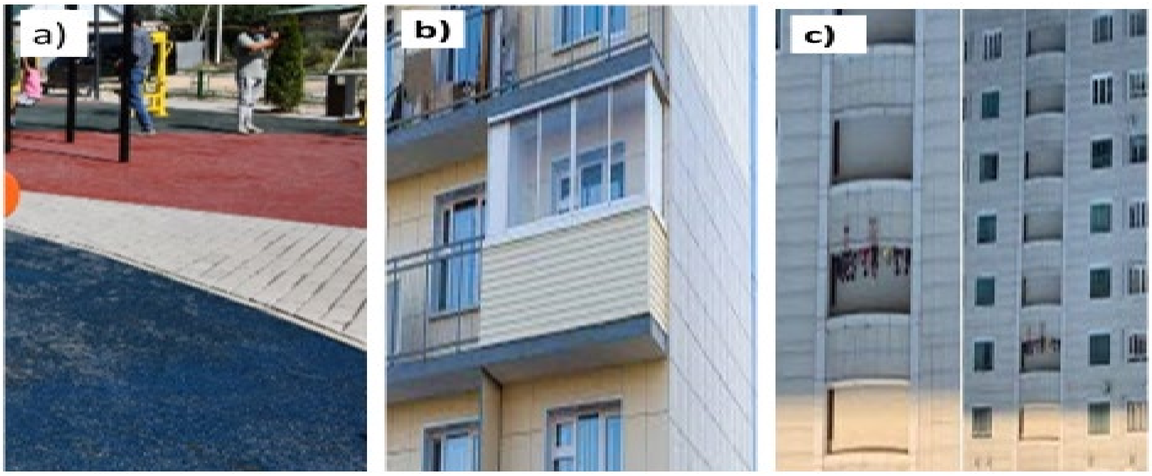

Figure 4 – (a) Use of equipment made from quality materials; (b, c) Access control (authors' materials).

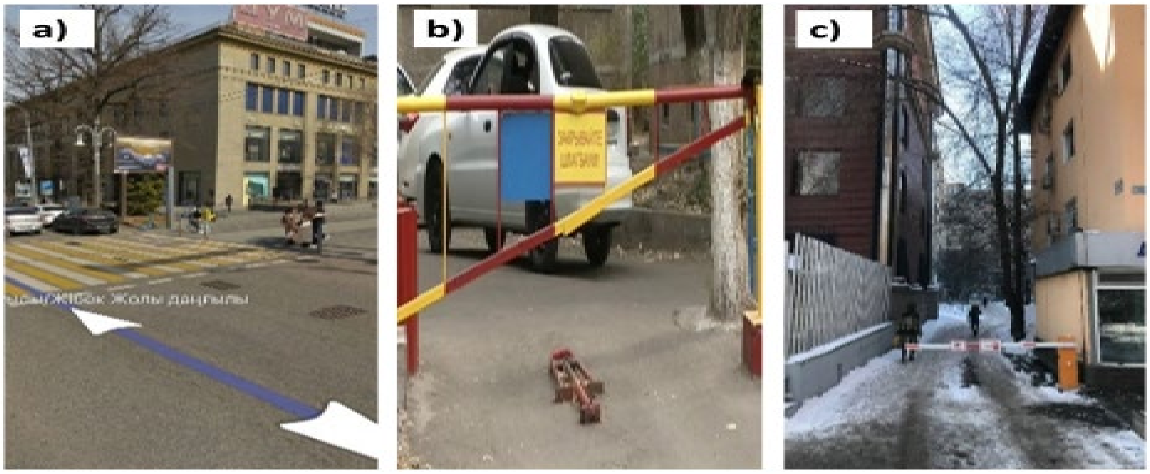

Figure 5 – Results of street compliance with the principles of "protection of space, "eyes on the street,"and "city for people": (a) High pedestrian trafficking; (b,c) Avoiding barriers and visibility of entrances (authors' materials

Figure 6 – (a) 24 hour street maintenance; (b) Organization of streets as equipped public spaces for meetings and communication; (c) Real symbolic barriers (authors' materials).

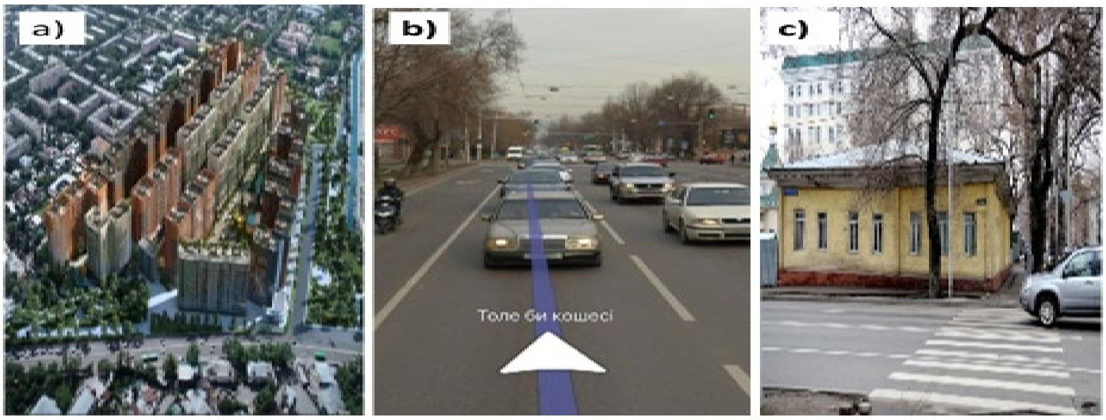

Figure 7 – District. Results of the neighborhood's compliance with the principles of "defensible space," "eyes on the street," and "city for people: (a) High building density; (b) Straight street configuration; (c) Variety of housing types (authors' materials).

Figure 8 – (a) Lack of large unused spaces, maintaining order; (b, c) Small neighborhoods (authors' materials).

The interdisciplinary features and functional capabilities that allow testing scientific developments and project proposals will make the digital three-dimensional model of the city the main guide in developing the "smart city" system in cities. Another important factor in substantiating the relevance of this topic is the need for cities to comply with international safety indices. The basis of the indices is the creation of maximum walking opportunities, reducing dependence on motor transport, and contributing to people's daily lives.

The UN has outlined the main urban planning directions in the real, sustainable urban development model. Also, this is the creation of environmentally friendly and affordable urban infrastructure. Therefore, promoting alternative architectural and urban planning visions and solutions for forming a safe urban environment is relevant for many countries. The concept of a digital three-dimensional model developed in this work using architectural and urban planning principles for solving criminal, environmental, infrastructural, and seismic safety will significantly contribute to creating comfortable conditions and improving the quality of life of people in cities.

5 CONCLUSIONS

This study analyzes existing architectural and technological models of urban development. The main security risks, such as criminal, infrastructural, environmental and seismic, are identified. Emphasizing the relevance of ensuring seismic safety, using the example of the city of Almaty, relevant recommendations are given. In order to comprehensively address the issues of managed urbanization in Kazakhstan, it is proposed to create a common neural platform in the form of a digital three-dimensional model of a "smart" city, based on the architectural and urban planning principles of a safe environment, mobility and socialization of urban infrastructure.

The concept of a digital three-dimensional model of a city proposed in this study will effectively contribute to improving safety in the volumetric-spatial solution of interior spaces of buildings, improving comfortable conditions on pedestrian streets and landscaping open spaces of urban areas. High-quality results of transformations at the level of buildings, courtyards, streets and microdistricts will increase the safety of the entire urban area. The creation of a safe urban environment using a digital three-dimensional model is in tune with the rapid trend of the spread of information digital technologies and the inevitability of the dynamic development of smart city systems around the world. This trend poses new challenges for architects, urban planners, designers and builders and requires searching for new ideas in the issue of creating a safe environment. Further development of this research may be related to studying the integration of digital three-dimensional models with innovative discoveries in architectural and urban planning activities that contribute to the formation of a safe urban environment.

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REVIEW ARTICLE

THERMAL INSULATION PROPERTIES OF SILICA AEROGELS: PROSPECTS FOR USE

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Abstract. *Silica aerogels are unique highly porous materials with exceptionally low thermal conductivity, which opens up broad possibilities for their application in the field of thermal insulation. This article examines the main thermal insulation properties of silica aerogels, emphasizing their ability to effectively reduce heat transfer through conduction, convection, and radiation mechanisms. The physicochemical characteristics of aerogels are discussed, including porosity, density, pore size, and their influence on thermal conductivity. Special attention is given to the nanoscale structure of aerogels, which ensures their high efficiency in insulation. The study presents data on how changes in these parameters can lead to improved thermal insulation properties. The article also analyzes the prospects for using silica aerogels in construction, energy-saving technologies, and other industries where high thermal insulation efficiency is required. Potential areas of application are considered, including building insulation, the creation of energy-efficient systems, and use in specialized industrial conditions. The work discusses key factors affecting the thermal conductivity of aerogels, as well as current research and developments aimed at optimizing their properties for mass application. The conclusion emphasizes the importance of silica aerogels as materials of the future, contributing to the reduction of energy consumption and increasing the sustainability of structures.*

Keywords: *Silica aerogels, thermal insulation, heat transfer, energy efficiency, sol-gel process.*

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ШОЛУ МАҚАЛА

КРЕМНЕЗЕМДІ АЭРОГЕЛЬДЕРДІҢ ЖЫЛУ ОҚШАУЛАУ ҚАСИЕТТЕРІ: ПАЙДАЛАНУ ПЕРСПЕКТИВАЛАРЫ

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Аңдатпа. *Кремнеземді аэрогельдер өте төмен жылу өткізгіштігі бар бірегей жоғары кеуекті материалдар болып табылады, бұл оларды жылу оқшаулау саласында қолдануға кең мүмкіндіктер ашады. Бұл мақалада кремний аэрогельдерінің негізгі жылу оқшаулау қасиеттері қарастырылады, олардың жылу өткізгіштік, конвекция және сәулелену механизмдері арқылы жылу беруді тиімді төмендету қабілетіне назар аударылады. Аэрогельдердің кеуектілігі, тығыздығы, тері тесігінің мөлшері және олардың жылу өткізгіштікке әсері сияқты физикалық-химиялық сипаттамалары талқыланады. Аэрогельдердің наноөлшемді құрылымына ерекше назар аударылады, бұл олардың жылу оқшаулауында жоғары тиімділігін қамтамасыз етеді. Зерттеу осы параметрлердің өзгеруі жылу оқшаулау қасиеттерінің жақсаруына қалай әкелетіні туралы деректерді ұсынады. Сондай-ақ, мақалада кремнеземді аэрогельдерді құрылыста, энергияны үнемдейтін технологияларда және жылу оқшаулаудың жоғары тиімділігі қажет басқа салаларда қолдану перспективалары талданады. Ғимараттарды оқшаулауды, энергияны үнемдейтін жүйелерді құруды және мамандандырылған индустриялық жағдайларда пайдалануды қоса алғанда, әлеуетті қолдану салалары қарастырылады. Жұмыста аэрогельдердің жылу өткізгіштігіне әсер ететін негізгі факторлар талқыланады, сонымен қатар олардың қасиеттерін жаппай қолдану үшін оңтайландыруға бағытталған ағымдағы зерттеулер мен әзірлемелер қарастырылады. Қорытынды кремнеземді аэрогельдердің энергия шығынын азайтуға және құрылымдардың тұрақтылығын арттыруға ықпал ететін болашақ материалдар ретіндегі маңыздылығын көрсетеді.*

Түйін сөздер: *Кремнеземді аэрогельдер, жылу оқшаулау, жылу беру, энергия тиімділігі, күл-гель процесі.*

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ОБЗОРНАЯ СТАТЬЯ

ТЕПЛОИЗОЛЯЦИОННЫЕ СВОЙСТВА КРЕМНЕЗЕМНЫХ АЭРОГЕЛЕЙ: ПЕРСПЕКТИВЫ ИСПОЛЬЗОВАНИЯ

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Аннотация. *Кремнеземные аэрогели являются уникальными высокопористыми материалами с исключительно низкой теплопроводностью, что открывает широкие возможности для их применения в области теплоизоляции. В данной статье рассматриваются основные теплоизоляционные свойства кремнеземных аэрогелей, акцентируя внимание на их способности эффективно снижать теплопередачу через механизмы теплопроводности, конвекции и излучения. Обсуждаются физико-химические характеристики аэрогелей, такие как пористость, плотность, размер пор и их влияние на теплопроводность. Особое внимание уделяется наноразмерной структуре аэрогелей, которая обеспечивает их высокую эффективность в теплоизоляции. В исследовании представлены данные о том, как изменение этих параметров может привести к улучшению теплоизоляционных свойств. Статья также анализирует перспективы использования кремнеземных аэрогелей в строительстве, энергосберегающих технологиях и других отраслях, где требуется высокая эффективность теплоизоляции. Рассматриваются потенциальные области применения, включая утепление зданий, создание энергоэффективных систем и использование в специализированных индустриальных условиях. В работе обсуждаются ключевые факторы, влияющие на теплопроводность аэрогелей, а также рассматриваются текущие исследования и разработки, направленные на оптимизацию их свойств для массового применения. Заключение подчеркивает важность кремнеземных аэрогелей как материалов будущего, способствующих снижению энергозатрат и повышению устойчивости строений.*

Ключевые слова:. *Кремнеземные аэрогели, теплоизоляция, теплопередача, энергоэффективность, золь-гель процесс.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ / ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

In the context of modern challenges related to climate change and the need to improve energy efficiency, there is an increasing demand for innovative materials that can minimize heat loss. Silica aerogels are materials with unique properties that allow for effective thermal insulation due to their nanoscale porous structure. Their ability to reduce heat transfer makes them one of the most promising materials for use in construction, industry, and energy.

However, despite their outstanding thermal insulation characteristics, there are still unresolved issues regarding the improvement of the mechanical strength and stability of aerogels under extreme operating conditions. Their high porosity, on one hand, ensures minimal thermal conductivity, but on the other hand, it reduces their structural strength, which limits their areas of application.

This article provides an overview of contemporary research aimed at enhancing the strength of silica aerogels without compromising their unique insulating properties. It also discusses the prospects of their use across a wide range of fields, from construction and building materials production to aerospace technologies, where their application could significantly reduce energy costs and improve the overall efficiency of thermal insulation systems.

Thus, the research aims to address existing gaps in the understanding of silica aerogels' properties and to develop methods for their optimization to expand practical applications in line with modern technological requirements.

2 LITERATURE REVIEW

Aerogels are solid materials with low density, predominantly mesoporous, possessing unique characteristics such as low density, high specific surface area, low dielectric constant, and extremely low thermal conductivity. Silica aerogels are distinguished by special properties, including a high specific surface area (500–1200 m^2/g), significant porosity (80–99.8%), low density (approximately 0.003 g/cm^3), high thermal insulation characteristics (0.005 W/m·K), as well as extremely low dielectric permeability (k = 1.0–2.0) and refractive index (~1.05). The structure of silica aerogel, obtained through SEM and TEM, is presented in **Figure 1 (Huang et al., 2019; F. Lou et al., 2023; Moner-Girona et al., 2003)**.

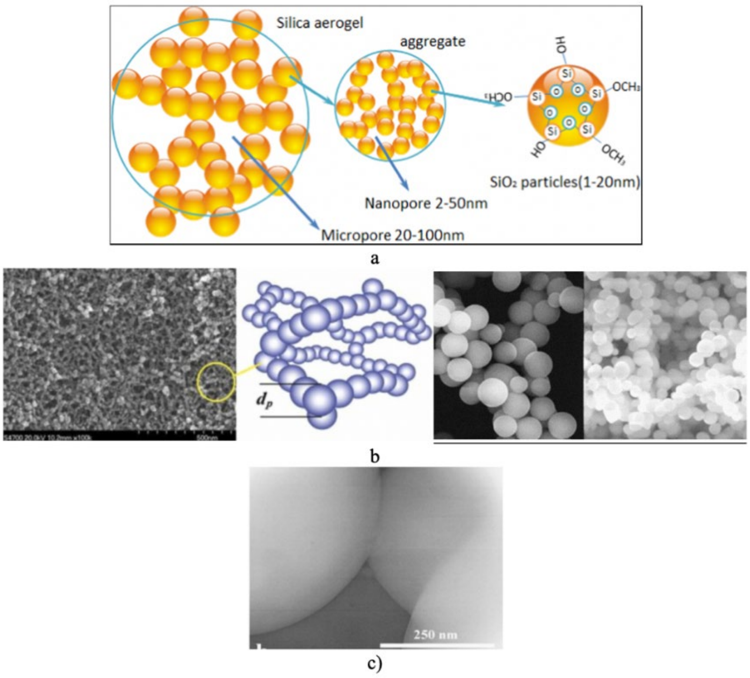

Figure 1 - Silica Aerogel: a) Structure, b) SEM Image, c) TEM Image

Table 1
Relevant Properties of Silica Aerogels (Huang et al., 2017)

Silica aerogel	Color	Translucent
	Density (g cm^{-3})	0.16×10^{-3}
	Thermal conductivity (W m^{-1}·K)	0.022 18
	Pore diameter (nm)	21.85
	BET (m^2 g^{-1})	715.57
	Pore volume (cm^3 g^{-1})	3.82
	Initial Melting point (°C)	—

Silica aerogels are primarily synthesized using the chemical sol-gel process. This method consists of two key stages: 1) gel formation under high humidity conditions and 2) drying of the resulting gel with an intermediate aging stage. In the first stage, the hydrolysis of silicon alkoxides occurs with the addition of appropriate solvents, catalysts, and water, resulting in a homogeneous solution. As a result, a colloidal dispersion of particles forms, which over time organizes into a three-dimensional network structure composed of solid and liquid phases. This process is called gelation, which is part of the sol-gel method, as shown in Figure 2 (Gesser & Goswami, 1989).

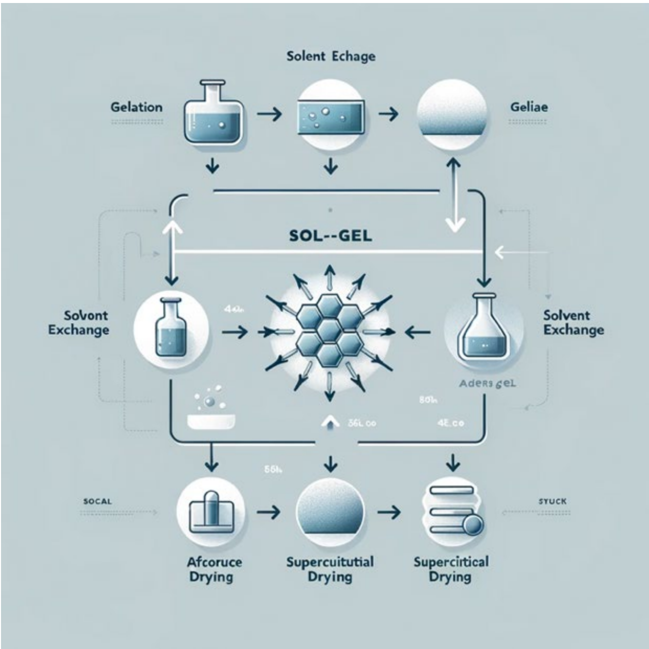

Figure 2 - Sol-Gel Process (Gesser & Goswami, 1989).

The forming gel can take the shape of a polymer chain or colloidal gel, depending on the pH value of the medium used during synthesis. The solvent is then distilled, leaving a viscous liquid that is re-dissolved in an alcohol-containing liquid, such as ethanol. To completely remove the residual solvent and water, the re-dissolution process in alcohol is carried out in several cycles. The second stage involves drying, which is a key moment in the production of aerogel, as previously noted, pressure and temperature significantly influence the properties of the material. During this stage, the remaining liquid is removed from the pores while preventing the destruction of the gel structure. Figure 3 presents the main stages of aerogel production. The aging process can be considered an intermediate stage between gelation and drying (Lee et al., 1995).

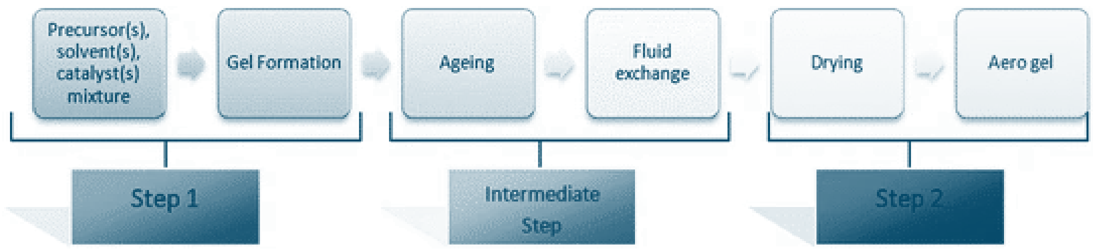

Figure 3 - Overview of Key Processes in Aerogel Production (Sachithanada et al., 2016).

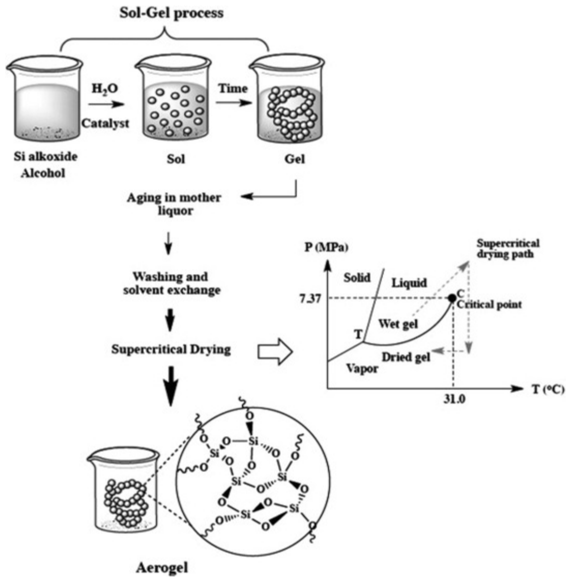

Figure 4 - Schematic Representation of a Typical Sol-Gel Synthesis Procedure for Obtaining Aerogels (Maleki et al., 2014).

3 MATERIALS AND METHODS

3.1 Heat Transfer Analysis through the Material

The industrial success of silica aerogels is primarily attributed to their use as highly effective thermal insulation materials. The thermal conductivity of silica-based aerogels can reach a minimum value of 0.012 W/(m·K), which is explained by their high porosity and complex particle network structure that limits the thermal conductivity of the solid phase. Additionally, the small pore sizes, smaller than the mean free path of gas molecules, reduce the thermal conductivity of the gas phase due to the Knudsen effect. This ultra-low thermal conductivity, which is twice lower than that of conventional air and traditional insulation materials, has led to the creation of a rapidly growing market estimated to be worth hundreds of millions of dollars. The overall thermal conductivity of the material significantly correlates with its density, as illustrated in Figure 5.

For standard insulation materials, an important factor is heat transfer due to radiation, and as pore sizes increase, air convection also becomes significant. As the density of materials increases, the thermal conductivity due to radiation decreases, while the thermal conductivity of the solid phase increases. These opposing effects create a U-shaped relationship between thermal conductivity and density. For aerogels, these effects also play a significant role, but there is an additional notable reduction in the thermal conductivity of the gas phase. This is because the pore sizes in aerogels are smaller than the mean free path of air molecules, which reduces the frequency of their collisions and decreases the heat transfer of the gas. As a result, the minimum overall thermal conductivity shifts to higher densities, achieving significant reductions in thermal conductivity values.

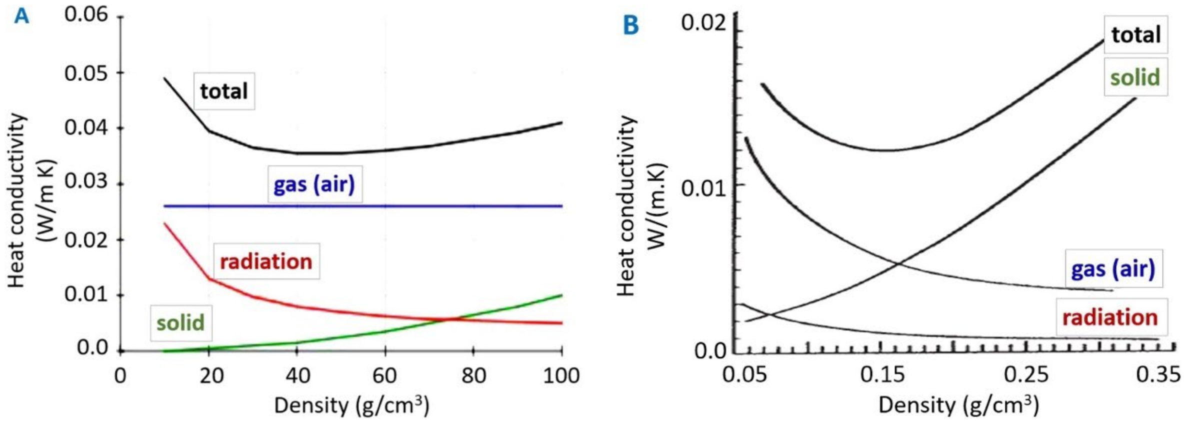

Figure 5 - A) Thermal Conductivity of Conventional Insulation **(Simmler et al., 2005)**, and B) Aerogel Materials **(Hüsing & Schubert, 1998)**.

Aerogels demonstrate outstanding thermal insulation characteristics, making them one of the most effective insulating materials known today. Their exceptional ability to prevent heat transfer is due to their nanoscale porous structure, which significantly reduces heat transfer through conduction, convection, and radiation. In particular, silica-based aerogels are characterized by extremely low thermal conductivity, even at high temperatures, with values around 0.012–0.015 W/(m·K) **(Koebel et al., 2012)**.

3.2 Analysis of Standards for Determining the Thermal Properties of Materials and Practical Laboratory Measurements

The optical characteristics of the glazing sample in the wavelength range of 300–2500 nm were evaluated using an infrared spectrophotometer operating in the ultraviolet range. The tests were conducted in accordance with the international standard ISO 9050:2003 "Glass in Building - Determination of Light Transmission, Solar Heat Gain Coefficient, Total Solar Energy Transmittance, Ultraviolet Transmission, and Related Parameters of Glazing." Thermal conductivity was measured using a flat thermal conductivity meter according to the standard GB/T10294-2008 "Thermal Insulation - Determination of Steady-State Thermal Resistance and Related Properties - Method for Protected Heating Device."

The measured thermal conductivity of the sample with silica aerogel was approximately 0.13 W/(m²·K). The calculated U-value for this sample was about 2.8 W/(m²·K). For the reference glazing sample, the thermal conductivity was measured as 0.15 W/(m²·K), and the U-value, according to calculations, was about 3.2 W/(m²·K). Thus, the thermal insulation properties of the glazing sample with silica aerogel significantly exceed the characteristics of a conventional double-glazing system **(Huang et al., 2015)**.

For the thermal conductivity determination of aerogel samples, the most widely applied methods are the Guarded Hot Plate (GHP), in the steady-state case, and the Transient Plane Source (TPS) method, for the transient methodologies. The apparatus and testing procedure for the GHP method are described in different standards, ASTM C177, European Standard EN 12667 and International Standard ISO 8302. Even though this method has been extensively used, the technique presents some drawbacks, such as the necessity of relatively large testing samples and usually long waiting time. The TPS method, especially the "Hot Disk ®" variants, has been adopted for fast characterization of thermal properties. The ASTM D7984 and the ISO 22007-2 define the devices and procedures for this methodology. The TPS method is reportedly capable of measuring thermal conductivities from 0.005 to 500 mW·m−1·K−1, in a large temperature range (cryogenic temperatures to 500 K). However, the two sample pieces needed must be similar and feature one entirely planar side, which can be sometimes challenging for aerogel samples **(Lamy-Mendes et al., 2021)**.

For acoustic measurements of sound absorption coefficients, two methods are most commonly used: the impedance tube method and reverberation chamber methods. The impedance tube, described in the standards ISO 10534-1 and ISO 10534-2, is used to assess sound absorption on small samples. In turn, reverberation chamber methods, as specified in standard ISO 354, are applied for measuring acoustic characteristics in larger samples. To evaluate sound insulation or sound transmission loss through air systems made from various materials, different approaches are employed depending on the sample size. The impedance tube is used for small samples, while methods outlined in the ISO 10140 series (Parts 1-5) are applied for larger samples, such as building materials or their cladding **(Mazrouei-Sebdani et al., 2021)**.

3.3 Analysis of Material Use in Building Projects.

Key Properties of Silica Aerogel for Application in Buildings **(Lamy-Mendes et al., 2021)**:

1. Pore structure and density - Silica aerogels are materials composed by ultrafine particles, linked in a pearl necklace 3D arrangement, and air-filled pores that usually contribute to 85–99.8% of the total aerogel volume. Therefore, when incorporated in composites, they lead to a reduction of their overall density and, thus, the weight of the building envelope, as well as an increase in the thermal resistance due to their low thermal conductivity.

2. Thermal conductivity - The thermal energy is transferred through silica aerogels by three mechanisms: solid conduction (λs), gaseous conduction (λg), and radiative (infrared) transmission (λr).

3. Optical properties - Silica aerogels show optical properties between transparent and translucent, depending on their internal structure.

4. Acoustic properties - Besides thermal insulation performance and the light transmission properties, the acoustic insulation in building envelope materials is very important, regarding both noise insulation and sound absorption. Among the unique properties of aerogels, their high porosity leads to low sound velocity, allowing them to be also applied as noise insulators and sound absorbing materials.

5. Other properties - Silica aerogels also show other advantageous properties, as non-flammability, non-toxicity and easy disposal when compared with other insulation products in the market. The commercial products containing silica aerogels are also considered as having the same properties.

Silica aerogels are the most common and widely studied type of aerogels. They are typically derived from silicon alkoxide precursors such as TMOS or TEOS using the sol-gel process. Silica aerogels are known for their excellent thermal insulation properties, low density, and high porosity. They can also transmit light with minimal scattering or absorption, making them transparent to visible light. These attributes make silica aerogels suitable for a variety of construction applications, including thermal insulation, energy-efficient glazing, and solar thermal collectors. They demonstrated that materials infused with aerogels are increasingly being designed and assessed for construction purposes, including applications like panels, blankets, cement, mortars, plasters, renders, concrete, glazing systems, and solar collector covers **Figure 6 (Gu & Ling, 2024)**.

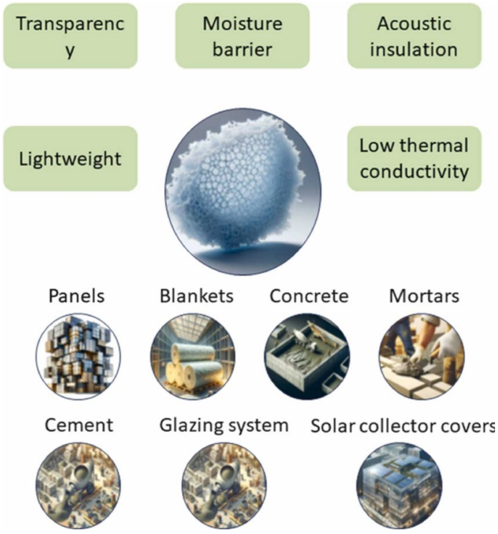

Figure 6 - Materials Containing Silica Aerogel for Use in Construction **(Gu & Ling, 2024)**

Window made of silica aerogel, characterized by high optical transparency and a refractive index of ≈1.52 **(Wang & Petit, 2020)**.

4 RESULTS AND DISCUSSION

Aerogels can be used in energy-efficient window constructions due to their unique properties. Transparent silica aerogels, which possess high thermal insulation and light transmittance, represent a promising solution for window glazing, providing significant energy savings. Silica-based aerogels, thanks to their transparency and exceptionally low thermal conductivity, can reduce energy losses for heating and cooling residential buildings by 25% due to decreased heat transfer through windows. The widespread use of monolithic silica aerogels in window systems can substantially lower energy costs. However, despite these advantages, aerogels exhibit insufficient optical transparency compared to ordinary glass due to light scattering and often have surface defects, which limits their appeal for window constructions.

To address these issues, several approaches have been proposed **Figure 7**. These include improvements in the technological process to enhance visible light transmittance, innovative mold designs to produce homogeneous aerogels, the use of thinner monoliths in window systems, and the application of artistic effects such as paints and laser engraving. The latter allows for the transformation of visible surface defects into elements of aesthetic design, similar to mosaics or stained glass **(Carroll et al., 2022)**.

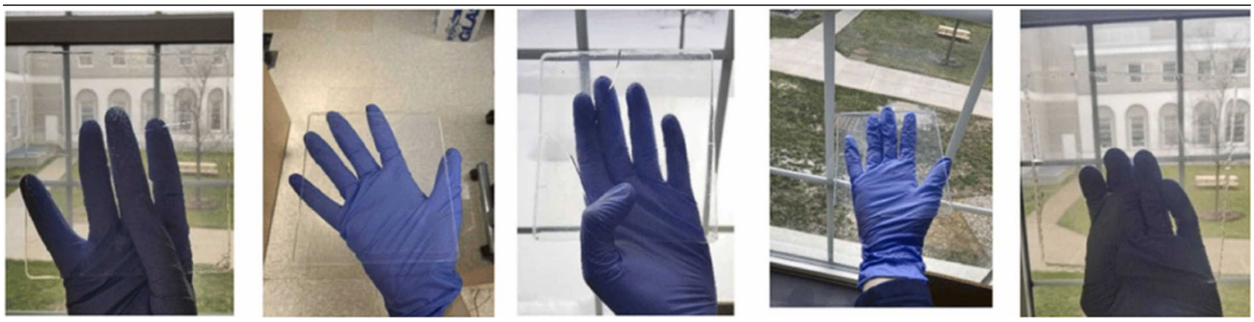

Figure 7 - Images of Monoliths Made of Silica Aerogel Measuring 13 × 12.5 × 0.5 cm, Manufactured Using Various Recipes **(Carroll et al., 2022)**.

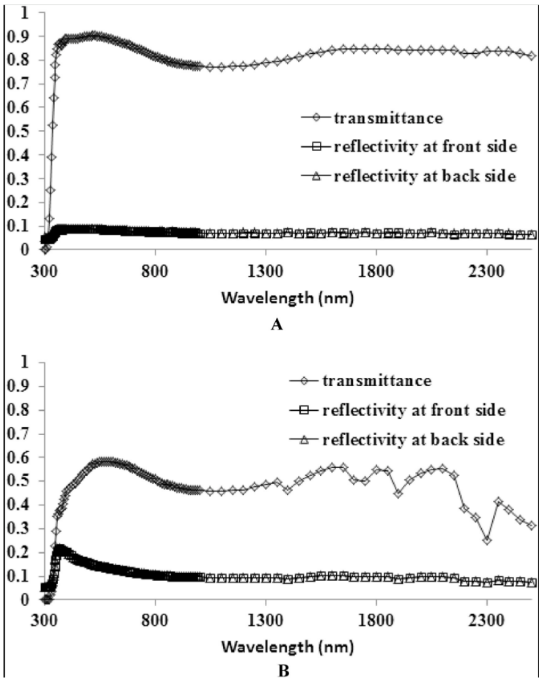

Figure 8 - Results of Optical Characteristics Testing. A. Control Window Sample; B. Silica Aerogel Window Glass Sample **(Huang & Niu, 2015)**.

To evaluate the optical characteristics, it is necessary to measure three key parameters: transmittance, front reflectance, and back reflectance. For these measurements, a reference glazing sample was prepared, which allowed for a clear assessment of the impact of the silica aerogel filler on the optical properties of glass constructions. The control glazing sample was identical to the sample containing silica aerogel, except that there was no aerogel filler between the two layers of glass in the control sample.

Figure 8 shows the optical characteristics of both samples. The results indicate that the addition of silica aerogel filler significantly reduces the light transmittance across the wavelength range. Before filling the sample with silica aerogel, the glass transmittance was approximately 0.8, whereas after introducing the silica aerogel, this value decreased to about 0.45. A slight increase in reflectance was also observed **(Huang & Niu, 2015)**.

In the context of the pressing issues of climate change and the necessity for energy conservation, the role of building insulation becomes particularly important. Aerogels, especially silica aerogels, represent one of the most effective materials for insulation due to their outstanding thermal insulation properties. These materials possess exceptionally low thermal conductivity even at high temperatures, attributed to their high porosity and nanostructured network, which hinders heat transfer through convection, conduction, and radiation.

Aerogel insulation materials can be used for finishing walls, roofs, and floors, significantly reducing heat transfer and enhancing the energy efficiency of buildings. The market offers aerogel coatings, panels, and slabs that simplify the installation process. Furthermore, due to their lightweight nature, aerogels contribute to reducing the overall weight of structures, which is an important aspect in construction **(Gu & Ling, 2024)**.

The exceptional thermal insulation properties of aerogels make them key components for enhancing energy efficiency in the construction sector. Modern buildings consume more than one-third of the world's energy resources, with a significant portion of this energy lost due to heat transfer through walls, windows, ceilings, and other enclosing structures **(Lamy-Mendes et al., 2021; Dou et al., 2023; Han et al., 2023)**.

The use of aerogel coatings, panels, or granulated aerogels in the enclosing structures of buildings significantly reduces thermal flow, leading to a decrease in energy demand for heating and cooling. Currently, commercial products such as Spaceloft aerogel insulation are available, which have an outstanding thermal conductivity of 15 mW/m·K and are designed for finishing walls, attics, and window inserts. Experimental data show that replacing traditional insulation materials with aerogels can reduce the thermal transmittance coefficient (U-value) by more than 50%. These exceptional performance characteristics, combined with the material's thinness and lightness, make aerogels particularly promising for the creation of zero-energy buildings **(Gu & Ling, 2024)**.

The acoustic properties of a building significantly affect the comfort and functionality of the interior space. Aerogels, due to their high porosity and complex internal structure, can effectively absorb sound waves, making them excellent sound insulators. These sound-absorbing properties are beneficial for various construction applications, from residential buildings requiring improved sound insulation to specialized spaces like recording studios and concert halls, where acoustic control is critically important. Silica aerogels exhibit unique acoustic properties, including particularly low sound speeds in the range of 100 to 300 m/s at densities from 0.07 to 0.3 g/m³. These values are significantly lower than sound speeds in air (343 m/s) and in quartz glass (≈5000 m/s) **(Gronauer et al., 1986)**.

A coating based on insulating materials, such as silica aerogels, has been developed **Figure 9 (Achard et al., 2011)**. This lightweight building mortar is designed for application on the external surfaces of buildings to create an effective thermal insulation coating. The composition of the mortar includes mineral and/or organic hydraulic binders, an insulating filler containing hydrophobic silica aerogel granules (or powder from this material), as well as a structuring filler and optional additives.

The building mortar is made using aerogel grains, which replace the sand typically used in traditional building mortars. It is produced industrially in the form of a dry mixture, consisting of carefully blended components. This mixture is packaged in bags and delivered to the construction site. On-site, the dry mixture is combined with water to form a paste with the necessary viscosity for application, for example, by spraying on the external surfaces of the building. The thickness of the coating is determined by the ease of its application, thanks to specially developed technologies.

Figure 9 - Coating based on silica aerogel **(Ibrahim et al., 2014)**.

5 CONCLUSIONS

Silica aerogel is characterized by a wide range of properties, which expands its wide range of applications. One of the main properties that silica aerogel is valued for is its pore structure and density, silica aerogels are composed of ultra-fine particles connected by 3D pearl necklaces and air-filled pores that typically make up 85-99.8% of the total aerogel volume. Therefore, when incorporated into composites, their overall density is reduced, and thus the weight of building envelopes, as well as thermal resistance is increased due to low thermal conductivity, which greatly expands the use of silica aerogel in various composites to support the properties of these composites.

Climate change and energy conservation are major issues in the modern world, so the role of building insulation has never been more important. The thermal conductivity of silica aerogels is extremely low, even at high temperatures, which is related to the high porosity and nanostructured network that inhibits heat transfer by conduction, convection, or radiation. Therefore, insulating materials based on silica aerogels can be used very widely, starting with roof insulation, wall insulation, and ending with floor insulation. This significantly reduces heat transfer, increases the energy efficiency of the building. In addition, the lightweight nature of silica aerogels reduces the overall weight of the structure, which is a critical consideration in construction.

In addition to the unique properties of aerogels, their high porosity leads to low sound speeds, which allows them to be used as noise insulators and sound absorbing materials, which further expands the application possibilities of these materials. Silica aerogels are also characterized by non-flammability, non-toxicity and easy removal compared to other insulating products on the market.

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RESEARCH ARTICLE

ACTUAL PROBLEMS OF APPLICATION OF COMPOSITE FLEXIBLE CONNECTIONS IN EXTERNAL THREE-LAYER WALL PANELS

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Abstract. *In this paper, the technical problems of using the structures of their three-layer panels with flexible connections made of polymer materials are considered on the example of a residential complex under construction in Astana. The study of three-layer panels with flexible composite bonds was carried out as a result of the appearance of cracks with an opening width of acrc = 0.05-0.1 mm. The main purpose of the study was to establish the causes of cracking and to develop recommendations for the exclusion of such phenomena in the structures of three-layer panels with flexible composite bonds, which was carried out in the following directions: preparatory research (study of technical and design documentation, review of scientific and technical literature (sources) in this field of theory of buildings and structures); full-scale study of external wall three-layer panels with flexible polymer bonds (the actual strength of concrete was determined; the entire technological chain of creation and erection of the structure under study was traced (manufacture, transportation, installation in the design position); actual reinforcement of panels was established); performing panel verification calculations for various design situations (a total of six design calculation options) based on software the Lira CAD complex; identification of the main causes of cracks and development of recommendations for the elimination of future technical problems in the design, manufacture, transportation and installation of three-layer panels with flexible composite bonds.*

Keywords: *wall panels, load-bearing elements, structures, facade, defects and damages.*

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ҒЫЛЫМИ МАҚАЛА

ҮШҚАБАТТЫ СЫРТҚЫ ҚАБЫРҒА ПАНЕЛЬДЕРІНДЕ КОМПОЗИТТІК ИКЕМДІ БАЙЛАНЫСТАРДЫ ҚОЛДАНУДЫҢ ӨЗЕКТІ МӘСЕЛЕЛЕРІ

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Аңдатпа. *Бұл жұмыста Астана қаласында салынып жатқан тұрғын үй кешенінің мысалында полимерлі материалдардан жасалған икемді байланыстары бар үш қабатты панельдердің конструкцияларын қолданудың техникалық мәселелері қаралды. Икемді композиттік байланыстары бар үш қабатты панельдерді зерттеу жарықтардың ені acrc=0,05…0,1 мм ашылу нәтижесінде жүзеге асырылды. Бұл зерттеудің негізгі мақсаты жарықтардың пайда болу себептерін анықтау және икемді композиттік байланысы бар үш қабатты панельдердің конструкцияларында осындай құбылыстарды болдырмау бойынша ұсыныстар әзірлеу болды. Бұл жұмыстар келесі бағыттарда жұмыс жүргізу кезінде анықталынды: дайындық зерттеу (ғимараттар мен үймереттер теориясы саласындағы техникалық және жобалық құжаттаманы қарау, ғылыми және техникалық әдебиеттерді (дереккөздерді) шолу); икемді полимерлі байланысы бар үш қабатты сыртқы қабырға панельдерін табиғи зерттеу (бетонның нақты беріктігін анықтау; зерттелетін құрылымды құру мен тұрғызудың барлық технологиялық тізбегін бақылау (дайындау, тасымалдау, жобалық жағдайға орнату); панельдердің нақты арматурасын орнату; ашылу ені acrc=0,05…0,1 мм кезінде ішкі бетон қабаты бойынша бетон бетіндегі қабырға панелінің жоғарғы және төменгі жиектерінің деңгейінде, сондай-ақ терезе саңылауларының тораптары аймағында жарықтарды анықтау;Лира САПР бағдарламалық кешені негізінде әр түрлі есептік жағдайларға арналған панельдік тексеру есептеулерін (есептеудің алты есептік нұсқасын алу) жүргізу; жарықтардың пайда болуының негізгі себептерін анықтау және икемді композиттік байланысы бар үш қабатты панельдерді жобалау, дайындау, тасымалдау және монтаждау кезінде болашақта техникалық проблемаларды жою бойынша ұсыныстарды әзірлеу.*

Түйін сөздер: *қабырға панельдері, тірек элементтері, құрылымдар, қасбет, ақаулар мен зақымдар.*

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НАУЧНАЯ СТАТЬЯ

АКТУАЛЬНЫЕ ПРОБЛЕМЫ ПРИМЕНЕНИЯ КОМПОЗИТНЫХ ГИБКИХ СВЯЗЕЙ В НАРУЖНЫХ ТРЕХСЛОЙНЫХ СТЕНОВЫХ ПАНЕЛЯХ

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Аннотация. *В данной работе рассмотрены технические проблемы применения конструкций их трехслойных панелей с гибкими связями из полимерных материалов на примере строящегося жилого комплекса в г. Астана. Исследование трехслойных панелей с гибкими композитными связями выполнено в результате появления трещин шириной раскрытия* a_{crc}*=0,05-0,1 мм. Основной целью исследования явилось установления причин трещинообразования и разработка рекомендаций по исключению подобных явлений в конструкциях трехслойных панелей с гибкими композитными связями, которая проводилась в следующих направлениях: подготовительное исследование (изучение технической и проектной документации, обзора научной и технической литературы (источников) в данной области теории зданий и сооружений); натурное исследование наружных стеновых трехслойных панелей с гибкими полимерными связями (определялась фактическая прочность бетона; прослежена вся технологическая цепочка создания и возведения исследуемой конструкции (изготовление, транспортировка, установка в проектной положение); установлено фактическое армирование панелей); выполнение поверочных расчетов панели на различные расчетные ситуации (всего шесть расчетных вариантов расчетов) на основе программного комплекса Лира САПР; определение основных причины появления трещин и разработка рекомендации по исключению в будущем технических проблем при проектировании, изготовлении, транспортировки и монтажа трехслойных панелей с гибкими композитными связями.*

Ключевые слова:. *стеновые панели, несущие элементы, конструкции, фасад, дефекты и повреждения.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС/ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

One of the primary objectives in advancing large-panel construction technologies is to enhance energy efficiency and energy conservation. This is achieved through the integration of composite polymer reinforcements, which are particularly promising for use in three-layer external wall panels.

To ensure the required reliability of three-layer reinforced concrete panels with composite connections, it is essential to develop appropriate structural solutions and conduct extensive experimental investigations. These include testing both individual panel elements with connections and the panels as a whole. Key aspects of this research involve addressing issues of anchoring, corrosion resistance, and fire safety of the connections, as well as examining the interaction between flexible connections and the concrete layers of load-bearing structures.

2 LITERATURE REVIEW

(Blazhko, 2015), in Flexible Basalt-Plastic Bonds for Use in Three-Layer Exterior Wall Panels, emphasized the necessity of developing an effective and reliable system for quality control of flexible composite connections during production. This system should be incorporated into the technological regulations for panel manufacturing. The study demonstrated that inaccuracies in the installation and embedding of flexible basalt-plastic connections, as well as technological factors during production, significantly affect the load-bearing capacity and durability of panels across various stages, including manufacturing, transportation, installation, and long-term operation.

(Lugovoy, 2014), in Composite Flexible Connections for Three-Layer Panels, identified several key advantages of using composite connections over traditional bonding methods for three-layer panels. Composite connections eliminate thermal bridges, which increases the thermal resistance of wall panels by 20–40% due to their low thermal conductivity (0,55 W/m·°C). This improvement enhances energy efficiency and conservation in large-panel construction. Furthermore, experimental and theoretical studies revealed essential physical and mechanical characteristics of panels with flexible polymer connections, including their strength under various stress-strain states (tension-compression, transverse bending, and shear along and across reinforcement fibers), elastic modulus, creep resistance, and durability in aggressive environments such as acids and alkalis for up to 100 years. The bond strength between flexible connections and concrete or mortar was also confirmed. Instead of increasing the insulation thickness in traditional panel designs, the use of flexible polymer connections eliminates thermal bridges caused by concrete keys or stainless-steel ties, significantly improving the reliability and cost-efficiency of three-layer panels.

In the study, **(Kovrigin, Maslov, and Wald 2017)** investigated the effects of alkaline exposure on flexible composite connections with wound strands. The results showed that such exposure significantly reduces bond strength with concrete—up to 90%. However, flexible connections featuring cylindrical-conical anchor expansions experienced only a 9% reduction in bond strength, ensuring operational reliability and durability of the structure.

The introduction of flexible composite connections in wall panels has significantly enhanced corrosion resistance and material efficiency. These panels also effectively meet regulatory requirements for thermal conductivity and heat resistance, optimizing the consumption of components.

Screw-type connections with periodic profiles, created by bonding strands of basalt and glass fibers impregnated with resin, are deemed impractical. During extraction from the concrete mass, shear failures occur in the contact zone due to the detachment of coarse sand from the reinforcing rod surface. Conversely, the use of anchor elements with cylindrical expansions at the ends of the rods ensures reliable and durable fixation of flexible connections in concrete.

In addition to the design of the anchor interface (e.g., cylindrical expansion at the end of the rod), the reliability of flexible connections depends on the composition of the binding element and the stability of the manufacturing process in terms of quality. Key factors include using raw materials with high initial strength and modulus of elasticity and determining the optimal volume ratio of filler to polymer matrix to achieve a uniform composite structure.

To ensure the required thermal stability of the composite, it is essential to select the appropriate glass transition temperature, ideally between 60–65°C, as verified by relevant testing protocols. Furthermore, quality standards for manufacturing flexible composite connections should include a robust acceptance testing system, with samples from each batch subjected to rigorous evaluation.

The foundation of composite reinforcement in constructions consists of fibers made from basalt, glass, aramid, and carbon, with thermoactive synthetic resin (plastic) serving as the binding agent **(Imomnazarov, Al Sabri, & Dirie, 2018)**. Compared to conventional steel reinforcement, composite reinforcement exhibits certain disadvantages: a low modulus of elasticity, reduced fire resistance, inability to be used as compressed reinforcement, and higher costs.

A significant obstacle to the widespread use of composite reinforcement is the lack of a robust regulatory framework. The low modulus of elasticity reduces the ultimate load capacity of flexural elements without pre-tensioning. Furthermore, traditional calculation methods for reinforced concrete structures with steel reinforcement are unsuitable for designs incorporating composite reinforcement.

Fire resistance is another critical challenge. When heated to 100°C, composite reinforcement made of glass or basalt fibers may degrade, requiring the development of specialized fire protection measures to ensure its viability in high-temperature conditions.

Despite these limitations, composite reinforcement offers notable advantages, including chemical resistance, electromagnetic transparency, and excellent dielectric properties, making it particularly beneficial in certain applications.

Filatov (2017) examined the use of three-layer panels with discrete connections (reinforced concrete walls) based on fiberglass and basalt-plastic reinforcement. The study investigated the temperature distribution within three-layer external wall panels, which consisted of an outer layer of expanded clay concrete (80 mm thickness), an insulating layer of polystyrene foam boards (PPS-25 type, 150 mm thickness), and an inner layer of expanded clay concrete (120 mm thickness). Average surface temperatures of external walls, heat flows, and thermal resistance values were determined. Thermodynamic calculations were verified through thermographic inspections, which confirmed the absence of thermal bridges in all cases.

According to **Kovrigin and Maslov (2016)**, existing GOST standards for composite connections exhibit several critical shortcomings:

1. There are no requirements for the organization of acceptance tests for composite flexible connections. These tests should not only include measurements of sample geometric dimensions but also determine the actual physical and mechanical characteristics of the products.
2. The standards lack requirements for bond strength between connections and the concrete of the load-bearing or facing layer after exposure to appropriate environmental conditions. This factor significantly influences the load-bearing capacity of panels incorporating polymer-composite flexible connections (e.g., glass and basalt fibers).
3. There are no correction coefficients that account for dynamic and climatic impacts on the strength of flexible connections and their anchoring systems within the concrete mass. This necessitates the development of additional calculation methods within the broader framework for composite constructions.
4. Specific (technically justified) schemes for the placement of flexible connections to optimize their inherent strength and ensure reliable and thermally efficient wall panels are absent.

The structural design of the anchoring element in flexible connections plays a pivotal role in their reliability and durability. This includes features such as protruding ribs along the entire length of the rod, square profile expansions formed by milling the composite rod, or cylindrical-conical expansions connected with cylindrical sanded anchor sections. Such features are essential to ensuring the reliable connection of the layers in three-layer panels. Therefore, all flexible connection designs should undergo strength testing in aggressive environments to verify both the connections and their anchoring systems before being approved for use.

Based on international methodologies, the following requirements have been established for testing the load-bearing capacity of flexible connections:

1. The quality of the connections should be assessed in terms of both their own strength and the strength of their nodes when bonded to the concrete mass of constructions.
2. Connections should undergo tests in alkaline environments to evaluate chemical aging under simultaneous static loading. The test duration should be at least 5,000 hours (compared to only 720 hours in Russia).
3. Statistical data on strength reduction over time should be collected, allowing extrapolation for the expected service life of the structure.
4. During testing, failures should occur exclusively within the concrete mass (i.e., the forms and failure modes of flexible connections should be uniform).

Flexible rod connections used in three-layer sandwich panels are sections of composite rods with a circular cross-section and anchor expansions at their ends to improve anchoring performance. These components include suspensions, supports, and braces, which are integral to the structural integrity of the panels.

To reduce shrinkage and deformation of concrete, which create conditions for crack formation during lifting and transportation, this study proposes diagonal flexible connections. These connections are made from high-strength fiberglass with low thermal conductivity and high resistance to alkaline and chemical environments, thereby eliminating thermal bridges and ensuring the corrosion resistance of the panels **(Nikolaev, Stepanova, & Demina, 2018)**.

Lugovoy and Kovrigin (2015) analyzed the application of three-layer reinforced concrete panels with composite flexible connections, including SPA 7.5 connections produced by the Biysk fiberglass factory. Replacing thermally conductive connectors such as metal ties and concrete keys with composite flexible connections effectively addresses the issue of thermal bridges. However, current GOST standards for flexible connections used in multilayer enclosures exhibit several shortcomings. First, they lack technical requirements for the bond strength between flexible connections and the concrete of the load-bearing or facing layer after exposure to alkaline environments, despite this factor being critical for determining the load capacity of the bonding node. Although alkaline testing does not significantly affect the strength of the primary rods of the connections, which retain a margin of safety, the absence of these requirements limits design accuracy. Second, there is no established procedure for statistically reliable determination of correction coefficients that account for dynamic and temperature impacts on the strength of flexible connections and their anchoring nodes. Third, calculation-based and justified schemes for arranging flexible connections within the concrete mass of constructions remain undeveloped.

To ensure the proper operation of panels with polymer composite flexible connections, they must comply with GOST standards and construction regulations, including **SP 63.1333012 Concrete and Reinforced Concrete Structures. General Provisions**, to prevent undesirable cracking processes. When calculating prefabricated structural elements exposed to loads during lifting, transportation, and installation, the load from the element's weight must include a dynamic coefficient of no less than 1.6 during transportation and 1.4 during lifting and installation.

When designing structures with flexible composite connections, operational factors such as freeze-thaw cycles, exposure to high-temperature fields, wind pressure pulsations, and similar conditions must be considered using appropriate reliability coefficients and working conditions. The design of three-layer panels with flexible composite reinforcement must strictly adhere to current standards, including Interstate Standard GOST 31938-22 Composite Polymer Reinforcement for Concrete Structures. General Technical Conditions **(Interstate Standard, 2022)** and Interstate Standard GOST 32486-15 Composite Polymer Reinforcement for Concrete Structures. Methods for Determining Structural and Technological Characteristics **(Interstate Standard, 2016)**.

3 MATERIALS AND METHODS

The scientific and technical assessment of a residential construction project in Astana was conducted in accordance with SP RK 1.04.04-101-2012 Inspection and Evaluation of the Technical Condition of Buildings and Structures **(SP RK 1.04-101-2012, 2015)** by the KazMIRR Institute. The assessment included three main stages: preparatory (preliminary) research, a full-scale investigation of external three-layer wall panels with flexible connections, and verification calculations for the external wall panel under various design scenarios.

The preparatory research established that the structural scheme of the building is a frame structure consisting of monolithic reinforced concrete pylons, shear diaphragms, and floor slabs. The strength, stability, and spatial rigidity of the building are ensured by the combined performance of the pylon system, shear diaphragms, horizontal floor disks, and foundation, as described by **Nuguzhinov et al. (2023), Nuguzhinov et al. (2021), and Mussabayev et al. (2023)**.

The panels used in the project are 3NSg-type panels in accordance with GOST 31310, which are three-layer external wall panels with flexible connections and a single-row cut design. These panels have a total thickness of 285 mm, comprising an internal reinforced concrete layer with a thickness of 80 mm, a mineral wool insulation layer with a thickness of 140 mm, and an external reinforced concrete layer with a thickness of 65 mm, as outlined in **NTP RK 01-01-3.1(4.1)-2017, GOST 14782-86, and GOST 5264-80**.

Flexible connections installed between the internal and external concrete layers ensure the combined performance of these layers in the external wall panel. These connections consist of suspensions, spacers, and braces made of fiberglass rods with a diameter of 7.5 mm. Each connection element performs a specific function: suspensions support the weight of the panel's external layer, spacers maintain the distance between the layers, and braces prevent horizontal displacement of the external layer relative to the internal layer, as described by **Nuguzhinov et al. (2022) and Nuguzhinov et al. (2021)**.

The reinforcement of the external and internal concrete layers of the three-layer external wall panels consists of Vr-1 class wire mesh with a diameter of 5 mm and a spacing of 100 mm, combined with frames containing longitudinal reinforcement made of AIII class rods with a diameter of 10 mm. The transverse reinforcement is made of Vr-1 class wire with a diameter of 5 mm. Additional reinforcement is provided at the corners of window openings using AIII class steel rods with a diameter of 8 mm and a length of 600 mm. Four lifting loops made of AI class reinforcement with a diameter of 10 mm are embedded in the internal concrete layer. To ensure vertical positioning, two loops made of AI class reinforcement with a diameter of 20 mm are installed in the upper part of the panel and are embedded in both concrete layers.

During the full-scale investigation of external three-layer wall panels with flexible connections, cracks with a width of acrc = 0,05–0,1 mm were identified in the internal concrete layer at the top and bottom levels of the wall panel, as shown in **Figure 1**.

4 RESULTS AND DISCUSSION

Selective probing of sections of the internal layer of the external three-layer wall panel, as well as control openings in specific areas, revealed that the reinforcement of the internal reinforced concrete layer complies with the project specifications. The reinforcement consists of Vr-1 class wire mesh with a diameter of 5 mm and frames containing longitudinal reinforcement made of AIII class rods with a diameter of 10 mm. The transverse reinforcement is also made of Vr-1 class wire with a diameter of 5 mm. Additional reinforcement at the corners of window openings was implemented using AIII class steel rods with a diameter of 8 mm and a length of 600 mm.

(a) (b)

Figure 1 – Crack in the internal concrete layer of three-layer wall panels: a) crack at the top level of the wall panel; b) crack at the bottom level of the wall panel **(Nuguzhinov et al., 2023)**.

Non-destructive tests to determine the strength of concrete in the internal load-bearing layers of the external three-layer wall panels showed that the actual concrete strength corresponds to the design class of concrete B20.

To investigate the causes of cracks in the external three-layer wall panels, a comprehensive field study was conducted across all stages, from production and movement of the panel from the assembly table to its final position at the construction site. Panels are formed in special metal molds, and to accelerate the curing process, thermal and moisture treatment is applied, ensuring that the concrete in the external and internal reinforced concrete layers achieves at least 80% of its design strength.

The reinforcement of the wall panels complies with the working drawings and includes flexible fiberglass connections. The first lifting of the panels from the assembly table was performed using an overhead crane and double-sling cable straps at an angle of 35–40° from the plane. After lifting the panels, cracks with widths ranging from acrc = 0,02–0,03 mm were observed on certain specimens.

Following lifting, the panels are placed in an inclined position onto racks located in the assembly shop and subsequently loaded onto panel trucks. The external wall panels are secured on the panel truck via the upper mounting loops using clamps. The lower part of the internal concrete layer of the external wall panels rests on a solid rubber strip laid on a timber support frame, as per **SP RK EN 1993-1-1:2005/2011 (2015) and SP RK 5.03-107-2013 (2015)**.

Upon the arrival of the panel truck with the examined external wall panels at the construction site, a visual inspection of the concrete layers revealed cracks with widths of acrc = 0,05–0,1 mm. Notably, cracks also appeared on panels that were previously free of such defects.

Based on the investigation results, the authors simulated various scenarios from production to installation of the panels and performed detailed calculations to determine the causes of cracks in the external three-layer wall panels. Verification calculations were carried out for different scenarios, including the moment of the first lift at an angle of 65° using tippers and lifting traverses to ensure force balance in the load slings with 80% concrete strength and a dynamic coefficient of 1,4, transportation of the panel with a dynamic coefficient of 1,6, lifting of the panel with a dynamic coefficient of 1,4, installation of the panel in its design position, and two panel installation variants.

The simulation of the wall panel was performed using the licensed software package LiraSAPR (**Figure 2**). The calculation model for the NS-1 wall panel was based on materials from detailed instrumental inspections and project documentation. The model was constructed through interactive input of load-bearing structures with the creation of a finite element mesh (nodes and elements). The input data included information on cross-sections, materials, support conditions, and loads. In each scenario, the actual concrete strength determined by field testing was considered. The external and internal layers of the wall panel were modeled using universal shell elements, while the flexible connections were modeled using general-purpose rod elements. The calculation model included all loads acting on the panel at a given moment depending on the specific design scenario.

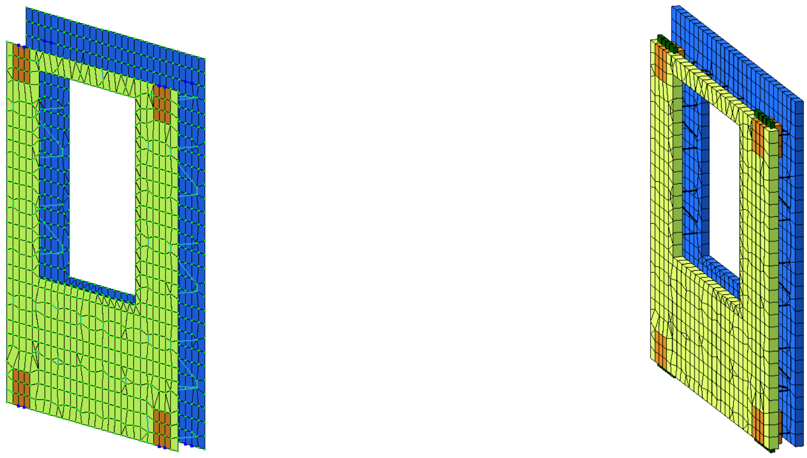

Figure 2 – Finite element model of the analyzed panel **(Nuguzhinov et al., 2023)**.

First Design Scenario: "Initial Lifting of the Panel". The first design scenario (**Figure 3**) is based on materials provided by the client and the results of the field investigation. The panel is lifted from the mold using a tilting device, which lifts the panel not horizontally but at an angle to the horizontal plane. Three angles were analyzed in the calculations: 15°, 45°, and 65°. In this scenario, the displacement constraints of the calculation model are set at the lifting loops and along the lower edge of the external layer.

The only load acting on the panel in this scenario is its self-weight, considered with a load reliability factor γ_f=1,1 and a dynamic coefficient of 1,4. The load from the insulation is distributed evenly across the external and internal layers of the wall panel, with a load reliability factor for the insulation of γ_f=1,2.

Second Design Scenario: "Transportation of the Panel". The transportation of the panel is performed using panel trucks. The panel is placed on rubber supports with the internal layer inclined at an angle of 3–5° to the vertical. In this scenario, the displacement constraints of the calculation model are located at the points of support under the panel and along the upper edge where the internal layer rests on the truck frame (**Figure 4**).

Third Design Scenario: "Lifting of the Panel". The lifting of the panel is conducted using a lifting traverse to ensure the self-balancing of forces in the slings. In this scenario, the displacement constraints of the calculation model are applied exclusively at the lifting loops of the panel (Figure 5).

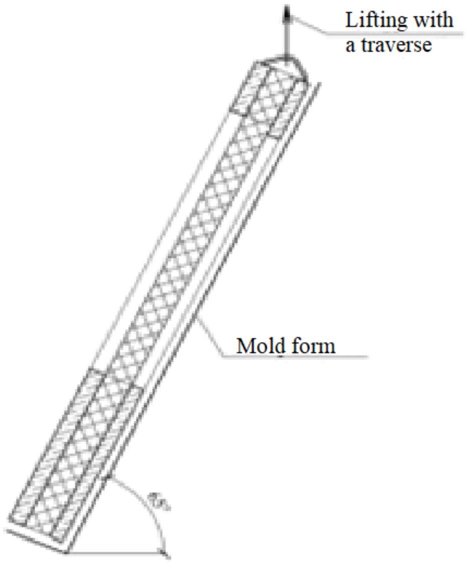

Figure 3 – First design scenario: Lifting the panel from the mold at angles of 15°, 45°, and 65° (authors' materials).

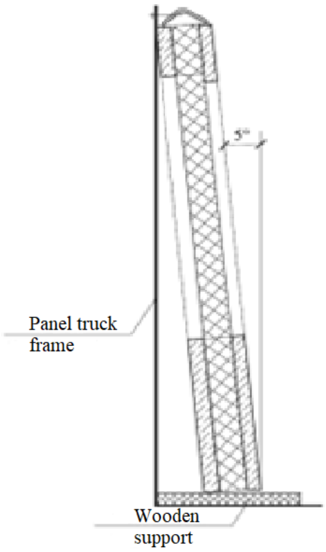

Figure 4 – Second design scenario: Transportation of the panel on a panel truck with an inclination of 3–5° to the vertical (authors' materials).

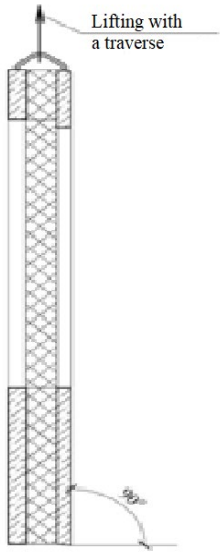

Figure 5 – Third design scenario: Lifting the panel using a lifting traverse (authors' materials).

Fourth Design Scenario: "Panel Installed in the Design Position". The panel is attached to the building's load-bearing structures using embedded parts located along the upper and lower edges of the internal layer, as specified in the construction detail album. In this design scenario, the displacement constraints of the calculation model are located at the points of the embedded parts (**Figure 6**).

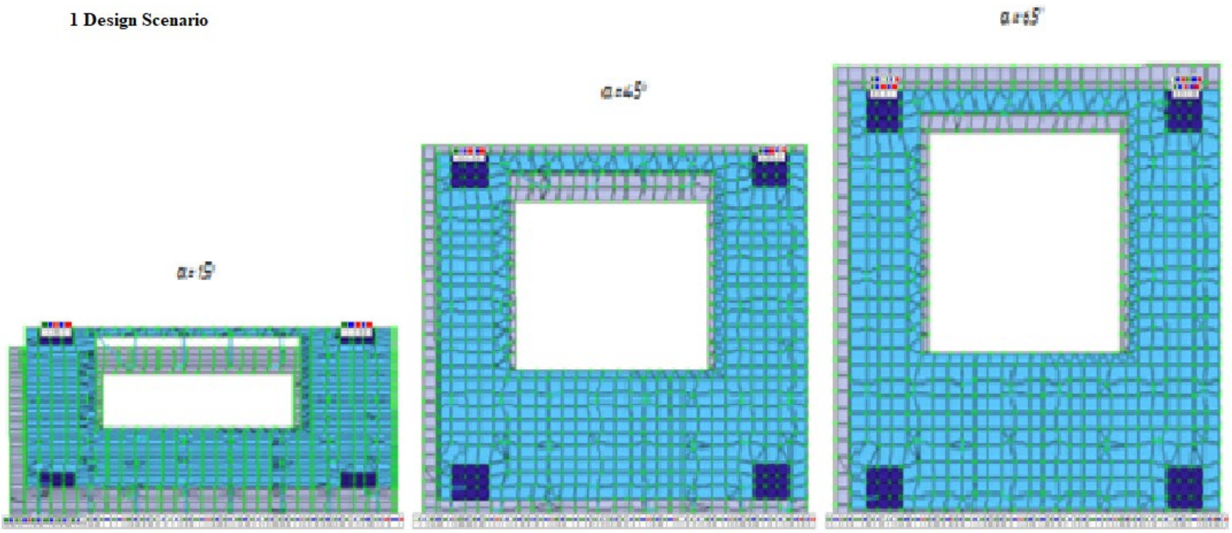

Figure 6 – Panel support fixations **(Nuguzhinov et al., 2023)**.

Fifth Design Scenario: "First Panel Installation Variant". According to the results of detailed instrumental inspections, it was determined that the wall panel has no upper gap between its internal layer and the floor slab. In this scenario, the upper edge of the internal layer of the wall panel is either entirely clamped by the floor slab or only one of its corners is clamped. To install the panel in its design position, non-design forces must be applied to the areas near the mounting loops located around the window opening on the internal side of the panel. The magnitude of these forces cannot be precisely measured, as they are applied outside the plane of the slab and vary widely (from manual force to the force generated by a winch). Additionally, each mounting loop experiences its own force. In this calculation scenario, it is assumed that the wall panel is supported along the lower edge and the right corner is wedged, requiring non-design forces to be applied to the mounting loops to position the panel in its design location. For the calculation, it was simplified that the force applied to each mounting loop is the same, approximately 250 kg.

Sixth Design Scenario: "Second Panel Installation Variant". According to the results of detailed instrumental inspections, it was observed that during installation, wall panels are temporarily supported by the outer surface of the lower panel.

The verification calculations indicated that in scenarios 2, 3, 4, and 6, the reinforcement of the wall panel is sufficient. However, in scenarios 1 and 5, when concrete strength is low and non-design forces are applied to the mounting loops, cracks may form in certain areas of the wall panel. It is worth noting that cracks were observed during the transportation phase of the panel according to the field investigations, although the calculations did not predict this. This suggests that additional dynamic loads, difficult to account for in calculations, may occur during transportation (road unevenness, improper panel fixation, speed of the panel truck, and other factors).

5 CONCLUSIONS

Based on the analysis of the causes of cracks in three-layer panels with flexible polymer connections observed after delivery to the construction site, the following conclusions and recommendations were made:

1. The absence of a technological control system for the installation of flexible connections significantly contributes to the formation of defects in the panels.
2. Violations of transportation conditions, particularly failure to adhere to standard requirements, result in additional dynamic loads that lead to cracking.
3. Insufficient attention is paid to areas of high stress concentration, such as the corners of window openings, during the design and reinforcement processes.
4. Improvement of technical regulations for the use of composite polymer reinforcement is required, including the implementation of a strict quality control system during the manufacturing process.
5. Designers should focus on optimizing the reinforcement structure in the areas surrounding window openings to minimize stress concentration.
6. Transportation of panels must be carried out in strictly horizontal positions in accordance with standard requirements to avoid unnecessary stress and deformation.
7. Advancements in computational platforms, utilizing modern application software and high-performance computing tools, are necessary to accurately model and evaluate the performance of complex and heterogeneous construction objects.

These measures aim to mitigate technical issues such as cracks on the surface of three-layer panels with flexible polymer connections and to ensure improved construction quality in the future.

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RESEARCH ARTICLE

CORROSION RESISTANCE OF CONCRETE IN AGGRESSIVE MEDIA

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Abstract. *Sulfate corrosion of concrete is the most common type of corrosion in Kazakhstan and is a complex physical and chemical process depending on many factors. Therefore, we studied the processes of cement and concrete corrosion in sulfate corrosive media. Methods of corrosion resistance assessment were developed taking into account the basic provisions of the theory of heterogeneous chemical processes occurring in cement stone or concrete under the action of various aggressive media. When studying the behavior of cement stone (concrete) in aggressive solutions, researchers use different criteria to evaluate corrosion resistance. In some cases, the criterion is based on the comparative change in the chemical composition of cement stone before and after exposure to aggressive solution, in others - on the change in the mechanical characteristics of concrete, and thirdly, on the magnitude of their volumetric deformations. Analysis of the study of the microstructure of cement stone of three compositions, showed the presence of clusters of elongated tubular crystals in the form of "needles", which are characteristic of the morphology of ettringite, formed in the zone of micropore formation. It was found that in the crystals of the modified cement stone their size decreases from 80 to 110 nm, which is significantly lower than in the control composition - from 200 to 300 nm and from 100 to 200 nm. Research on the strength of concrete with micro silica consumption from 10 to 15%, the results of which showed an accelerated process of hydration.*

Keywords: *concrete, aggressive environment, corrosion, sulfate, resistance, cement stone, micro silica.*

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АГРЕССИВТІ ОРТАДАҒЫ БЕТОННЫҢ КОРРОЗИЯҒА ТӨЗІМДІЛІГІ

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Аңдатпа. *Бетонның сульфатты коррозиясы Қазақстанда коррозияның ең көп таралған түрі болып табылады және көптеген факторларға байланысты күрделі физика-химиялық процесс болып табылады. Сондықтан біз сульфатты коррозиялық ортадағы цемент пен бетонның коррозия процестерін зерттедік. Коррозияға төзімділікті бағалау әдістері әртүрлі агрессивті орталардың әсерінен цемент таста немесе бетонда жүретін гетерогенді химиялық процестер теориясының негізгі ережелерін ескере отырып жасалған. Коррозиялық ерітінділердегі цемент тасының (бетонның) мінез-құлқын зерттеу кезінде зерттеушілер коррозияға төзімділікті бағалау үшін әртүрлі критерийлерді пайдаланады. Кейбір жағдайларда критерий агрессивті ерітіндінің әсеріне дейін және одан кейін цемент тасының химиялық құрамының салыстырмалы өзгеруіне, басқаларында бетонның механикалық сипаттамаларының өзгеруіне, үшіншіден, олардың көлемдік деформацияларының мөлшеріне негізделген. Үш құрамды цемент тасының микроқұрылымын зерттеу кезінде жүргізілген талдау микропоралардың пайда болу аймағында пайда болатын эттрингит морфологиясына тән "инелер" түріндегі ұзартылған құбырлы кристалдардың шоғырларының болуын көрсетті. Модификацияланған цемент тастарының кристалдарында олардың мөлшері 80 - ден 110 нм-ге дейін азаятыны анықталды, бұл бақылау құрамынан едәуір төмен-сәйкесінше 200-ден 300 нм-ге дейін және 100-ден 200 нм-ге дейін. Микрокремнезем шығыны 10-нан 15% - ға дейінгі бетонның беріктігі бойынша зерттеулер жүргізілді, оның нәтижелері гидратацияның жеделдетілген процесін көрсетті.*

Түйін сөздер: *бетон, коррозиялық орта, коррозия, сульфат, төзімділік, цемент тасы, микро кремний диоксиді.*

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НАУЧНАЯ СТАТЬЯ

КОРРОЗИОННАЯ СТОЙКОСТЬ БЕТОНА В АГРЕССИВНЫХ СРЕДАХ

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Аннотация. *Сульфатная коррозия бетона является наиболее распространенным видом коррозии в Казахстане и представляет собой сложный физико-химический процесс, зависящий от многих факторов. Поэтому мы изучили процессы коррозии цемента и бетона в сульфатно-агрессивных средах. Методы оценки коррозионной стойкости были разработаны с учетом основных положений теории гетерогенных химических процессов, протекающих в цементном камне или бетоне под действием различных агрессивных сред. При изучении поведения цементного камня (бетона) в агрессивных растворах исследователи используют различные критерии для оценки коррозионной стойкости. В одних случаях критерий основан на сравнительном изменении химического состава цементного камня до и после воздействия агрессивного раствора, в других - на изменении механических характеристик бетона, и, в-третьих, на величине их объемных деформаций. Анализ, проведенный при изучении микроструктуры цементного камня трех составов, показал наличие скоплений удлиненных трубчатых кристаллов в виде "игл", которые характерны для морфологии эттрингита, образующихся в зоне образования микропор. Было обнаружено, что в кристаллах модифицированного цементного камня их размер уменьшается с 80 до 110 нм, что значительно ниже, чем в контрольном составе - с 200 до 300 нм и со 100 до 200 нм соответственно. Проведены исследования прочности бетона с расходом микрокремнезема от 10 до 15%, результаты которых показали ускоренный процесс гидратации.*

Ключевые слова: *бетон, агрессивная среда, коррозия, сульфат, стойкость, цементный камень, микрокремнезем.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ / ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

In connection with the wide application of concrete and reinforced concrete structures and the development of new areas in the Republic of Kazakhstan with aggressive external environments (mineralized soils and groundwater) one of the main tasks of construction is to ensure the durability of concrete under the action of various external aggressive environments. For this purpose it is necessary to know not only the essence of corrosion, i.e. the changes that occurred in cement stone or concrete under the action of aggressive media, but also the speed of these processes.

To estimate the corrosion rate, it is necessary to use specially developed methods taking into account the main provisions of the theory of heterogeneous chemical processes occurring in cement stone or concrete under the action of various aggressive media.

Sulfate corrosion of concrete is the most common type of corrosion in Kazakhstan and is a complex physical and chemical process depending on many factors. Therefore, we studied the processes of cement and concrete corrosion in sulfate corrosive media. At the same time, the assessment of corrosion resistance of concrete by a single has an important scientific and practical significance. It should be noted that in recent years there have been many publications on this issue, but the results of these studies are not comparable and builders cannot get an unambiguous answer about the resistance of a particular material.

The variety of research methods leads to the fact that the results of determining the corrosion resistance of cements are not comparable.

2 LITERATURE REVIEW

A review of the information available in the literature shows that the methods of determining the sulfate resistance of cements (concretes) can be divided into four groups: the visual method of assessment, which records changes in the appearance of samples, such as the appearance of cracks and distortion of the sample (**Fedosov S.V., 2003; Sheinfeld A.V., 2014; Brykov A.S., 2014**).

This method has significant disadvantages: evaluation of cement durability is subjective and is not expressed quantitatively. Moreover, the determination of durability based on external signs of fracture may lead to incorrect results, since concrete fracture often occurs uniformly throughout the entire volume, without the formation of noticeable cracks, and at the same time the strength of the specimen is almost zero, its shape may still be well preserved. If the specimens are placed in an aggressive solution after long storage in water, a protective crust of calcium carbonate is usually formed on their surface, and then destruction will occur only inside, where there are free lime, not converted to $CaCO_3$; the external shape of the specimen may remain unchanged (**Glass G.K., Buenfeld N., 2000; Stroganov V.F., 2014**).

Therefore, qualitative visual inspection of the specimens is necessary as an additional way to confirm the quantitative characteristics obtained by other methods to evaluate the corrosion resistance of concrete. Some authors (**Alekseev S.N., et al., 1990; Rozental N.K., 2006**) consider the method of measuring the deformations of the specimens to be reliable when evaluating the sulfate corrosion of concrete. The increase in the size of cement-sand and concrete specimens stored for a long time in an aggressive environment occurs as a result of crystallization of corrosion products - gypsum and calcium hydrosulfoaluminate, occupying a larger volume than the original substances. In some countries, the strain method is proposed as a standard method (**Pullar-Strecker P., 1988; Bazhenov Y. M., 2002; Rahman M., et al., 2012**) to evaluate the sulfate resistance of cements and concretes.

The main disadvantage of the strain measurement method is that its accuracy depends on the accuracy of the instrument recording the elongation of the specimens. In addition, it must be taken into account that the magnitude of expansion does not increase in direct proportion with the rate of corrosion, but usually increases very rapidly just before the process of concrete decomposition, that is, a false impression of well-being is created, which can lead to accident and destruction of buildings and structures. Therefore, the deformation method as well as the visual method for assessing the sulphate resistance of cements can be used as a supplementary method.

3 MATERIALS AND METHODS

Recently, various physicochemical methods of corrosion process investigation have become widespread. This group includes non-destructive methods of control, such as determining the concentration of hydrogen ions (pH) in the liquid phase of concrete and concrete samples stored in aggressive liquids or determining the amount of calcium ions transferred into solution from the samples. These methods are very effective in studying the causes of the nature of corrosion and can be used, as well as the first two groups of methods as additional to confirm the quantitative characteristics obtained by the main method.

The most widespread among the accelerated methods for determining sulfate resistance is the method that determines changes in the strength characteristics of samples stored in aggressive sulfate media of high concentration (**Erofeev V.T., et al., 2020; Mahmoodian, M. & Li, C.Q., 2011**).

Neither deformations, nor external signs of deterioration, nor changes in the chemical composition of cement stone unambiguously determine the condition of concrete structures operating in aggressive environments; their load-bearing capacity and service life can be assessed by changes in strength properties. It should be noted that the current GOST defines the corrosion resistance of cements by their strength properties. The change in strength properties of concrete can be monitored by three indicators: compressive, tensile and flexural strength.

In the process of exposure of concentrated sulfate solutions on concrete in the pores of cement stone will be released in the solid phase of new formations, which in the initial period compact and harden the concrete. The process of filling the pores and voids with the neoplasms leads to an increase in the compression resistance of the specimens and can create the perception that there are no destructive processes. In addition, pores and capillaries close during load application in compressive testing of concrete, which leads to an overestimation of the compressive strength.

At the same time, when concrete pores are filled with gypsum formed in the process of concrete corrosion, the process of bending resistance reduction is observed (**Alekseev S.I.,& Ivanov F.M., 2000**).

Considering the above, it is reasonable to choose the strength characteristic, namely the flexural strength, as a criterion of concrete corrosion resistance, because the results of determining the compressive strength are overestimated due to objective reasons, and the bending tensile test is difficult (**Stepanova V.F., 2016; Glass G.K., Buenfeld N., 2000**).

The flexural strength is a direct quantitative characteristic of the condition of the structure in an aggressive environment; the flexural test is easy to perform, and based on the study of literature data and laboratory studies can be recommended as a criterion for the corrosion resistance of cement and concrete.

Therefore, we evaluated the corrosion resistance of samples by their bending test. In this case, the dimensions of the tested specimens should be such that the ratio between the span of the supports and the height of the specimens - beams, i.e. its cross-section was not less than 4, because at its smaller value in the bending test may occur failure not from bending tension, but from folding stresses (**Fedosov S. V., & Bazanov S. M., 2003**). The distance from the supports to the edge of the specimen should be at least 1cm. Beam specimens with a cross section of 10x10 mm and length of 6 cm meet the above requirements (for the evaluation of corrosion resistance of cements.) Corrosion resistance of concrete was determined on beam specimens with a cross section of 100x100 mm and length of 400 mm where the distance between the supports was 300 mm.

Observance of the above conditions and methods of testing cements and concretes for sulfate resistance will allow to objectively assess their true resistance and obtain reliable results regardless of the regional location of testing laboratories. This will allow manufacturers to reasonably approach the choice of cements for concrete and reinforced concrete structures operating in aggressive sulfate environments.

4 RESULTS AND DISCUSSION

The composition of cement-sand samples should be 1:3 (Cement : Volsky sand), and the water-cement ratio is 0.6. The mobility of the mortar is 75-80 mm of immersion of the cone "StroiTsNIILa".

The prepared mortar is transferred to a pre-wiped wet cloth stirrer bowl stirred in it for 2.5 minutes (20 revolutions of the stirrer bowl)

The samples are compacted on a shaking table (30 blows for 30+5 s).

After manufacturing, the samples are stored in the molds for 24 +2 hours in a bath with a hydrovlichicheskom shutter. Then the samples are unmolded and placed in tubs with drinking water in a horizontal position so that they do not touch each other. The water should cover the specimens by at least 20 mm. The distance between the samples must also be at least 20 mm.

After 28 days from the date of their manufacture, the samples are removed from water and placed in Na_2SO_4 solution. The amount of corrosive solution should be not less than 100 ml for each specimen. Control specimens are left to harden in water until the moment of testing. The change of solution is made when the concentration of sulfate ion in the test solution decreases by no more than 10%, which is established by determining the concentration of the initial solution. It is not allowed to restore the initial concentration of aggressive solutions by adding salt or concentrated solutions.

Concentration control of working aggressive solutions during their preparation is carried out by the density of solutions, which is controlled by measuring their density using areometers at a given temperature, at a temperature of 20+2 ^{0}C. Determination of flexural strength of specimens is carried out after 56 days, 6 and 12 months. The number of specimens for one test period should be at least 10. It is recommended to make control long-term tests in terms of 1, 2 and 3 years. The test shall be performed not later than 1 hour after the specimens have been removed from the solution. The specimens shall be wiped dry before testing.

Concrete specimens are stored in sulphate mortar for the same period as cement-sand specimens, with the only difference being that the amount of aggressive mortar must be such that it covers the specimen on all sides by at least 20 mm.

A quantitative characteristic of cement durability is the durability coefficient (K_{st}), which is calculated as the ratio of the flexural strength of samples tested in Na_2SO_4 solution to the strength of control samples cured in water.

We tested concrete made on Portland cement of 400 DO grade. As a coarse aggregate we used crushed stone of Koturbulak deposit of 5-20 mm fraction, fine aggregate was sand with a coarseness modulus of 2.2.

The data analysis showed that when cement is mixed with a suspension of activated micro silica, it leads to intensification of the hydration process and binding of formed calcium hydroxide ($Ca(OH)_2$) by micro silica to the formation of low basic calcium hydrosilicates, which causes its reduction by more than 23% relative to pure cement stone, reduction of the intensity of analytical lines (C_3S), and, accordingly, compaction and strengthening of the cement stone structure.

The strength of concrete with complex additives was studied on different concretes. In all cases, equilibrated mixtures with stiffness of 20-21 s were used, which were obtained by reducing the water content. The results obtained are presented in Table 1.

Table 1
Effect of complex chemical admixtures on concrete strength

№	Additive content, %			Concrete density, kg/m³	Compressive strength, MPa, at the age of		
	Master Air 200	Master Rheobuild 1000	C-3		7 days heat and humidity treatments	28 days heat and humidity treatments	28 days of curing under normal conditions
1	0	0	0	2385	30,8	41.4	41.8
2	0.6	0	0	2400	36.1	53.7	53.0
3	0.6	1.0	0	2400	37.4	55.5	54.2
4	0.6	1.0	0.16	2380	39.1	58.8	57.2
5	0	0	0	1930	23.8	32.0	34.6
6	0.6	0	0	1940	26.8	39.6	40.1
7	0.6	1.0	0	1940	28.8	39.9	41.0
8	0.6	1.0	0.16	1935	27.0	38.9	39.6

From the obtained results it follows that at introduction of Master Air 200 the strength of heavy concrete at the age of 12 hours after heat and humidity treatment increases by 17%, and in 28-day curing by 30%; after 28 days of curing in normal conditions by 27%. At introduction of complex admixture Master Air 200+Master Rheobuild 1000 the strength of heavy concrete at the age of 12 hours after heat and humidity treatment increases by 20%, and in 28-day curing by 34%; after 28 days of curing in normal conditions by 30%. At introduction of complex admixture Master Air 200+Master Rheobuild 1000+C-3 the strength of heavy concrete at the age of 12 hours after heat and humidity treatments increases by 27%, and in 28-day by 42%; after 28 days of curing in normal conditions by 37%.

At introduction of Master Air 200 the strength of concrete at the age of 12 hours after heat and humidity treatment increases by 13%, and in 28-day curing by 24%; after 28 days of curing in normal conditions by 16%. At introduction of complex admixture Master Air 200+Master Rheobuild 1000 the strength of concrete at the age of 12 hours after heat and humidity treatment increases by 21%, and in 28-day by 25%; after 28 days of curing in normal conditions by 19%. At introduction of complex admixture Master Air 200+Master Rheobuild 1000+C-3 the strength of concrete at the age of 12 hours after heat and humidity treatment increases by 14%, and in 23-day by 22%; after 28 days of curing in normal conditions by 14%.

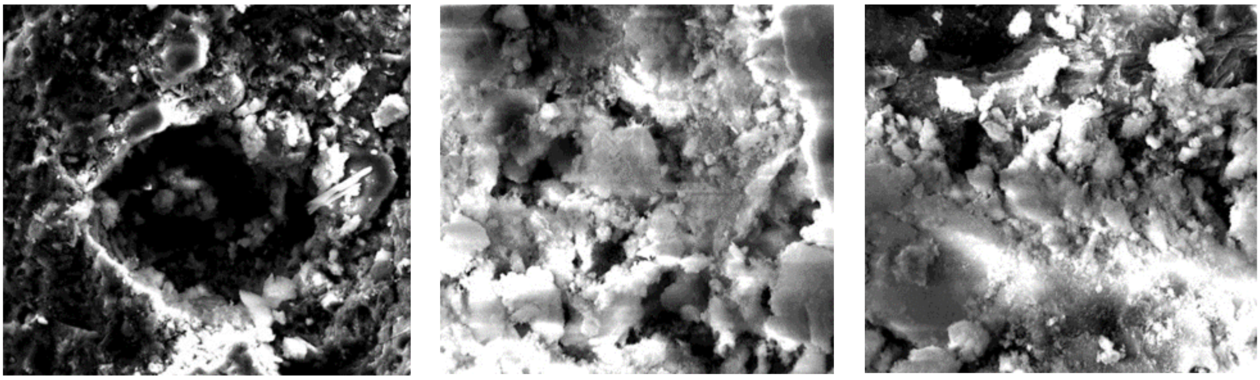
From the analysis of the obtained results it follows that when Master Air 200 or Master Air 200+Master Rheobuild 1000 additives are introduced, the strength of lightened heavy concrete increases more intensively in all cases. When the complex admixture Master Air 200+Master Rheobuild 1000+C-3 is introduced, the strength of the concrete decreases by 3-7% and the strength of the concrete increases by 6 - 8%. It follows that the technological effects achieved by the introduction of Master Air 200 and Master Air 200+Master Rheobuild 1000 additives into concrete are equivalent. The use of Master Air 200+Master Rheobuild 1000+C-3 complex admixture in concrete is more effective than in other admixtures.

Analysis of the study of the microstructure of cement stone of three compositions, showed the presence of clusters of elongated tubular crystals in the form of "needles", which are characteristic of the morphology of ettringite, formed in the zone of micropore formation.

It is established that in the crystals of the modified cement stone their size decreases from 80 to 110 nm, which is much lower than in the control composition - from 200 to 300 nm and from 100 to 200 nm. The established changes are connected with formation of additional amount of low-base calcium hydrosilicates due to alkaline excitation of silica-containing particles.

The cement stone was found to have a denser and more homogeneous fine porous structure with micropore sizes ranging from 0.1 to 1 μm Figure 1 (c) in the composition (Portland cement +

micro silica + Master Air 200), the main range was from 2 to 5 μm **Figure 1(b)** in the control sample, from 2 to 10 μm **Figure 1 (a)** with the presence of pores up to 100 μm.



(a) (b) (c)

Figure 1 – Microstructure of cement stone: (a) control sample; (b) portland cement + micro silica; (c) portland cement + micro silica + Master Air 200

The obtained positive results of cement stone modification formed the basis for the development of concrete composition with a given complex of operational properties.

5 CONCLUSIONS

Tests of concrete samples after 6 months of exposure in Master Air 200 solution of 5% concentration showed that the flexural strength of concrete increased compared to the initial one by about 5-7%. This can be explained by the fact that probably the process of cement hydration is still ongoing (due to the presence of sufficient clinker stock) and the absence of calcium hydroxide binding components in the concrete. In addition, the introduction of Master Air 200 into the concrete mix compacted the concrete structure due to its polymerization in the pores and capillaries, which increased the water resistance of concrete W12. It should be noted that similar effect on the influence on technological parameters of concrete mix and concrete.

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RESEARCH ARTICLE

DYNAMIC CHARACTERISTICS FOR TRANSPORT STRUCTURES WITH ELASTIC SUPPORTS

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Abstract. *Currently, the issues of strengthening the load-bearing capacity of transport structures under the action of dynamic loads are becoming increasingly relevant. To ensure a reserve of structural strength under dynamic impacts, active methods of protection are increasingly being used. The use of active methods of protection in the form of pliable supports makes it possible to increase the energy intensity of the "support-structure" system and reduce the intensity of the dynamic impact. They play the role of dampers, reducing vibration amplitudes and absorbing deformation energy. The dynamic characteristics of transport structures play a significant role in the oscillatory process, because the resistance of the structure to external influences depends on them. By changing them, you can lower the value of the dynamic coefficient, thereby reducing the dynamic effect. The aim of the research is to evaluate the influence of the stiffness of the support links of transport structures on the dynamic characteristics of road overpass spans. To determine the natural frequencies, a homogeneous partial differential equation is used, the solution of which is presented using hyperbolic functions. The solution of the transcendental equation is obtained using the approximation method. The relevance of the obtained results lies in the fact that when using elastically supple supports in transport structures it is possible to change dynamic characteristics and thereby increase the strength reserve and reduce the dynamic effect.*

Keywords: *compliance, rigidity of supports, natural frequencies, inertial forces, approximation method..*

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ҒЫЛЫМИ МАҚАЛА

СЕРПІМДІИКЕМДЕЛГЕН ТІРЕКТЕРІ БАР КӨЛІК ҚҰРЫЛЫМДАРЫНЫҢ ДИНАМИКАЛЫҚ СИПАТТАМАЛАРЫ

С.Х. Достанова [1], Г.Т. Қасымова [2], Қ.Е. Тоқпанова [3], О.Е. Тулегенова [2], Г.О. Сарсенова [1]

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Аңдатпа. *Қазіргі уақытта динамикалық жүктемелердің әсерінен көліктік конструкциялардың жүк көтергіштігін күшейту мәселелері өзекті болуда. Динамикалық әсерлер кезінде конструкциялық беріктік қорын қамтамасыз ету үшін қорғаныстың белсенді әдістері көбірек қолданылуда. Берілгіш тіректер түріндегі қорғаныстың белсенді әдістерін қолдану «тірек-конструкция» жүйесінің энергия сыйымдылығын арттыруға және динамикалық әсердің қарқындылығын төмендетуге мүмкіндік береді. Олар тербеліс амплитудаларын төмендететін және деформация энергиясын сіңіретін демпферлердің рөлін атқарады. Көлік конструкцияларының динамикалық сипаттамалары тербелмелі процесте маңызды рөл атқарады, себебі конструкцияның сыртқы әсерлерге төзімділігі соларға байланысты. Оларды өзгерту арқылы динамикалық коэффициенттің мәнін төмендете отырып, динамикалық әсерді азайтуға болады. Бұл жұмыста тірек байланыстарының қаттылығына байланысты автомобиль өтпе аралықтарының меншікті тербеліс жиіліктерінің өзгеруі зерттеледі. Алынған нәтижелердің өзектілігі көлік конструкцияларында серпінді тіректерді пайдалану кезінде серпінді сипаттамаларды өзгертуге және осылайша беріктік резервін арттыруға және серпінді әсерді төмендетуге болатындығында.*

Түйін сөздер: *икемделгіштік, тіректердің қаттылығы, меншікті жиіліктер, инерциялық күштер, жуықтау әдісі.*

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НАУЧНАЯ СТАТЬЯ

ДИНАМИЧЕСКИЕ ХАРАКТЕРИСТИКИ ДЛЯ ТРАНСПОРТНЫХ КОНСТРУКЦИЙ С УПРУГОПОДАТЛИВЫМИ ОПОРАМИ

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Аннотация. *В настоящее время большую актуальность приобретают вопросы усиления несущей способности транспортных конструкций при действии динамических нагрузок. Для обеспечения резерва прочности конструкций при динамических воздействиях все более используют активные способы защиты. Применение активных способов защиты в виде податливых опор позволяет повысить энергоемкость системы «опора-конструкция» и снизить интенсивность динамического воздействия. Они играют роль демпферов, снижая амплитуды колебаний и поглощая энергию деформаций. Динамические характеристики транспортных сооружений играют значительную роль в колебательном процессе, т.к. от них зависит сопротивление конструкции внешним воздействиям. Изменяя их, можно понизить значение динамического коэффициента, тем самым снизить динамический эффект. Целью исследований является оценка влияния жесткости опорных связей транспортных конструкций на динамические характеристики пролетных строений автодорожных путепроводов. Для определения собственных частот используется однородное дифференциальное уравнение в частных производных, решение которого представлено с использованием гиперболических функций. Решение трансцендентного уравнения получено с использованием метода приближений. Актуальность полученных результатов заключается в том, что при использовании упругоподатливых опор в транспортных конструкциях можно изменять динамические характеристики и тем самым повысить резерв прочности и снизить динамический эффект.*

Ключевые слова: *податливость, жесткость опор, собственные частоты, инерционные силы, метод приближений*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС/ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

The analysis of oscillatory processes of transport structures, especially road bridges, under the influence of mobile load is becoming increasingly relevant. As the weight and intensity of the moving load increases with the length of the overlapping spans, dynamic phenomena increase and this causes increased requirements for their operation.

In the process of vibrations, the ability of a structure to resist external influences depends on its dynamic characteristics. Therefore, it is important to strengthen the load-bearing capacity of structures at the expense of internal and external reserves. Traditional methods and means of protecting buildings and structures from dynamic impacts include a large range of various measures aimed at increasing the load-bearing capacity of building structures.

Currently, to ensure the resistance of structures under intense dynamic impacts, active protection methods are increasingly being used. The use of active protection methods in the form of flexible supports allows increasing the energy intensity of the support-structure system and reducing the intensity of dynamic impact. As a result, the cost of structures and the complexity of their restoration is reduced.

The development and implementation of active methods for protecting reinforced concrete structures under dynamic loading requires the development and improvement of effective methods for dynamic calculation of systems that include both the structures themselves and the means of active protection. At the same time, for a reliable assessment of the stress-strain state, the developed calculation methods should take into account not only the basic physical laws of deformation of reinforced concrete under dynamic influences, but also the features of deformation of malleable supports. They absorb strain energy and act as dampers.

The problem of improving methods for calculating reinforced concrete structures on flexible supports under dynamic loading is an actual scientific problem of great practical importance **(Galyautdinov Z.R., 2021; Gridnev S.Yu., 2013; Kolotovichev Yu.A., 2023)**.

Experimental studies show that the use of flexible supports of constant stiffness for loads characterized by the stage of increase and decrease can have both a positive effect on the operation of structures (reduce the amplitudes of vibrations) and a negative one. This circumstance must be taken into account when designing structures on flexible supports in order to avoid the appearance of large forces and displacements in the structures compared to structures on non-displaced supports. To increase the effectiveness of increasing the resistance of reinforced concrete structures to dynamic impacts, it is advisable to use flexible supports of variable stiffness. To do this, it is necessary to optimize the rigidity of flexible supports, taking into account the physical and geometric parameters of spans **(Galyautdinov Z.R., 2021; Gridnev S.Yu., 2013)**.

In the following, the use of elastically malleable supports of superstructures in road overpasses is considered. To optimize the rigidity of flexible supports, it is necessary to deduce the dependences of the natural frequencies of transverse vibrations of superstructures on them, as well as their influence on the stress-strain state of the system under the action of external dynamic loads. Analytical and variation methods are used to solve these problems. It is proposed to vary the stiffness of supports by iteration method when solving the characteristic equation.

2 LITERATURE REVIEW

The development and implementation of active methods for protecting reinforced concrete structures under dynamic loading requires the development and improvement of effective methods for dynamic calculation of systems that include both the structures themselves and the means of active protection. At the same time, for a reliable assessment of the stress-strain state, the developed calculation methods should take into account not only the basic physical laws of deformation of reinforced concrete under dynamic influences, but also the features of deformation of malleable supports. They absorb strain energy and act as dampers.

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The fundamental theory of dynamics and stability of building and transport structures, modern analytical and numerical methods using software packages for calculating dynamic characteristics, the theory of oscillations, and taking into account various types of nonlinearity are considered in many works **(Kadisov G.M., 2012; Yegorychev O.O., 2005; Bekshayev S.Ya., 2013; Sedighi H.M., 2012; Sedighi H.M., 2011; Ryabukhin A.K., 2020; Ray W.Cl., 1977; Korenev B.G., 1972; Nikolaenko N.A., 1998)**.

For buildings and transport structures in seismic areas, issues of seismic protection and seismic isolation, as well as the elimination of resonant vibrations using flexible supports, are important **(Dostanova S.Kh., 2020; 2021)**. При рассмотрении движущейся нагрузки на мостовых конструкциях для уменьшения динамического эффекта необходимо более точно экспериментально и теоретически определять частоты и формы собственных колебаний **(Dostanova S.Kh., 2023)**.

Despite the existing experimental and theoretical studies of transport structures, some issues require clarification when determining dynamic characteristics, searching for an internal reserve of strength, and enhancing reliability and safety under the action of moving loads.

Due to the intensive development of road transport and increasing requirements for their operation, it is necessary to improve and develop experimental and theoretical research using innovations and scientific achievements in the field of road sector.

In the following, the use of elastically malleable supports of superstructures in road overpasses is considered. To optimize the rigidity of flexible supports, it is necessary to deduce the dependences of the natural frequencies of transverse vibrations of superstructures on them, as well as their influence on the stress-strain state of the system under the action of external dynamic loads. Analytical and variation methods are used to solve these problems. It is proposed to vary the stiffness of supports by iteration method when solving the characteristic equation.

3 MATERIALS AND METHODS

3.1 METHOD FOR DETERMINING THE NATURAL VIBRATION FREQUENCIES OF LOAD-BEARING BEAMS OF SUPERSTRUCTURES

Free transverse vibrations of a rod with a distributed mass are considered. The superstructure is considered as a beam on two elastically pliable supports with rigidity C_1 and C_2. It is assumed that each span of the split bridge operates independently of each other. Consider a beam on control supports (**Figure 1**). Free vibrations of a beam with a uniformly distributed mass are described by a fourth-order partial differential equation **(Leontiev E.V., 2020; Korobko V.I., 2007; Bekshayev S.Ya., 2013; Sedighi H.M., 2012; Sedighi H.M., 2011; Ryabukhin A.K., 2020)**.

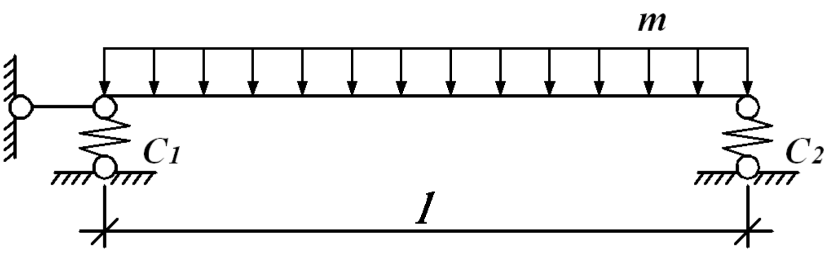

Figure 1 – Design diagram of a beam on regulating supports (authors' material)

The differential equation of free vibrations without taking into account the resistance forces has the form **(Galyautdinov Z.R., 2021; Gridnev S.Yu., 2013; Kolotovichev Yu.A., 2023; Kadisov G.M., 2012; Yegorychev O.O., 2012)**.

$$EI\frac{\partial^4 y}{\partial x^4} + m(x)\frac{\partial^2 y}{\partial t^2} = 0 \tag{1}$$

In equation (1) y=y(x,t)- are the unknown deflections, EI - flexural stiffness, m(x)- linear mass. We restrict ourselves to finding only such solutions of equation (1) that determine standing waves, i.e., the bending shape that does not depend on time. These solutions correspond to the main waveforms. For such waveforms, the solution can be obtained by separating the variables, then the solution and equation (1) can be written as:

$$\begin{gathered} y(x,t) = \sum_{k=1}^{\infty} y_k(x,t) = \sum_{k=1}^{\infty} y_k(x)T_k(t), \\ EI(\sum_{k=1}^{\infty} y_k^{(IV)}(x)) + m(x)(\sum_{k=1}^{\infty} y_k(x)T_k^{//}(t)) = 0 \end{gathered} \tag{2}$$

Combining the sums and equating the terms of the same name, we obtain a system of differential equations:

$$EI\frac{\partial^4 y_k(x)}{\partial x^4}T_k(t) + m(x)y_k(x)\frac{\partial^2 T_k(t)}{\partial t^2} = 0, \qquad k = 1,2,3,....... \tag{3}$$

Dividing each term in (3) by a value $m(x)y_k(x)T_k(t)$, we obtain the sum of two terms, each of which depends on only one variable. We introduce a notation for the relations of the following quantities:

$$\frac{EIy_k^{IV}(x)}{m(x)y_k(x)} = -\frac{T_k^{//}(t)}{T_k(t)} = \omega_k^2 \tag{4}$$

These relations are independent of the variables x,t and represent the squares of the natural vibration frequencies of a beam with a distributed mass. By introducing the notation (4), the system (3) decomposes into two independent systems of ordinary differential equations:

$$y_k^{(IV)}(x) - \lambda_k^4 y_k(x) = 0, \quad k = 1,2,3,....$$
$$\lambda_k^4 = \frac{m(x)\cdot\omega_k^2}{EI} \quad (5)$$

$$T_k''(t) + \omega_k^2 T_k(t) = 0, \quad k = 1,2,3.... \quad (6)$$

In equation (6) ωk - the frequency of natural oscillations corresponding to k-form. Using the Euler method for solving linear ordinary equations, the solutions of equations (5) and (6) can be represented as:

$$y(x,t) = \sum_{k=1}^{\infty} y_k(x)T_k(t),$$
$$y_k(x) = Ach(\lambda_k x) + Bsh(\lambda_k x) + C\cos(\lambda_k x) + D\sin(\lambda_k x),$$
$$T_k(t) = A_k \sin\omega_k t + B_k \cos\omega_k t \quad (7)$$

General solution for deflections:

$$y(x,t) = \sum_{k=1}^{\infty} \frac{(Ach(\lambda_k x) + Bsh(\lambda_k x) + C\cos(\lambda_k x) + D\sin(\lambda_k x))}{(A_k \sin\omega_k t + B_k \cos\omega_k t)},$$

In (7), the values A, B, C, and D are constants determined from the anchoring conditions (boundary conditions), and A_k, B_k a are constants determined from the initial conditions, i.e., displacements and velocities at the initial time t=0.

The expression for $y_k(x)$ defines the main form of vibrations corresponding to the frequency ωk, it defines a static elastic line caused by the running load $q_k = m(x)\omega_k^2 y_k$. If the running mass is constant along the length of the rod, $m(x) = m = const$, then we can write for the parameter s_k :

$$\lambda_k = l\sqrt[4]{\frac{m\omega_k^2}{EI}} \quad (8)$$

For the case when the beam is hinged at the edges, the boundary conditions will be:

$$\text{at } x = 0 \qquad M_0 = 0,\ Q_0 = y_0 \cdot C_1,$$
$$\text{at } x = l \qquad M_l = 0,\ Q_l = -y_l \cdot C_2, \quad (9)$$

where y_0 – displacement at the origin, y_l - beam displacement at $x = l$; M_0 and M_l -moment at $x = 0$ and $x = l$, respectively, Q_0 and Q_l -transverse forces at $x = 0$ and $x = l$, respectively.

Let us express the coefficients A, B, C, and D in terms of the initial parameters y_0, φ_0, M_0, Q_0, then the standing waves can be represented as **(Leontiev E.V., 2020; Korobko V.I., Korenev B.G., 1972)**:

$$\left.\begin{aligned}
&y_x = y_0 S_x + \frac{\varphi_0}{\lambda} T_x - \frac{M_0}{\lambda^2 EI} U_x - \frac{Q_0}{\lambda^3 EI} V_x ,\\
&\varphi_x = y_0 \lambda V_x + \varphi_0 S_x - \frac{M_0}{\lambda EI} - \frac{Q_0}{\lambda^2 EI} U_x ,\\
&M_x = -y_0 \lambda^2 EIU_x - \varphi_0 \lambda EIV_x + M_0 S_x + \frac{Q_0}{\lambda} T_x\\
&Q_x = -y_0 \lambda^3 EIT_x - \varphi_0 \lambda^2 EIU_x + M_0 \lambda V_x + Q_0 S_x
\end{aligned}\right\} \quad (10)$$

In (10) S_x, T_x, U_x, V_x are the Krylov functions:

$$S_x = \frac{ch\lambda x + \cos\lambda x}{2}, \qquad T_x = \frac{sh\lambda x + \sin\lambda x}{2},$$
$$U_x = \frac{ch\lambda x - \cos\lambda x}{2}, \qquad V_x = \frac{sh\lambda x - \sin\lambda x}{2}$$

$$\left.\begin{aligned}
&y_x = y_0 S_x + \frac{\varphi_0}{\lambda} T_x - \frac{y_0 C_1}{\lambda^3 EI} V_x\\
&\varphi_x = y_0 \lambda V_x + \varphi_0 S_x - \frac{y_0 C_1}{\lambda^2 EI} U_x ,\\
&M_x = -y_0 \lambda^2 EIU_x - \varphi_0 \lambda EIV_x + \frac{y_0 C_1}{\lambda} T_x ,\\
&Q_x = -y_0 \lambda^3 EIT_x - \varphi_0 \lambda^2 EIU_x + y_0 C_1 S_x
\end{aligned}\right\} \quad (11)$$

In (11) C_1 - is the stiffness of the support at $x = 0.$ Using (11), we write down the expressions for deflection, moment and transverse force at $x = l.$ As a result we obtain a system of three homogeneous equations with respect to three unknowns: y_0, φ_0, y_l.

$$\left.\begin{aligned}
&y_{x=l} = y_0 S_{x=l} + \frac{\varphi_0}{\lambda} T_{x=l} - \frac{y_0 C_1}{\lambda^3 EI} V_{x=l} ,\\
&M_{x=l} = 0 = -y_0 \lambda^2 EIU_{x=l} - \varphi_0 \lambda EIV_{x=l} + \frac{y_0 C_1}{\lambda} T_{x=l}\\
&Q_x = -C_2 y_{x=1} = -y_0 \lambda^3 EIT_{x=l} - \varphi_0 \lambda^2 EIU_{x=l} + y_0 C_1 S_{x=l}
\end{aligned}\right\} \quad (12)$$

$$S_{x=l} = \frac{ch\lambda l + \cos\lambda l}{2}, \qquad T_{x=l} = \frac{sh\lambda l + \sin\lambda l}{2},$$
$$U_{x=l} = \frac{ch\lambda l - \cos\lambda l}{2}, \qquad V_{x=l} = \frac{sh\lambda l - \sin\lambda l}{2}$$

Equating the determinant of the system with unknowns y_0, φ_0, y_i, to zero, we obtain a transcendental equation with respect to the unknown quantity λ.

$$(S_{x=l}-\frac{C_1}{\lambda^3 EI}V_{x=l}-1)y_0+\frac{\varphi_0}{\lambda}T_{x=l}-y_{x=l}=0,$$
$$-y_0(\lambda^2 EIU_{x=l}-\frac{C_1}{\lambda}T_{x=l})-\varphi_0\lambda EIV_{x=l}=0$$
$$-y_0(\lambda^3 EIT_{x=l}-C_1S_{x=l})-\varphi_0\lambda^2 EIU_{x=l}+C_2y_{x=l}=0$$

$$\begin{vmatrix} (S_{x=l}-\frac{C_1}{\lambda^3 EI}V_{x=l}-1) & \frac{1}{\lambda}T_{x=l} & -1 \\ -(\lambda^2 EIU_{x=l}-\frac{C_1}{\lambda}T_{x=l}) & -\lambda EIV_{x=l} & 0 \\ -(\lambda^3 EIT_{x=l}-C_1S_{x=l}) & -\lambda^2 EIU_{x=l} & C_2 \end{vmatrix}=0 \tag{13}$$

The determinant (13) is a frequency equation from which the frequencies of natural vibrations are determined:

$$F(\lambda)=(S_{x=l}-\frac{C_1}{\lambda^3 EI}T_{x=l}-1)(-\lambda EIV_{x=l}C_2)-\frac{1}{\lambda}T_{x=l}(-\lambda^2 EIU_{x=l}+\frac{C_1}{\lambda}T_{x=l})C_2+$$
$$(-\lambda^2 EIU_{x=l}+\frac{C_1}{\lambda}T_{x=l})\lambda^2 EIU_{x=l}+\lambda EIV_{x=l}(\lambda^3 EIT_{x=l}+C_1S_{x=l})=0 \tag{14}$$

Equation (14) can be written as:

$$-\lambda^7(EI^2)[(U_{x=l}{}^2)+T_{x=l}V_{x=l}]+\lambda^4 EI[(-C_2V_{x=l}S_{x=l}+V_{x=l}C_2+C_2\,T_{x=l}U_{x=l}+C_1T_{x=l}U_{x=l}+C_1V_{x=l}S_{x=l}]+$$
$$+\lambda C_1C_2[V_{x=l}T_{x=l}-(T_{x=l}{}^2)]=0$$

The parameter λ is also included in the arguments of circular functions. Assuming one of the supports or 2 supports is rigid, we can consider 3 special cases:

1. $C_1=\infty$

$$F(\lambda)=(S_{x=l})(-\lambda EIV_{x=l}C_2)-\frac{1}{\lambda}T_{x=l}(-\lambda^2 EIU_{x=l})C_2+$$
$$+(-\lambda^2 EIU_{x=l})\lambda^2 EIU_{x=l}+\lambda EIV_{x=l}(-\lambda^3 EIT_{x=l})=0 \tag{15}$$

2. $C_2=\infty$

$$F(\lambda)=(-\lambda EIU_{x=l}+\frac{C_1}{\lambda}T_{x=l})\lambda^2 EIU_{x=l}+\lambda EIV_{x=l}(-\lambda^3 EIT_{x=l}+C_1S_{x=l})=0 \tag{16}$$

3. $C_1=C_2=\infty$

$$F(\lambda)=(-\lambda^2 EIU_{x=l})\lambda^2 EIU_{x=l}+\lambda EIV_{x=l}(-\lambda^3 EIT_{x=l})=0 \tag{17}$$

Equation (17) corresponds to rigid constraints. The frequency of natural vibrations is expressed in terms of the parameter λ:

$$\omega_k=l^2\lambda_k\sqrt{\frac{EI}{m}} \tag{18}$$

Knowing the natural frequencies, we can use formula (12) to determine deflections, rotation angles, bending moments, and transverse forces.

With rigid supports $C_1 = C_2 = \infty$, then the frequencies are determined depending on the number of half-waves k by the following formulas:

$$\omega_1 = \frac{\pi^2}{l^2}\sqrt{\frac{EI}{m}}, \qquad k=1, \qquad \omega_2 = \frac{4\pi^2}{l^2}\sqrt{\frac{EI}{m}}, \qquad k=2, \qquad \omega_3 = \frac{9\pi^2}{l^2}\sqrt{\frac{EI}{m}}, \qquad k=3$$

In general, equation (14) can be represented as a nonlinear function of the parameter λ:

$$F(\lambda) = 0 \tag{19}$$

This equation is a transcendental equation with respect to the unknown λ, which is a parameter of the natural frequency ω **(Bekshayev S.Ya., 2013; Sedighi H.M, 2012; Sedighi H.M, 2011; Ruabukhin A.K.,2020)**. This equation has countless solutions, so in the future it is necessary to determine the minimum values of the unknown quantity. Knowing λ, we can find the values of the eigenfrequencies. To solve equation (19), we can use the approximation method. Let's say that two parameter values are found $\lambda = a, b$, where the function $F(\lambda)$ takes two values of different signs, i.e. $F(a)F(b) < 0$. In this case there is at least one point between a and b where $F(\lambda) = 0$. As an initial approximation, we can take the midpoint of the segment $[a,b]$, i.e. $x_0 = \frac{a+b}{2}$.

The iterative process consists of successive refinement of the initial approximation $\lambda = x_0$. Each such step is called an iteration. As a result of iterations, a sequence of approximate values of the root $x_1, x_2, x_3 ... x_n$ is found . If these values approach the true value of the root as n increases, then the iterative process converges. The method of dividing a segment in half is as follows. Let's assume that we found the segment [a,b] that contains the desired root value $x = c$, i.e. $a < c < b$. As an initial approximation of the root with$_0$, we take the midpoint of the segment, i.e. $c_0 = \frac{a+b}{2}$. Next, we study the values of the function $F(x)$ at the ends of the segment $[a, c_0]$ and $[c_0, b]$, i.e. at points a, c_0, b. The one where the function $F(x)$ at the ends of which takes different values contains the desired root, so we take it as a new segment. Discard the second half of the segment $[a,b]$ where $F(x)$ does not change. As the first iteration of the root, we take the middle of the new segment, etc. Thus, after each iteration, the segment on which the root is located is halved, i.e. after n iterations, it is halved.

Let for definiteness $F(a) < 0$, $F(b) > 0$ (Fig. 2). As an initial approximation of the root, we take $c_0 = \frac{a+b}{2}$. Since in the case $F(c_0) < 0 < F(c)$, under consideration, then $c_0 < c < b$ we consider only the segment $[c_0, b]$. Next approximation: $c_1 = \frac{c_0 + b}{2}$. In this case, we discard the segment [c$_1$,b], since $F(c_1) > 0$ and $F(b) > 0$, i.e. $c_0 < c < c_1$. Similarly, we find other approximations: i.e. $c_2 = \frac{c_0 + c_1}{2}$, etc.

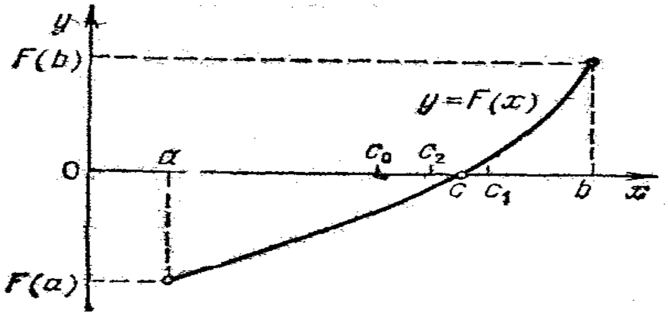

Figure 2 – Iteration method (authors' material)

The iterative process is continued until the value of the function $F(x)$ after n-th iteration becomes less than absolute value of some given value ε, i.e. $|F(c_n)| < \varepsilon$. You can also estimate the length of the resulting segment: if it becomes less than the permissible error, then the calculation stops. **Figure 3** shows a flowchart of this algorithm.

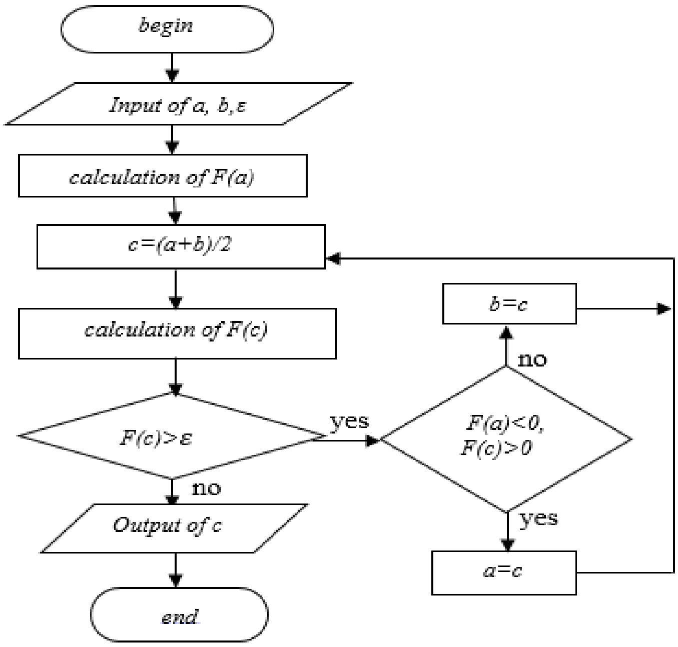

Figure 3 – Flowchart for solving the transcendental equation (authors' material)

By analogy, we can consider the case when the left support of the rod is an absolutely rigid connection, and the right support is elastically pliable (**Figure 4**) **(Ray W. 1977; Korenev B.G., 1972; Nikolaenko N.A., 1988)**.

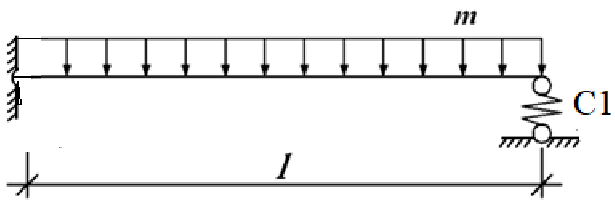

Figure 4 – Design scheme with one elastic support (authors' material)

For the case of a rigid connection at the left end and a hinged support of the beam on the right, the boundary conditions will be:

$$\text{at } x=0 \qquad y_0=0, \quad \varphi_0=0$$

$$\text{at } x=l \qquad y_l=0, \quad Q_l=-y_l\cdot C_1, \tag{20}$$

where y_0 – displacement at the origin, y_l - beam displacement at $x=l$; M_0 and M_l -moment at $x=0$ and $x=l$, respectively, Q_0 and Q_l -transverse forces at $x=0$ and $x=l$, respectively.

Let us express the coefficients A, B, C, and D of solution (7) in terms of the initial parameters y_0, φ_0, M_0, Q_0, , then the standing waves can be represented as:

$$\left.\begin{aligned} y_x &= -\frac{M_0}{\lambda^2 EI}U_x - \frac{Q_0}{\lambda^3 EI}V_x \\ \varphi_x &= -\frac{M_0}{\lambda EI} - \frac{Q_0}{\lambda^2 EI}U_x, \\ M_x &= M_0 S_x + \frac{Q_0}{\lambda}T_x \\ Q_x &= M_0\lambda V_x + Q_0 S_x \end{aligned}\right\} \tag{21}$$

In (21) S_x, T_x, U_x, V_x are the Krylov functions:

$$S_x = \frac{ch\lambda x + \cos\lambda x}{2}, \qquad T_x = \frac{sh\lambda x + \sin\lambda x}{2},$$

$$U_x = \frac{ch\lambda x - \cos\lambda x}{2}, \qquad V_x = \frac{sh\lambda x - \sin\lambda x}{2}$$

Using the boundary conditions, we obtain:

$$\begin{aligned} y_{x=0} &= 0 = -\frac{M_0}{\lambda^2 EI}U_{x=0} - \frac{Q_0}{\lambda^3 EI}V_{x=0}, \\ M_{x=l} &= 0 = M_0 S_{x=l} + \frac{Q_0}{\lambda}T_{x=l}, \\ y_{x=l} &= 0 = -\frac{M_0}{\lambda^2 EI}U_{x=l} - \frac{Q_0}{\lambda^3 EI}V_{x=l}, \\ Q_{x=l} &= -y_l\cdot C_1 = M_0\lambda V_{x=l} + Q_0 S_{x=l} \end{aligned} \tag{22}$$

As a result, we obtain a system of three homogeneous equations with respect to three unknowns: M_0, Q_0, y_l. Equating the determinant for the unknowns to zero, we obtain a transcendental equation with respect to the unknown parameter λ.

$$S_{x=l}\left(-\frac{1}{\lambda^3 EI}V_{x=l}C_1 + S_{x=l}\right) - \frac{1}{\lambda}T_{x=l}\left(-\frac{1}{\lambda^2 EI}U_{x=l}C_1 + \lambda V_{x=l}\right) = 0 \tag{24}$$

$$U_{x=0} = \frac{ch0 - \cos 0}{2} = 0, \qquad V_x = \frac{sh0 - \sin 0}{2} = 0.$$

$$U_{x=l} = \frac{ch\lambda l - \cos\lambda l}{2}, \qquad V_x = \frac{sh\lambda l - \sin\lambda l}{2}$$

Assuming the right support is rigid, we can consider a special case:

1. $C_1 = \infty$

$$F(\lambda)= S_{x=l}(S_{x=l}) - \frac{1}{\lambda} T_{x=l}(\lambda V_{x=l}) = 0 \qquad (25)$$

4 RESULTS AND DISCUSSIONS

4.1 Results of dynamic calculation of a road overpass

Figure 5 shows a general view of the overpass. The overpass in the longitudinal direction is made three-span. Static system of superstructures is beam-split. Support of beams on supports is hinged.

Superstructure-reinforced concrete, three-span, superstructure No. 1 and No. 3 consists of T-shaped reinforced concrete beams with a length of 11.36 m, made according to the standard design of reinforced concrete prefabricated superstructures without diaphragms with frame reinforcement of a periodic profile.

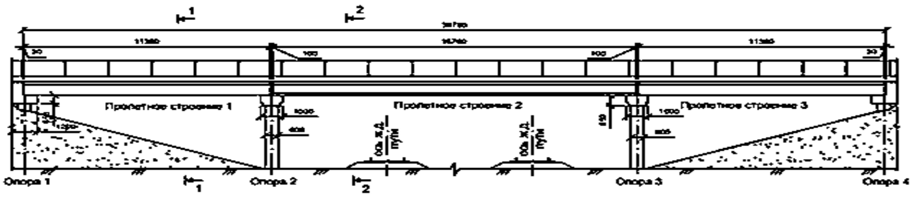

Figure 5 – General view of the overpass (authors' material)

Using the proposed algorithm, the eigenfrequencies of transverse vibrations of spans are determined for the case of hinged fastening of the ends of load-bearing beams $(C_1 = C_2 = \infty)$ and for the case of elastic-yielding supports with different stiffness values (table 1) **(Dostanova S.Kh., 2020; 2021; 2023)**.

Table 1.
Values of natural frequencies and oscillation periods (authors' material)

Span No.	Anchoring conditions	Eigenfrequencies ω_1, Hz	Periods of oscillation sec
1,3	Hinge support $C_1 = C_2 = \infty$	9,82	0,64
2	Hinge support $C_1 = C_2 = \infty$	5,86	1,07
1,3	Elastic support (C_1=C_2=100 kN/cm)	5,52	1,14
2	Elastic support (C_1=C_2=100 kN/cm)	4,84	1,55
1,3	Elastic support (C_1=C_2=200 kN/cm)	5,44	1,15
2	Elastic support (C_1=C_2=200 kN/cm)	4,44	1,25
1,3	Elastic support (C_1=C_2=400 kN/cm)	7,66	0,82
2	Elastic support (C_1=C_2=400 kN/cm)	5,32	1,18
1,3	Elastic support (C_1=C_2=800 kN/cm)	8,55	0,74
2	Elastic support (C_1=C_2=800 kN/cm)	5,38	1,17

Figure 6 shows a graph of changes in the frequency of natural vibrations ω in Hz depending on the stiffness of elastic supports C_1 in kN/cm. For two spans of an automobile overpass. The graph shows 2 asymptotes (1) and (3) corresponding to rigid supports: 1 for the first and third spans; 3 for the second span. Curve 2 corresponds to the first span, and curve 4 corresponds to the second span. It can be seen from the graphs that as the stiffness of the supports increases, the natural oscillation frequencies approach values close to those of rigid supports.

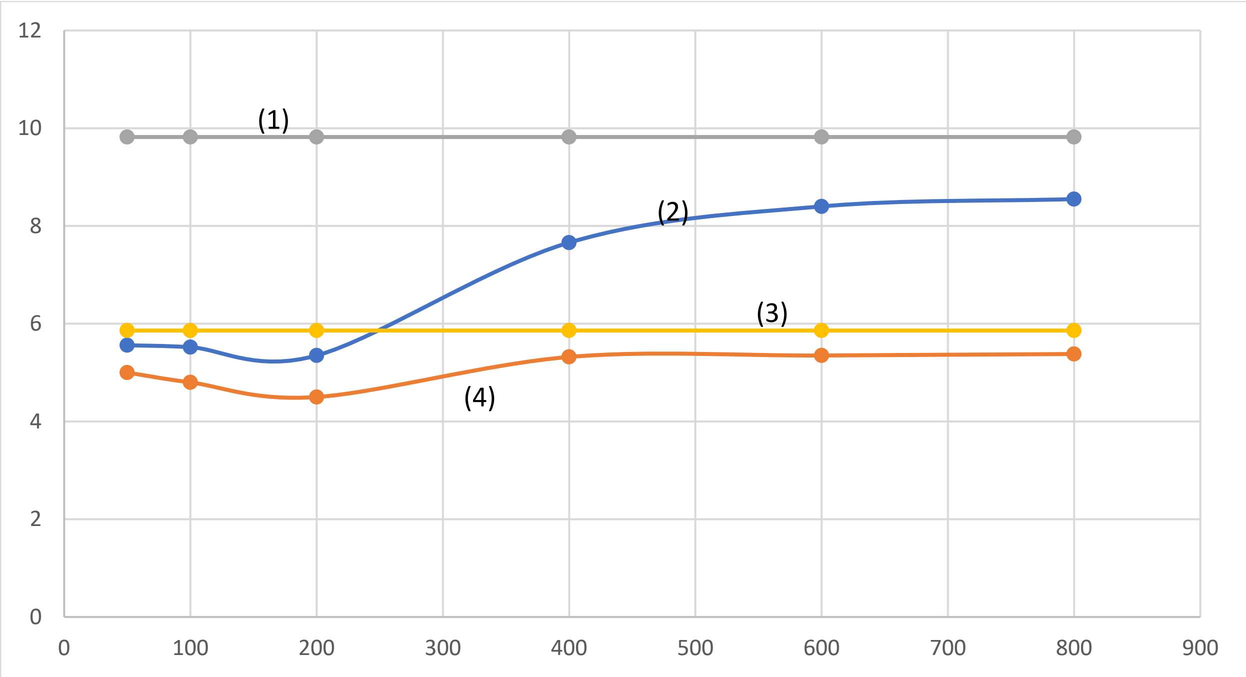

Figure 6 – Graph of changes in the frequency of natural vibrations ω in Hz depending on the stiffness of elastic supports C_1 in kN / cm for two spans of an automobile overpass: (1) for the first, (3) for the second span with rigid supports, (2) corresponds to the first and (4) to the second span for elastic supports (authors' material)

The obtained graphs allow us to evaluate the influence of the stiffness of the supports on the dynamic safety margin of the whole system **(Dostanova S.Kh.2020; 2021; 2023)**. When transport moves at speed v, the dynamic coefficient μ for a single-mass system can be approximated by the following formula:

$$\mu = \frac{1}{1 - \frac{vl}{\pi}\sqrt{\frac{m}{EI}}} = \frac{1}{1 - \frac{v}{\omega} \cdot \frac{\pi}{l}}$$

In this formula m is the span mass, EI is the bending stiffness, l is the span length, ω is the natural frequency. From the obtained graphs it is seen that the most optimal for the 1st and 2nd spans is the stiffness of support links equal to 200 kN / cm. Reduction of frequencies leads to reduction of the value of dynamic coefficient at speed v=40 km/hour by 15-20%. This makes it possible to increase the reserve of dynamic strength by adjusting the stiffnesses of the support links.

5 CONCLUSIONS

The presented algorithm for calculating the dynamic characteristics of transport structures using elastic-yielding supports and the results of theoretical calculations allow us to draw the following conclusions:

1. When using resilient supports in transport structures, you can change the dynamic characteristics and thereby increase the strength reserve and reduce the dynamic effect.

2. Regulating support devices reduce the natural vibration frequencies of the beam, thereby removing it from the resonant zone by 9% or more. By changing the stiffness of the supports, you can optimize the values of dynamic characteristics using the method of successive approximations.

3. An increase in the length of the span beams leads to a decrease in natural frequencies and an increase in internal forces and deflections with free vibrations up to an average of 32%.

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RESEARCH ARTICLE

INVESTIGATION OF PHYSICO-CHEMICAL PROPERTIES CHANKANAI DEPOSIT ZEOLITES FOR ENHANCED MODIFIED CONCRETE PRODUCTION

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Abstract. *This study examines the physico-chemical properties of the Chankanai deposit zeolite and its potential as an additive in the production of modified concrete. The focus is on the investigation of the structural characteristics of zeolite, its chemical composition, and its modifying ability. Zeolites are aluminosilicate minerals with high adsorption capacity, and their use in building materials has the potential to enhance the strength, durability, and environmental friendliness of final products. X-ray diffraction (XRD) and scanning electron microscopy (SEM) methods were applied to analyze the structure and morphology of zeolites. The XRD methods allowed for the determination of the crystal structure and phase composition of zeolite samples, revealing the presence of dominant mineral phases and their spatial arrangement. Using SEM, the microstructure and morphological features of zeolite particles were investigated, enabling an assessment of their porosity and distribution within the material. As a result of the experiments, it has been found that zeolites exhibit a high sorption capacity, well-developed porous structure, thermal stability, and resistance to chemical substances, making them promising raw materials for manufacturing cement composites, concrete, and other building materials. Additionally, the potential of enhancing the performance of these materials through the use of zeolites as well as the environmental and economic benefits associated with them have been discussed.*

Keywords: *zeolite, Chankanai deposit, modified concretes, adsorption capacity, durability, environmental friendliness, physical properties.*

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ҒЫЛЫМИ МАҚАЛА

ЖАҚСАРТЫЛҒАН МОДИФИКАЦИЯЛАНҒАН БЕТОН ӨНДІРУ ҮШІН ЧАНКАНАЙ КЕН ОРНЫНЫҢ ЦЕОЛИТТЕРІНІҢ ФИЗИКАӨХИМИЯЛЫҚ ҚАСИЕТТЕРІН ЗЕРТТЕУ

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Аңдатпа. *Бұл зерттеу Чанканай кен орнының цеолитінің физика-химиялық қасиеттерін және оның модификацияланған бетондарды өндіруге арналған қоспа ретіндегі перспективаларын қарастырады. Цеолиттің құрылымдық ерекшеліктерін, оның химиялық құрамын және модификация қабілетін зерттеуге баса назар аударылады. Цеолиттер-жоғары адсорбциялық қабілеті бар алюминий силикаттары және оларды құрылыс материалдарында қолдану соңғы өнімнің беріктігін, беріктігін және тұрақтылығын арттыра алады. Цеолиттердің құрылымы мен морфологиясын талдау үшін рентгендік фазалық талдау (XRD) және сканерлеуші электронды микроскопия (SEM) әдістері қолданылды. Рентгендік фазалық әдіс цеолиттердің кристалдық құрылымы мен фазалық құрамын анықтауға, басым минералдардың болуын және олардың кеңістіктік ұйымдастырылуын анықтауға мүмкіндік берді. SEM көмегімен цеолит бөлшектерінің микроқұрылымы мен морфологиясы зерттелді, бұл олардың кеуектілігі мен материалдағы бөлшектердің таралуын бағалауға мүмкіндік берді. Эксперименттер нәтижесінде цеолиттердің жоғары сорбциялық қабілеті, дамыған кеуекті құрылымы, ыстыққа төзімділігі және химиялық реагенттердің әсеріне төзімділігі анықталды, бұл оларды цемент композиттерін, бетонды және басқа құрылыс материалдарын өндіруге перспективалы шикізат етеді. Сонымен қатар, цеолиттерді пайдалану арқылы құрылыс материалдарының өнімділігін жақсарту мүмкіндіктері, сондай-ақ олардың экологиялық және экономикалық артықшылықтары талқыланады.*

Түйін сөздер: *цеолит, Чанканай кен орны, өзгертілген бетондар, адсорбция қабілеті, беріктігі, тұрақтылығы, физикалық қасиеттері.*

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НАУЧНАЯ СТАТЬЯ

ИССЛЕДОВАНИЕ ФИЗИКО-ХИМИЧЕСКИХ СВОЙСТВ ЦЕОЛИТОВ МЕСТОРОЖДЕНИЯ ЧАНКАНАЙ ДЛЯ ПРОИЗВОДСТВА УЛУЧШЕННОГО МОДИФИЦИРОВАННОГО БЕТОНА

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Аннотация. *В данном исследовании рассматриваются физико-химические свойства цеолита месторождения Чанканай и его перспективы в качестве добавки для производства модифицированных бетонов. Основное внимание уделено изучению структурных особенностей цеолита, его химического состава и способности к модификации. Цеолиты - это алюмосиликаты с высокой адсорбционной способностью, и их использование в строительных материалах может повысить прочность, долговечность и экологичность конечного продукта. Для анализа структуры и морфологии цеолитов были использованы методы рентгенофазового анализа (XRD) и сканирующей электронной микроскопии (SEM). Рентгенофазовый метод позволил определить кристаллическую структуру и фазовый состав цеолитов, выявив наличие доминирующих минералов и их пространственную организацию. С помощью SEM были изучены микроструктура и морфология частиц цеолита, что позволило оценить их пористость и распределение частиц в материале. В результате экспериментов было выявлено, что цеолиты обладают высокой сорбционной способностью, развитой пористой структурой, термостойкостью и стойкостью к воздействию химических реагентов, что делает их перспективным сырьем для изготовления цементных композитов, бетона и других строительных материалов. Кроме того, обсуждаются возможности улучшения эксплуатационных характеристик строительных материалов за счет использования цеолитов, а также их экологические и экономические преимущества.*

Ключевые слова: *цеолит, месторождение Чанканай, модифицированные бетоны, адсорбционная способность, долговечность, экологичность, физические свойства.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Бұл зерттеуді Қазақстан Республикасы Ғылым және жоғары білім министрлігінің Ғылым комитеті қаржыландырады (№AP22685758 «Монолитті құрылысқа арналған құрамында цеолиті бар модификацияланған бетон" гранты).

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ екенін растайды.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

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КОНФЛИКТ ИНТЕРЕСОВ

Авторы подтверждают, что конфликта интересов нет.

1 INTRODUCTION

In recent years, the construction industry has been increasing interest in the use of natural zeolites to create modified concretes with improved physical and mechanical properties. Zeolites are natural aluminosilicates with a microporous structure, which gives them unique sorption and catalytic properties. Due to these qualities, zeolites can significantly improve the properties of concrete, such as strength, durability and resistance to aggressive environments.

The Chankanai deposit, located in the Almaty region of Kazakhstan, is one of the promising sources of natural zeolite. The study of the physico-mechanical characteristics of zeolite from this deposit, as well as its potential as an additive for the modification of concrete mixtures, is an urgent task for the construction science and industry of Kazakhstan. The introduction of zeolite into the composition of concrete can not only improve its performance properties but also reduce the environmental impact by reducing the need for traditional cement components.

The purpose of this study is to study the properties of the zeolite of the Chankanai deposit and assess its effect on the characteristics of modified concrete, which will allow the development of more stable and efficient building materials.

2 LITERATURE REVIEW

Concrete is one of the most common building materials for civil and military use due to its high mechanical stability and durability. However, its production has a significant impact on the environment since the production process of Portland cement, the main hydraulic component of concrete is accompanied by CO_2 emissions amounting to approximately 6% of global emissions of this gas (**Hefni et al., 2018**). Over time, concrete structures are exposed to various factors of destruction, such as shrinkage, freezing, and exposure to chlorides and sulfates, which reduce their durability. It is also important to take into account the costs of maintenance, protection, repair and restoration of existing concrete structures. Several practical solutions have been proposed to solve these problems. The first is to improve concrete's mechanical structure and durability during the production process. The second is to reduce the consumption of Portland cement in the production process. These two approaches can be implemented by optimizing the packing density of particles in concrete (**Kurda et al., 2019**) and partially replacing Portland cement with natural pozzolans and/or by-products of industrial production of pozzolan materials, such as crushed granular blast furnace slag (GGBFS), fly ash, or silica fume **(Eskandari et al., 2015; Markiv et al., 2016; Nuruddin et al., 2014; Shariq et al., 2016)**.

Zeolites are hydrated aluminosilicates that are mainly composed of four-, five- and six-membered rings formed by silicon-oxygen tetrahedra. Some of the silicon atoms in these rings can be replaced by aluminum (**Zhdanov & Yegorova, 1968; Rabo, 1980; Zhdanov et al., 1981; Pekov et al., 2004**). In the intercrystalline space, there is a system of interconnected channels that contain micro-cavities. These cavities are filled with exchange cations and water molecules. Zeolite is a nanoscale material that forms an ordered structure when molecules and ions are embedded into its framework. This creates a unique material with specific properties (**Kryuchin et al., 2010**). Due to their strictly defined pore sizes and intercrystalline cavities, both natural and synthetic zeolites are excellent sorbents - molecular "sieves" (**Breck, 1976**) capable of selectively absorbing and releasing molecules of various substances. After dehydration, zeolites can have a porosity of up to 50% or more, and their crystal structure is formed by fragments of tetrahedral anions $[SiO4]^{4-}$ and $[AlO4]^{5-}$ combined into a three-dimensional framework with cavities and channels of 0.2-1.5 nm scale.

Natural zeolite is becoming an increasingly popular component in concrete production due to its pozzolanic properties and positive effect on environmental friendliness. The addition of zeolite as a supplementary cementing material reduces CO_2 emissions by decreasing the amount of Portland cement required while improving the performance of concrete. However, research shows that the impact of zeolite on mechanical properties and durability depends on several factors, including the composition of the zeolite, level of replacement, and testing conditions.

The incorporation of natural zeolite into concrete has led to a significant improvement in its mechanical properties. Uzal and Turanli (**Uzal & Turanlı, 2012**) studied cements containing a high concentration of zeolite and found that the strength of the cement stone increased due to the formation of additional C-S-H phases. This is because of the pozzolanic reaction, in which zeolite reacts with calcium hydroxide to produce additional hydrated phases, reducing porosity and increasing the density of the material. However, when a large proportion of cement is replaced with zeolite (more than 30%), the strength gain may be slowed in the early stages. This can be a disadvantage for applications that require rapid strength development.

Pezeshkian et al. (**Pezeshkian et al., 2020**) examined the impact of natural zeolite on ultra-high-performance concrete (UHPC) and observed a decrease in autogenous shrinkage. This decrease helps lower the likelihood of cracking by enhancing water retention and reducing the rate of heat release during hydration. Nevertheless, the delayed hydration process could be problematic for applications where quick strength development is essential. Similarly, Ranjbar et al. (**Ranjbar et al., 2013**) reported that the addition of zeolite improved the rheological properties of self-compacting concrete by minimizing water bleeding and increasing water retention, resulting in a more homogeneous mixture. However, they also noted that when a high percentage of cement was replaced with zeolite, the initial strength of the concrete decreased due to the lower reactivity of the zeolite. Several researchers have investigated the durability of concrete containing zeolite. While zeolite can improve the properties of concrete, it is important to consider each project's specific conditions and requirements when deciding whether to use it.

Natural zeolite has been shown to have a positive effect on the durability of concrete, enhancing its resistance to various aggressive factors. Studies by Cryptavicius et al. (**Kriptavičius et al., 2023**) and Singgu et al. (**Sinngu et al., 2024**) have demonstrated that the addition of zeolite to concrete can improve its resistance to chloride and sulfate attack. Zeolite reacts with calcium hydroxide in the concrete to form additional calcium silicate hydrate (C-S-H) gels, which help to seal the microstructure of the concrete and reduce its permeability. This, in turn, reduces the risk of chloride and sulfate penetration, leading to increased durability.

The effectiveness of zeolite in improving concrete durability is dependent on several factors, including its chemical composition, physical characteristics such as particle size, and mineralogical composition. It is important to carefully select and use zeolite that is suitable for the specific application in order to maximize its benefits. Despite the obvious advantages of using natural zeolite in concrete, there are several challenges associated with its use. One of the main problems lies in the variability of zeolite composition, which can affect its pozzolanic activity and, consequently, the properties of the concrete. Uzal and Turanli (**Uzal & Turanlı, 2012**) noted that excessive amounts of zeolite can slow down strength gain due to its slow reaction in the early stages of hydration, limiting its use in applications requiring rapid strength development.

Several number of researchers emphasized the importance of optimizing zeolite replacement levels in concrete. Improper composition selection can lead to decreased strength and reduced durability. To achieve optimal results, it is crucial to consider the specific application requirements and characteristics of the selected zeolite.

In conclusion, while the use of zeolite has many benefits, it also presents challenges that must be addressed. By carefully considering these factors, engineers can optimize concrete formulations and ensure successful outcomes in various applications. Natural zeolite is a promising component for concrete modification that offers several advantages, including improved mechanical properties and increased durability. Its use can reduce the amount of Portland cement used, leading to a reduction in CO_2 emissions and lower costs. However, to effectively utilize zeolite, it is important to consider its chemical composition, level of replacement, and operating conditions.

3 MATERIALS AND METHODS

Zeolite was received from Chankanai deposit (Almaty region, Kazakhstan, LTD Taza Su). The zeolite was grinned, ground, and sieved to 200 mesh (or 105 nμ) in size. The certified chemical composition of natural zeolite is provided in **Table 1.** To determine the elemental composition, the sample was subjected to X-ray spectral analysis at the Superprob 733 device (Japan), and to determine the mineral composition to X-ray phase analysis at the DRON - 3 device (USSR), and a Scanning electron microscope JEOL (Japan) was used to determine the microstructure.

Table 1
Chemical composition of the studied zeolite, mass % (author's material).

Oxides	ω, %	Oxides	ω, %
SiO_2	67.38	Na_2O	1.08
Al_2O_3	16.67	K_2O	1.57
FeO	3.62	TiO_2	0.6
CaO	6.3	MnO	0.17
MgO	2.60	Total	100

4 RESULTS AND DISCUSSION

It is known that zeolites are nanoporous crystalline aluminosilicates containing water molecules and exchangeable cations such as K+, Na+, Ca^2+ and Mg^2+, which neutralize excess negative charges arising from the isomorphic substitution of Si^{4+} with Al^{3+}. The primary structural unit of zeolites is conventionally taken to be the TO4 tetrahedron, where T is a silicon or aluminum atom Tetrahedra, connecting with each other, form cuboctahedra (sodalite cells), from which the elementary cells of zeolite are built from three-, four-, five- or six-membered rings that make up its crystalline framework (**Nisbet, 1997; Sweeck et al. 1990**). The cuboctahedra are connected to each other by channels, the accessibility of which is determined by the free cross-section of the entrance holes (windows) formed by rings of interconnected tetrahedra.

The sorption properties of zeolite rocks are significantly influenced by both the mineral composition and the structural characteristics of the mineral (**Figure 1**). Zeolites possess a microporous structure, and zeolite-containing rock is a mixture of zeolite and other impurity minerals. As a result, meso- and macropores are formed between zeolite particles and the surrounding rock matrix, which aids in the interdiffusion of exchangeable ions within the sorbent–sorbate system (**Mamytbekov et al., 2024**). Impurity minerals, such as layered aluminosilicates like montmorillonite and occasionally halloysite, may also be present.

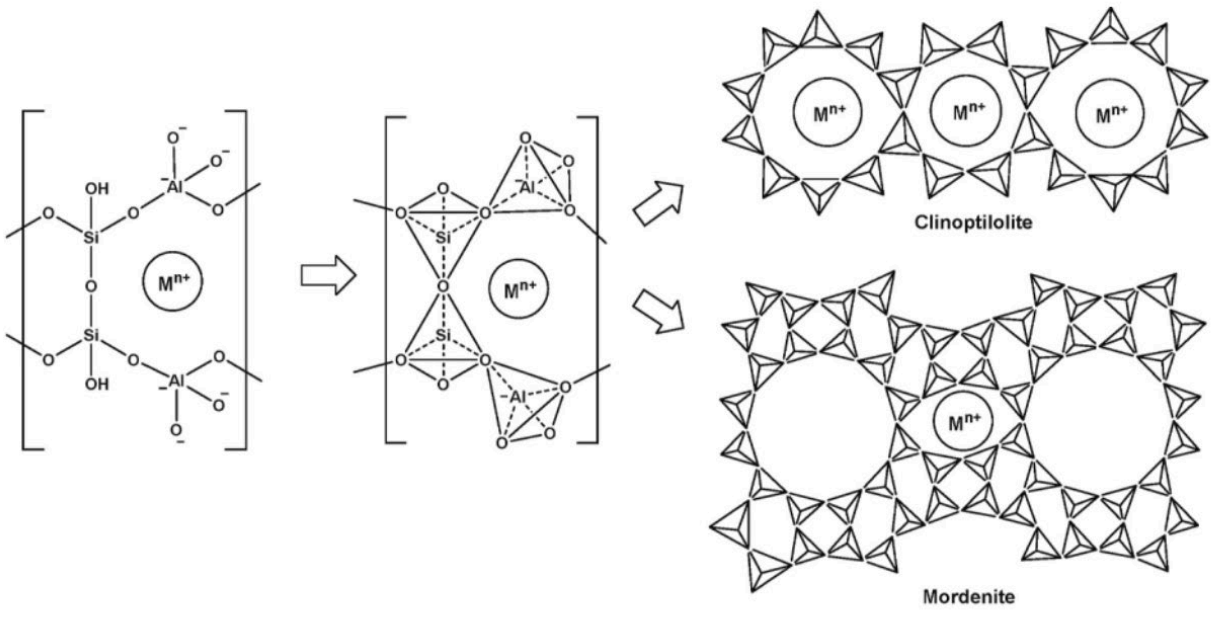
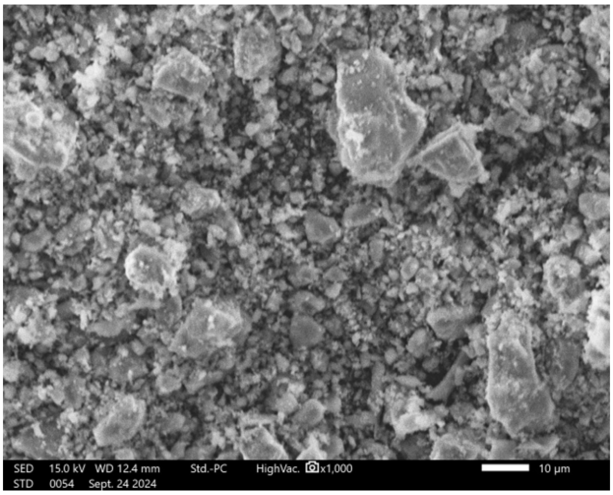
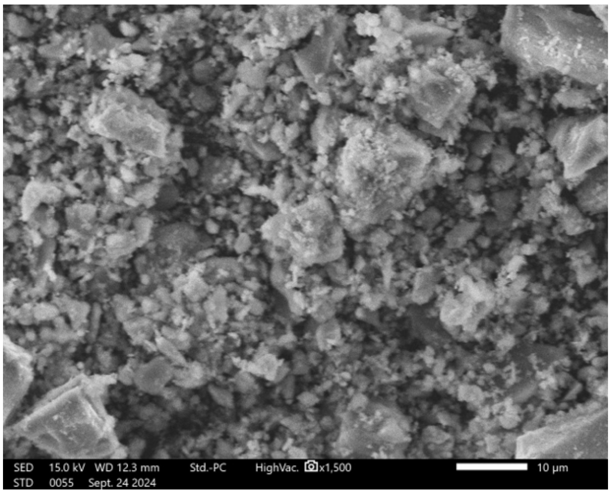


Figure 1 – General zeolite structure (Nisbet, 1997; Sweeck et al. 1990).

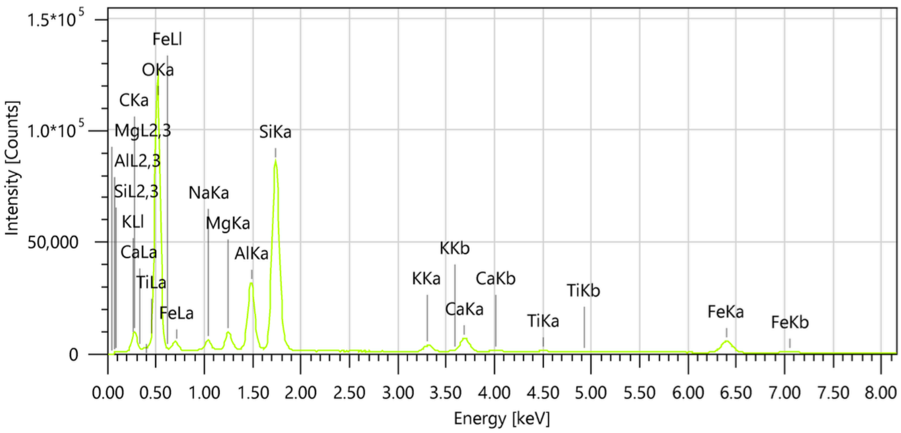
4.1 SEM ANALYSIS

The microstructural characteristics of the zeolite samples were evaluated using Scanning Electron Microscopy (SEM), which provided valuable insights into the morphology, particle size distribution, and surface texture, as demonstrated on Figure 2.





(a) **(b)**



(c)

Figure 2 – SEM images of Zeolite (a) (b) and elemental analysis (c) (author's material).

The images show irregularly shaped particles, which is typical for natural zeolites. The particles have a granular texture and vary in size. At a magnification of 1500, agglomerations of small crystalline particles can be distinguished, which form larger structures. Individual larger crystals are also visible, probably with well-defined faces, which may indicate the presence of clinoptilolite or other zeolite phases. The scale (10 μm) shows that the particles range from sub microns to several microns.

Fine particles can contribute to an increase in the total surface area, which has a positive effect on the adsorption properties of zeolite. The visible crystals have a size of about 1-5 microns, which is typical for natural zeolites used as adsorbents. The surface of the particles looks rough and porous, which is an important characteristic of zeolites, since the porous structure provides a high specific surface area. The presence of pores and the heterogeneous structure of the surface can be a confirmation of the high adsorption capacity of zeolite, which makes it suitable for use in water purification processes or as a catalyst. The particles tend to agglomerate, which is typical for fine crystalline minerals. Agglomeration can affect the effectiveness of zeolite application in industrial processes, as it reduces the available surface.

SEM images of natural zeolite show that the sample consists of irregularly shaped particles ranging in size from a submicron to several microns, having a highly developed porous surface. Such structural features confirm the potential of zeolite for use in adsorption and catalytic processes.

4.2 XRD ANALYSIS

During the study, X-ray diffraction analysis (XRD) of a sample of natural zeolite was performed to determine its mineral composition (**Figure 3**). Characteristic peaks are observed on the resulting diffractogram, which make it possible to identify the main and secondary phases in the sample. Based on a comparison of the values of interplane distances with the database of standard diffraction maps (PDF), it is assumed that clinoptilolite dominates in the sample, which is confirmed by the presence of peaks at 3.98 Å and 3.34 Å. The presence of mordenite is also likely (peaks at 9.02 Å and 6.73 Å), which is typical for natural zeolites, often mixtures of several phases.

Natural zeolites are rarely found in their pure form, and peaks are also observed on the diffractogram, which may correspond to impurities. For example, the peak at 3.34 Å may be associated with quartz, since this value is typical for this mineral.

XRD analysis showed that the studied sample of natural zeolite contains clinoptilolite and probably mordenite, as well as impurities of other mineral phases such as quartz. These results are important for understanding the properties of zeolite and can be used to evaluate its adsorption and catalytic characteristics. Results of semi-quantitative X-ray phase analysis of crystalline phases: Clinoptilolite – (Na, K, Ca)2.5Al_3(Al,Si)2$Si_{13}O_{36}$•12H_2O 84.5%; quartz – SiO_2 -10.2%; Albite (Feldspar) – Na($AlSi_3O_8$) – 5.3%.

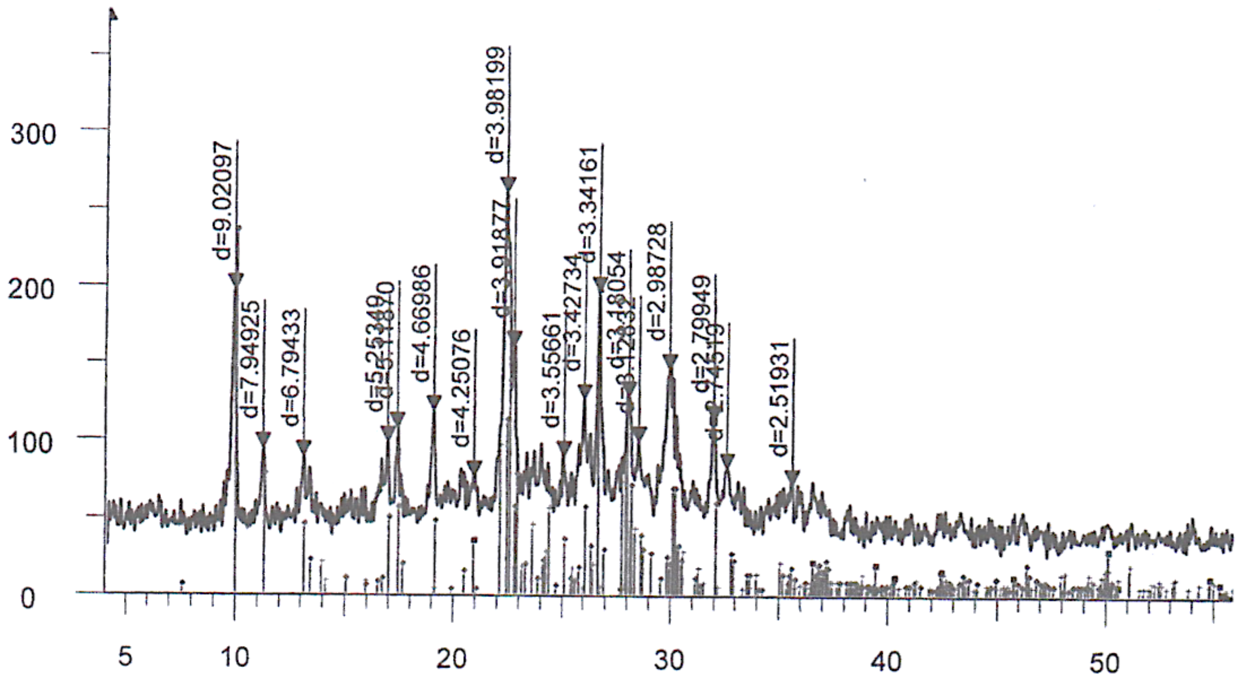


Figure 3 – XRD spectra of Zeolite (author's material).

5 CONCLUSIONS

During the study, the structural, chemical and morphological characteristics of natural zeolite from the Chankanai deposit (Almaty region, Kazakhstan) were studied. The conducted analyses, including SEM, X-ray diffraction and X-ray spectral analysis, allowed us to determine the basic mineral composition and structural features of the sample. The results showed that the main mineral is clinoptilolite with possible admixtures of mordenite and quartz, which is typical for natural zeolites, often containing mixtures of several phases.

SEM analysis revealed that zeolite particles have an irregular shape and granular texture, and their size varies from submicron to several microns. The surface morphology, represented by small crystalline particles with a coarse, porous structure, confirms the high sorption capacity of zeolite. These structural features make this material promising for use in adsorption and catalytic processes, especially in water purification and industrial catalysis.

XRD analysis confirmed the presence of clinoptilolite as the main phase, while peaks corresponding to quartz and possibly mordenite were found. This indicates a complex mineral composition of the sample under study.

Thus, the study showed that zeolite from the Changkanai deposit has a high potential for practical applications, such as water purification, due to its structural features, high specific surface area, and excellent adsorption characteristics. In the future, research could evaluate the catalytic properties of zeolite, study its durability, and develop optimization methods for various industrial applications.

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RESEARCH ARTICLE

EFFECT OF THE NUMBER OF STOREYS ON SEISMIC RESISTANCE OF HIGH-RISE MONOLITHIC BUILDINGS IN ALMATY

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Abstract: *The article considers the issues of the construction of high-rise monolithic buildings in Almaty. High-rise construction has received significant development in the territory of the metropolis - more than several dozen buildings more than 20 stories high have been built. Experimental studies of the proper dynamic characteristics of high-rise buildings (periods and forms of natural oscillations, oscillation decrement) and verification of the correctness of the calculation assumptions adopted during their design are relevant. The influence of height on the proper dynamic characteristics of high-rise monolithic buildings constructed in Almaty is analyzed. Data are provided on determining the dynamic characteristics of a 22-storey monolithic building using the building pull-out method with the subsequent abrupt release of the applied load. The results are compared with the data on the proper dynamic characteristics of four high-rise buildings (more than 20 stories high) obtained as a result of vibration tests: - 25-storey Kazakhstan Hotel; - 35-storey building on Al Farabi Street (Nurly-Tau district); - 22-storey building of the Stolichny Tsentr residential complex; -26-storey building of the residential complex "Megatowers". The results of the work can be used in the design of high-rise monolithic buildings.*

Keywords: *high-rise monolithic building, concrete, reinforcement, full-scale testing, testing methods, dynamic characteristics of the building.*

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ҒЫЛЫМИ МАҚАЛА

АЛМАТЫ ҚАЛАСЫНДАҒЫ БИІК МОНОЛИТТІ ҒИМАРАТТАРДЫҢ СЕЙСМИКАЛЫҚ ТӨЗІМДІЛІГІНЕ ҚАБАТТЫЛЫҚТЫҢ ӘСЕРІ

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Аңдатпа. *Алматы қаласында биік монолитті ғимараттар салу мәселелері қарастырылуда. Биіктік құрылысы мегаполис аумағында айтарлықтай дамыды-биіктігі 20 қабаттан асатын бірнеше ондаған ғимараттар салынды. Биік ғимараттардың өзіндік динамикалық сипаттамаларын эксперименттік зерттеу (меншікті тербелістердің кезеңдері мен формалары, тербелістердің декреті) және оларды жобалау кезінде қабылданған есептік алғышарттардың дұрыстығын тексеру өзекті болып табылады. Алматы қаласында салынған биік монолитті ғимараттардың өзіндік динамикалық сипаттамаларына биіктіктің әсері талданады. 22 қабатты монолитті ғимараттың динамикалық сипаттамаларын ғимаратты тарту әдісімен анықтау, содан кейін қолданылатын жүктемені күрт босату туралы мәліметтер келтірілген. Нәтижелер дірілді сынау нәтижесінде алынған төрт биік ғимараттың (биіктігі 20 қабаттан асатын) өзіндік динамикалық сипаттамаларының деректерімен салыстырылады: - "Қазақстан" 25 қабатты қонақ үйі; - Әл-Фараби көшесі бойындағы 35 қабатты ғимарат ("Нұрлы - Тау" ауданы); - "Астаналық орталық" ТК 22 қабатты ғимараты; - "Мегатауэрс"ТК 26 қабатты ғимараты. Жұмыс нәтижелерін көп қабатты монолитті ғимараттарды жобалау кезінде пайдалануға болады.*

Түйін сөздер: *көп қабатты монолитті ғимарат, бетон, арматура, табиғи сынақ, сынақ әдістері, ғимараттың динамикалық сипаттамалары.*

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НАУЧНАЯ СТАТЬЯ

ВЛИЯНИЕ ЭТАЖНОСТИ НА СЕЙСМОСТОЙКОСТЬ ВЫСОТНЫХ МОНОЛИТНЫХ ЗДАНИЙ В АЛМАТЫ

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Аннотация. *Рассматриваются вопросы строительства в городе Алматы высотных монолитных зданий. Высотное строительство получило значительное развитие на территории мегаполиса - построено свыше нескольких десятков зданий высотой более 20 этажей. Актуальными являются экспериментальные исследования собственных динамических характеристик высотных зданий (периоды и формы собственных колебаний, декремент колебаний) и проверка корректности расчетных предпосылок, принятых при их проектировании. Анализируется влияния высоты на собственные динамические характеристики высотных монолитных зданий, построенных в г. Алматы. Приводятся данные по определению динамических характеристик 22-этажного монолитного здания методом оттяжки здания с последующим резким сбросом приложенной нагрузки. Результаты сравниваются с данными собственных динамических характеристик четырех высотных зданий (высотой более 20 этажей), полученных в результате вибрационных испытаний: - 25 этажная гостиница «Казахстан»; - 35 этажное здание по улице Аль Фараби (район «Нурлы - Тау»); - 22 этажного здания ЖК «Столичный центр»; -26-ти этажное здание ЖК «Мегатауэрс». Результаты работы могут быть использованы при проектировании высотных монолитных зданий*

Ключевые слова: *высотное монолитное здание, бетон, арматура, натурное испытание, способы испытаний, динамические характеристики здания*

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1 INTRODUCTION

Currently, Almaty tends to sharply increase the height (number of floors) of buildings erected in conditions of high seismicity **(Yerzhanov et al., 2020)**. This trend is due to two main factors: modern urban planning requirements and an acute shortage of free territory in large cities. This trend is inherent in many large cities around the world.

If at the end of the twentieth century, the tallest building located in the 9-point districts of the CIS countries was the 25-story hotel "Kazakhstan", built in Almaty, then starting in 2005, Kazakhstani and foreign construction companies began to erect dozens of 20–35-story high-rise monolithic buildings in Almaty **(Yerzhanov et al., 2020)**.

The design and construction of high-rise buildings in seismic areas is a complex engineering task, the correct solution of which is possible only if there is an appropriate regulatory framework, as well as special logistical and technological support **(Farzaliyev & Guluzadeh, 2022).**

During the certification of 2023-2024, 32 houses with several floors above 18 floors were identified out of 1777 surveyed houses. Among the 322 (approximately 2,100 houses) multi-story residential complexes built over the past 15-20 years, high-rise buildings (over 18 floors) account for about 3%.

The building regulations of the Republic of Kazakhstan, as well as similar norms of other CIS countries, do not contain provisions regulating the rules and construction of high-rise buildings in due volume.

Therefore, there is a significant amount of experimental research devoted to the study of the dynamic characteristics of high-rise buildings, and comparing their results with computational studies. Numerous experimental data and classification of high-rise buildings in regulatory documents of various countries **(Farzaliyev, 2018)**.

Numerous studies **(Farzaliyev & Pahomov, 2022)** have noted the effects of building configuration on seismic resistance (plan dimensions, height, flexibility, symmetry, etc.) **(Gaidzhurov & Volodin, 2023).**

At first glance, an increase in building height may seem equivalent to a rise in the span of a cantilever beam. But this is not the case. With an increase in a building's height, the value of its period of natural vibrations usually increases, and a change in the period of vibrations means a change (in the upper or lower level) in the building's responses and the magnitude of the corresponding efforts **(Ereiz et al., 2021)**.

It is unlikely that an earthquake can cause intense ground movements with high acceleration and a period of basic vibrations equal to 2 seconds; usually, for observed earthquakes, this value was no more than 0.5 seconds. Under high-intensity seismic effects, high-frequency ground vibrations are predicted for the city of Almaty.

Therefore, a building with a height of more than 20 floors with a main oscillation period of more than 1 s will experience less mass acceleration than a building with a height of 5-10 floors with a period of 0.5 s.

The period of natural oscillations **(Furtado et al., 2023)** of buildings is a function not only of height but also of flexibility, floor height, type of structural system, building material used, and mass distribution. Therefore, a change in the size of a building can simultaneously cause a change in the periods of its oscillations, which accordingly contributes to an increase or decrease in the magnitude of seismic loads.

2 LITERATURE REVIEW

Earthquake resistance of buildings is one of the key tasks of modern construction, especially in earthquake-prone regions. High-rise monolithic buildings, as a rule, have characteristics that affect their resistance to earthquakes. This review examines the main aspects of the influence of several stories on the seismic resistance of such structures **(Gioffrè et al., 2022)**.

The seismic resistance of buildings is determined by the ability of the structure to withstand dynamic loads arising from earthquakes. The main factors affecting earthquake resistance include:

Geometric characteristics (height, shape);

Materials and their properties;

Structural elements (frame, stiffness systems);

Basic calculation and design methods.

The aim was to determine the main dynamic characteristics of a high-rise monolithic building in Almaty of a frame-wall structural system and verify the correctness of the design assumptions adopted during its design, and the reliability of the results obtained during computational studies. However, numerous studies show that often the experimental oscillation period does not coincide with the calculated value of the specified parameter **(Pascua et al., 2023)**.

Therefore, the purpose of the work is to:

- by pulling off the building and relieving the load, determine the value of the oscillation period along two orthogonal axes oriented in longitudinal and transverse directions;
- to determine the characteristics of energy dissipation during free vibrations of the building. This is the logarithmic decrement of the oscillation;
- to compare the results of determining the dynamic characteristics of the building by calculation with their experimental values;
- analysis of the effect of height on the intrinsic dynamic characteristics of high-rise monolithic buildings constructed and subjected to vibration tests in Almaty.

3 MATERIALS AND METHODS

The dynamic characteristics of a 22-storey building are investigated. The building was erected on a site with a seismicity of 9 points. The category of soils according to seismic properties is I. The conditions complicating the seismological or engineering-geological conditions of the construction site have not been identified. The building is designed with 3 underground floors, one basement, 21 above-ground residential floors, and an upper technical floor.

The basic design spatial planning and structural solutions of the test object are shown in Figure 1-2. The building has a Y-shaped shape in plan and is separated from adjacent objects by antiseismic seams. The design height of the building from the top of the foundation plate to the top of the monolithic coating is about 85.700 m.

Figure 1 - General view of the building (author's materials)

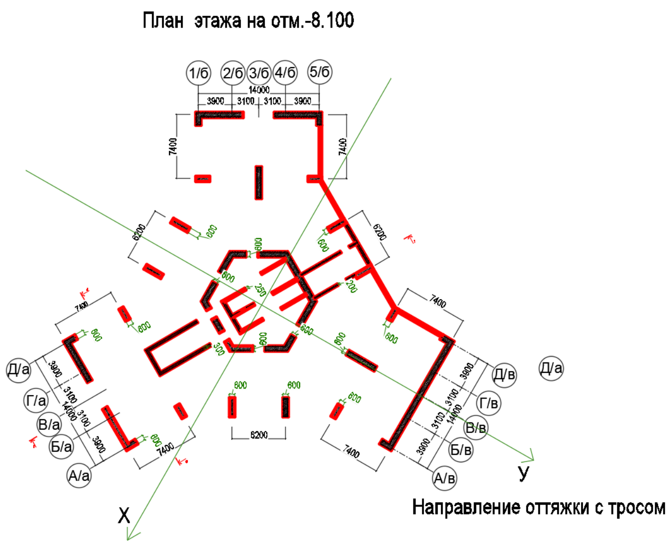

Figure 2 - Object plan (author's materials)

Structurally, the object under study **(Polimeno et al., 2018)** is a spatial frame-wall system. The cellar, basement, and 21 above-ground floors of the building are made of reinforced concrete structures, and the technical floor is made of steel structures. The thickness of the main reinforced concrete walls of the building in question is assumed to be variable in height – from 600...500mm in the levels of the lower floors to 400mm in the levels of the upper floors. In case of horizontal impacts, the joint work of reinforced concrete walls is ensured by horizontal floor discs. The floors of the building are made of monolithic reinforced concrete and have a thickness of 200 mm. The foundation plate has a thickness of 2000mm. The design strength of the concrete foundation plate is accepted in 25, walls: to m. 11,450m – B45, from m. 11,450 to 31,250 – B40, from m. 31,250 to m. 51.050 – B35, from m. 51.050 to m. 70,850 – B30. The walls of the basement, elevator shafts, and floor slabs are made of concrete B25.

The test was carried out using the method of pulling off the building, followed by a sharp release of the applied load resulting in free vibrations. The length of the cable was approximately 90 meters. The point of application of the load is the floor slab of the 20th floor. The vibrations were recorded by the RSM digital measuring complex, equipped with AT1105 digital accelerometers and SM-3 seismic receivers. Seismic receivers were installed **(Wang et al., 2022)** on the floor slabs on the 9th, 15th, and 17th and on the core of the 19th floor. The accelerometers AT1105 c are phased relative to each other. Figure 3-4 shows digital accelerometers, as well as a photo of a digital instrumentation and measurement system.

The instantaneous discharge was created by the breakage of special inserts made of class A240 reinforcing steel with a diameter of 6 and 8mm with a force of 1.5-2.5 tc. The insert connected a cable fixed at the bottom level of the last floor (covering) of the building to the power plant (car) shown in Figure 5-6.

Figure 3- Photo of digital sensors (author's materials)

Figure 4 - Photo of the digital instrument panel**-** measuring system (author's materials)

Figure 5 - Cable attachment to building structures (author's materials)

Figure 6 - Insertion of a cable connection with a power plant (car) (author's materials)

4 RESULTS AND DISCUSSIONS

The table shows **(Table 1-2)** the dynamic characteristics of the building during the drawback tests.

Table 1
Initial dynamic parameters of high-rise monolithic buildings (author's materials)

№ in order	Name of the objects	Test methods	Experimental periods of free oscillations, s	Estimated periods of free fluctuations, s
			in the longitudinal direction along the Y axis	in the longitudinal direction along the Y axis
1	2	3	4	5
1	in the longitudinal direction along the Y axis, a 22-storey residential building in Almaty	By means of a cable tie	0,9	1,08

Table 2
Initial dynamic parameters of high-rise monolithic buildings (author's materials)

№ in order	Name of the objects	Test methods	Experimental logarithmic decrements of oscillations	Coefficient ξ (in % of critical value)
			in the longitudinal direction along the Y axis	in the longitudinal direction along the Y axis
1	2	3	4	5
2	22-storey residential building in Almaty	By means of a cable tie	0,114–0,268	1,82-4,27

Theoretical estimates of the oscillation periods of the building were carried out using a computer complex. The periods of natural oscillations in the first form, determined by calculation (T_1= 1.08 s), the differences in the calculated and experimental oscillation periods are due to the failure to consider partitions and other non-constructive elements in the work of the building structures.

In general, the calculated and experimental measurement results are not contradictory.

4.1 ENGINEERING ANALYSIS OF THE EFFECT OF HEIGHT ON THE INTRINSIC DYNAMIC CHARACTERISTICS OF HIGH-RISE MONOLITHIC BUILDINGS CONSTRUCTED AND SUBJECTED TO VIBRATION TESTS IN ALMATY

Structural solutions of high-rise monolithic buildings **(Table 3)** represent a complex engineering task that requires taking into account many factors such as seismicity, wind loads, geological conditions, etc. The choice of the optimal design depends on the specific construction conditions and building requirements.

Table 3
The main design solutions of the considered high-rise monolithic buildings constructed and subjected to vibration tests in Almaty (author's materials)

№ in order	The purpose of the object	Floor	The design scheme	The shape in the plan	Foundation, walls and ceilings	Partitions	External wall fences
1	2	3	4	5	6	7	8
1	Office Complex «Nurly-Tau»	22	Frame and wall	Y	Monolithic, reinforced concrete	Thermal blocks	Stained glass windows
2	Office Complex «Nurly-Tau»	35	Frame and wall	Y	Monolithic, reinforced concrete	Thermal blocks	Stained glass windows

3	Residential complex « Stolichny Tsentr »	22	Frame and wall	Y	Monolithic, reinforced concrete	Thermal blocks	Stained glass windows
4	Residential complex «Mega Towers»	26	The wall	Rectangu lar	Monolithic, reinforced concrete	Thermal blocks	Stained glass windows
5	Hotel «Kazakhstan»	25	Barrel-diaphragm	Ellipsoid	Monolithic, reinforced concrete	-	Stained glass windows

An assessment of the dynamic characteristics of high-rise monolithic buildings **(Table 4)** is a prerequisite for ensuring their safety and reliability.

Table 4
Initial dynamic parameters of high-rise monolithic buildings (author's materials)

№ in order	Name of the objects	Test methods	Experimental periods of free oscillations, s	Estimated periods of free fluctuations, s
			in the longitudinal direction along the Y axis	in the longitudinal direction along the Y axis
1	2	3	4	5
1	Office Complex «Nurly-Tau»	The drawback method	0,85-0,95	1,08
2	Office Complex «Nurly-Tau»	Vibration test	1,31/1,48	1,38
3	Residential complex «Stolichny Tsentr»	Vibration test	0,944/1,152	1,510
4	Residential complex «Mega Towers»	Vibration test	1,03/1,18	1,55
5	Hotel «Kazakhstan»	Vibration test	1,05/1,10	1,55

Note – The experimental values of the oscillation periods given in the numerator correspond to the initial stages of the tests and in the denominator to the final stage of the tests.

The dynamic characteristics of high-rise monolithic buildings **(Table 5)** are the most important factor determining their resistance to various types of impacts, such as seismic vibrations, wind, and other dynamic loads.

Table 5
Initial dynamic parameters of high-rise monolithic buildings (author's materials)

№ in order	Name of the objects	Test methods	Experimental logarithmic decrements of oscillations	Coefficient ξ (in % of critical value)
			in the longitudinal direction along the Y axis	in the longitudinal direction along the Y axis
1	2	3	4	5
1	Office Complex «Nurly-Tau»	The drawback method	0,114-0,268	1,82-4,27
2	Office Complex «Nurly-Tau»	Vibration test	0,08	1,27
3	Residential complex « Stolichny Tsentr »	Vibration test	0,09	1,43
4	Residential complex «Mega Towers»	Vibration test	0,11	1.75
5	Hotel «Kazakhstan»	Vibration test	0,10	1.59

The period of natural vibrations of a building depends on: the dimensions in the plan, height, area, and mechanical properties of the walls, the characteristics of the foundation soils, the supporting structure of the structure, and others **(Atabekyan et al., 2022)**. In the practice of designing earthquake-resistant buildings with a rigid structural scheme, empirical formulas are usually used to determine the value of the period T, the first form of natural oscillations:

$$T = \alpha \cdot n$$

where

n - the number of floors;

α - a coefficient depending on the structures of buildings and the type of foundation α = 0.04....0.09.

Research experience has shown that in many cases such a simplified approach without proper analysis **(Nemchinov et al., 2015)** of a specific situation can lead to serious errors, which, however, go into "reserve" **(Khalikova et al., 2021)**. They may underestimate the assessment of the condition of a completely sound building, but not vice versa. Therefore, it is more reliable in modern conditions to analyze and compare the natural oscillation frequencies of real objects and their ideal model **(Khazov, 2022)**. In this regard, experimental studies of facilities built in the city of Almaty with load-bearing walls made of monolithic reinforced concrete with the same types of soil conditions (I-first) and seismicity of the construction site (9 points) make it possible to clarify the empirical dependence of the value of the period T, the first form of natural oscillations on the number of floors of high-rise buildings.

Based on the statistical processing of the data obtained from the tests, the coefficient α in the empirical formula (1) is recommended to be equal to 0.04.

5 CONCLUSIONS

1. The value of the oscillation period of a 22-storey residential building of a frame-wall structural system fluctuates within 0.87 – 0.95 seconds.

2. The value of the logarithmic decrement of oscillations varies between 0.11-0.27 (1.8-4.27% of the critical value).

3. Based on the analysis of experimental tests, the coefficient α – coefficient (formula 1), equal to 0.04 for wall structural systems with types of ground conditions (I-first) and seismicity of the construction site, has been clarified and recommended (9 points) for the conditions of Almaty.

4. The difference between the experimental and calculated values of the oscillation period in the first form is up to 27%. The reason is the lack of consideration of non-structural elements of the building (for example, partitions) and enclosing structures.

5. Testing at home by the method of load relief (drawback) is quite informative. The method allows you to accurately determine the period of its oscillations in the basic form and the initial decrement of the oscillation.

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RESEARCH ARTICLE

THE COMPARISON OF DEFORMATION CALCULATION RESULTS OF STRUCTURES UNDER SEISMIC IMPACT USING MOHR-COULOMB AND HARDENING SOIL SMALL (HSS) SOIL MODELS

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Abstract. *This study examines the behavior of buildings under seismic impacts considering different soil models. Nowadays, along with the use of numerical methods in the analysis and design of engineering projects, it is known that this method is widely used in the analysis of problems related to geotechnical engineering construction. Comparative data on displacements, moments, and forces have been obtained for the Mohr-Coulomb soil model and the Hardening Soil Small (HSS) model. The software Plaxis 2D is used for the analysis of both models. The application of such complexes requires special attention to soil foundation models and parameter assignment. The selection of appropriate parameters and soil models can significantly influence the results of numerical analysis. The Mohr Coulomb elastic-plastic model is one of the most widely used models adopted in cases of hardness estimation of materials independent of surface tension. However, it was found that, the stress stiffness in the behaviour model and the difference in stiffness between initial loading and unloading/re-loading are important modelling aspects when discussing seismic effects and play an important role in predicting ground motions. A comprehensive comparison of the results for the Mohr-Coulomb and Hardening Soil models reveals several important differences, which are presented in this article.*

Keywords: *Plaxis 2D, Hardening Soil Small, Mora-Coulomb, hardening, soil model.*

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ҒЫЛЫМИ МАҚАЛА

МОР-КУЛОН ТОПЫРАҒЫ МЕН HARDENING SOIL SMALL (HSS) МОДЕЛЬДЕРІ БОЙЫНША СЕЙСМИКАЛЫҚ ӘСЕРЛЕРГЕ КОНСТРУКЦИЯЛАРДЫҢ ДЕФОРМАЦИЯЛАРЫН ЕСЕПТЕУ НӘТИЖЕЛЕРІН САЛЫСТЫРУ

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Аңдатпа. *Бұл зерттеу әртүрлі топырақ үлгісіндегі сейсмикалық әсерлердегі ғимараттардың мінез-құлқын қарастырады. Қазіргі уақытта инженерлік жобаларды талдау және жобалау кезінде сандық әдістерді қолданумен қатар, бұл әдіс инженерлік-геологиялық құрылысқа қатысты тапсырмаларды талдауда кеңінен қолданылатыны белгілі. Мора-Кулон топырақ моделі үшін қозғалыстар, моменттер, күш-жігер және топырақты қатайтатын Hardening soil small моделі бойынша салыстырмалы деректер алынды. Осы модельдердің екеуін де талдау үшін plaxis 2D бағдарламалық жасақтамасы қолданылады. Мұндай кешендерді қолдану топырақ негізінің модельдеріне және параметрлердің мақсатына ерекше назар аударуды қажет етеді. Тиісті параметрлер мен топырақ моделін таңдау сандық талдау нәтижелеріне айтарлықтай әсер етуі мүмкін. Кулонның серпімді-пластикалық Мора моделі-беттік керілуге қарамастан материалдардың қаттылығын бағалау жағдайында қабылданған ең көп қолданылатын модельдердің бірі. Дегенмен, мінез-құлық үлгісіндегі кернеу қаттылығы және бастапқы жүктеме мен түсіру/қайта жүктеу арасындағы қаттылық айырмашылығы сейсмикалық әсерлерді талқылау кезінде модельдеудің маңызды аспектілері болып табылатыны және топырақтың ауытқуын болжауда маңызды рөл атқаратыны анықталды. Мора-Кулон жағдайлары мен топырақтың қатаюы үшін нәтижелерді толық салыстыру осы мақалада келтірілген кейбір маңызды айырмашылықтарды береді.*

Түйін сөздер: *Plaxis 2D, Hardening Soil Small, Мора-Кулон, қатайту, топырақ моделі*.

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НАУЧНАЯ СТАТЬЯ

СРАВНЕНИЯ РЕЗУЛЬТАТОВ РАСЧЕТА ДЕФОРМАЦИЙ КОНСТРУКЦИЙ НА СЕЙСМИЧЕСКОЕ ВОЗДЕЙСТВИЯ ПО МОДЕЛЯМ ГРУНТА МОРА-КУЛОНА И HARDENING SOIL SMALL (HSS)

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Аннотация. *В этом исследования рассматривается поведение зданий при сейсмических воздействиях при разной модели грунта. В настоящее время, наряду с использованием численных методов при анализе и проектировании инженерных проектов, известно, что этот метод широко применяется при анализе задач, связанных с инженерно-геологическим строительством. Получены сравнительные данные по перемещениям, моментам, усилиям для модели грунта Мора-Кулона и модель твердеющий грунта Hardening soil small. Для анализа обеих этих моделей используется программное обеспечение Plaxis 2D. Применение таких комплексов требует особого внимания к моделям грунтового основания и назначения параметров. Выбор соответствующих параметров и модели грунта может оказать существенное влияние на результаты численного анализа. Упруго-пластическая модель Мора Кулона - одна из наиболее широко используемых моделей, принимаемых в случаях оценки твердости материалов независимо от поверхностного натяжения. Однако было обнаружено что, жесткость по напряжению в модели поведения и разница в жесткости между начальной нагрузкой и разгрузкой/повторной нагрузкой являются важными аспектами моделирования при обсуждении сейсмических воздействий и играют важную роль в прогнозировании колебаний грунта. Полное сравнение результатов для случаев Мора-Кулона и упрочнения почвы дает некоторые важные различия, которые представлены в этой статье.*

Ключевые слова: *Plaxis 2D, Hardenig Soil Small, Мора-Кулона, упрочнения, модель грунта.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Жұмыс Қазақстан Республикасы Ғылым және жоғары білім министрлігінің Ғылым комитетінің қолдауымен "Тұрақты құрылыс саласын интеграцияланған дамыту: инновациялық технологиялар, өндірісті оңтайландыру, ресурстарды тиімді пайдалану және технологиялық парк құру" BR21882292 бағдарламалық нысаналы қаржыландыру шеңберінде орындалды.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ екенін растайды.

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КОНФЛИКТ ИНТЕРЕСОВ

Авторы подтверждают, что конфликта интересов нет.

1 INTRODUCTION

One of the most successful examples is the ideal elastoplastic Mohr-Coulomb model. Based on typical results from indoor soil tests, this model describes the stress-strain conditions across the entire range of load variations up to the limit values. However, many years have passed since the development of this model, and today there are models that surpass it in terms of the realistic representation of soil behavior (**Sokolova, 2021**).

The Hardening Soil (HS) and Hardening Soil Small (HSS) models have recently gained popularity among designers. This is primarily due to the active urban development, which demands precise and cost-effective calculations for excavations and assessments of impacts on neighboring buildings, for which the HSS model is essential (**Schanz et al., 1999, Benz et al., 2009**).

2 LITERATURE REVIEW

A nonlinearly deformable spherical elastoplastic model, reinforced with volumetric compression and shear, accounts for the natural stress state of the soil. It distinguishes between primary and secondary loads. This model is recommended for drilling and similar tasks where shear deformation dominates. It can be used for modeling weak soils (but only if the model's behavior and laboratory curves can be verified), viscous soils, and sandy soils. It optimally describes loading and unloading tasks (**Alekseev et al., 2019**). This model represents an evolution of the hardening soil model, which accounts for low-stress areas. Unlike the hardening soil model, it better captures the consequences of deformation and more accurately determines compressible layers and zones that affect nearby buildings. Recently, the HSS (hardening soil) model or the hardened soil model has been widely used in soil environment calculations. These models are typically divided into specific groups characterized by independent laws of soil behavior under different deformation modes. The Hardening Soil model corresponds more closely to the actual behavior of soil as it uses a hyperbolic relationship between strain and deviatoric stress. The main advantage of using the hardening soil model is that it allows for the consideration of plastic deformation under different loading paths. However, it also has some drawbacks. Firstly, the complexity of applying the model to real-world practical tasks, and secondly, the excessive strain on the model due to mathematical dependencies (**Vakili et al., 2013**).

3 MATERIALS AND METHODS

In this article, we describe a comparison between parameter selection and calculation results for a soil model, conducted using the Plaxis 2D software package. The task was set in a two-dimensional configuration. Engineering-geological data were taken from specific sections typical of Almaty. In this study, a soil mass of 10×10 meters was modeled, and characteristics were sequentially assigned to each engineering-geological element (EGE) selected from a typical geological profile of Almaty. Special attention was given to silty and clayey soils with low strength and stiffness properties **(Figure 1)**.

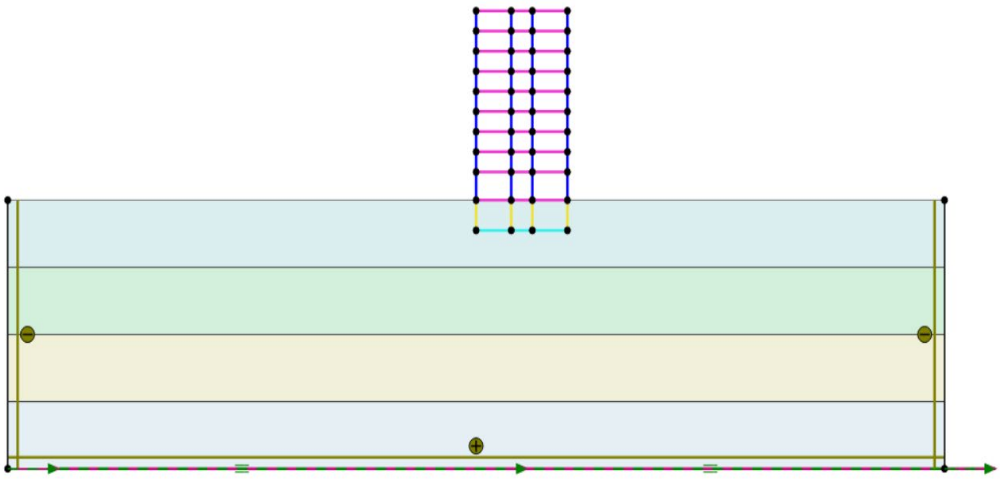


Figure 1 – Calculation scheme (author's material).

Table 1
Basic soil characteristics and additional parameters for the Mora-Coulomb and HSS models

Name of soil	Main characteristics of soils	Additional parameters for the HSS model
IGE-1. dusty grey sandy loam with plant remains, with interlayers of sand, flowing	γ=18.8 kN/m^3, ν=0.35, c=7 кПа, ϕ= 21, E=5400 kPa.	E_{50}^{ref}=5400 kPa, E_{oed}^{ref}=5400 kPa, E_{ur}^{ref}=16200 kPa, Ko=0.642, G=74644 kPa, $\gamma_{0.7}$=0.34*10^{-3}
IGE-2. dusty grey grey loams, vaguely layered with plant remains, flowing	γ=18.9 kN/m^3, ν=0.35, c=4 kPa, ϕ= 17, E=5000 kPa.	E_{50}^{ref}=5000 kPa, E_{oed}^{ref}=5000 kPa, E_{ur}^{ref}=15000 kPa, Ko=0.708, G=75203 kPa, $\gamma_{0.7}$=0.376*10^{-3}
IGE-3. dusty grey sandy loam with gravel, pebbles, with interlayers of loam, plastic	γ=21.4 kN/m^3, ν=0.35, c=20 kPa, ϕ= 21, E=12000 kPa.	E_{50}^{ref}=12000 kPa, E_{oed}^{ref}=12000 kPa, E_{ur}^{ref}=36000 kPa, Ko=0.642, G=136620 kPa, $\gamma_{0.7}$=0.248*10^{-3}
IGE-4. dusty grey sandy loam with gravel, boulders with loam interlayers hard	γ=21.8 kN/m^3, ν=0.35, c=21 kPa, ϕ= 30, E=16000 kPa.	E_{50}^{ref}=16000 кПа, E_{oed}^{ref}=16000 kPa, E_{ur}^{ref}=48000 kPa, Ko=0.5, G=149326 kPa, $\gamma_{0.7}$=0.258*10^{-3}

The building is located in the city of Almaty. It is a 12-story building with a basement. The basement height is 4.5 meters, and the typical floor height is 3 meters. The building's width is 15.6 meters, and its length is 30 meters. The structural system of the building is a wall-frame system. The thickness of the basement walls is 300 mm, while the walls above the basement are 200 mm thick. The thickness of the foundation slab is 1000 mm, made of concrete class B25. The foundation slab has a preparation layer of 100 mm, made of concrete class B7.5.

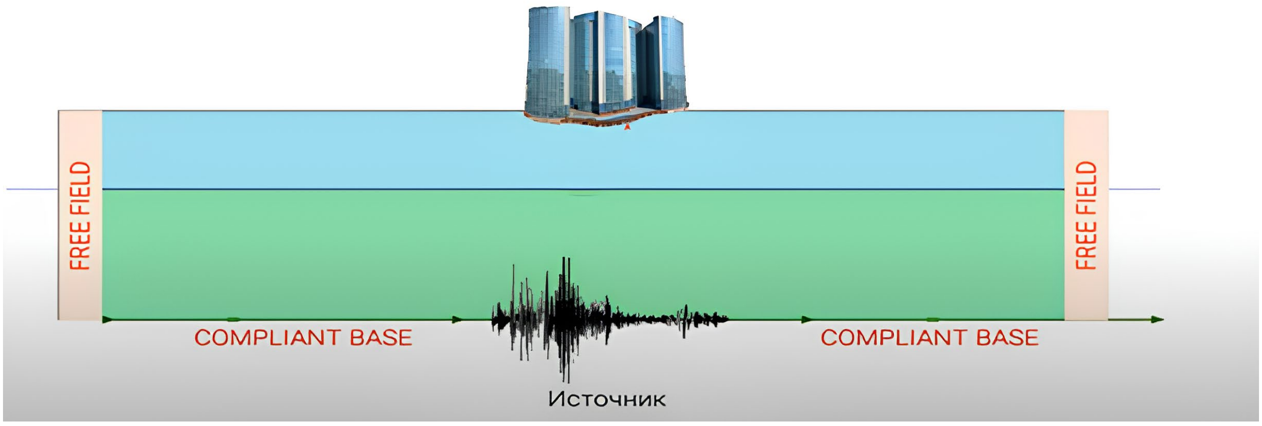
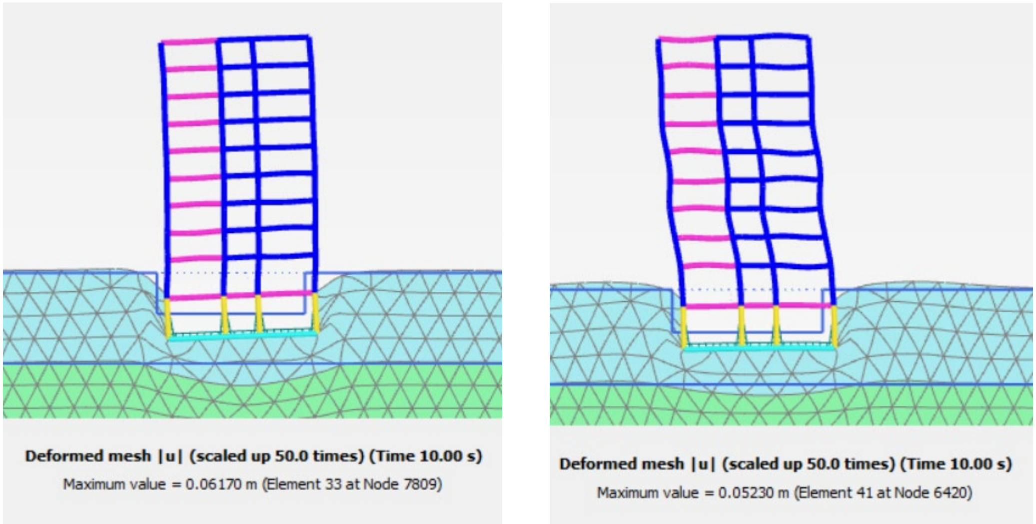


Figure 2 – Boundary conditions in PLAXIS 2D (author's material).

When performing calculations using the finite element method, it is essential to correctly assign boundary conditions. Seismic waves generated within and beyond the computational model can propagate over long distances, so the boundaries of the computational model must accurately reflect the real conditions that need to be simulated (**Brinkgreve et al., 2011**).

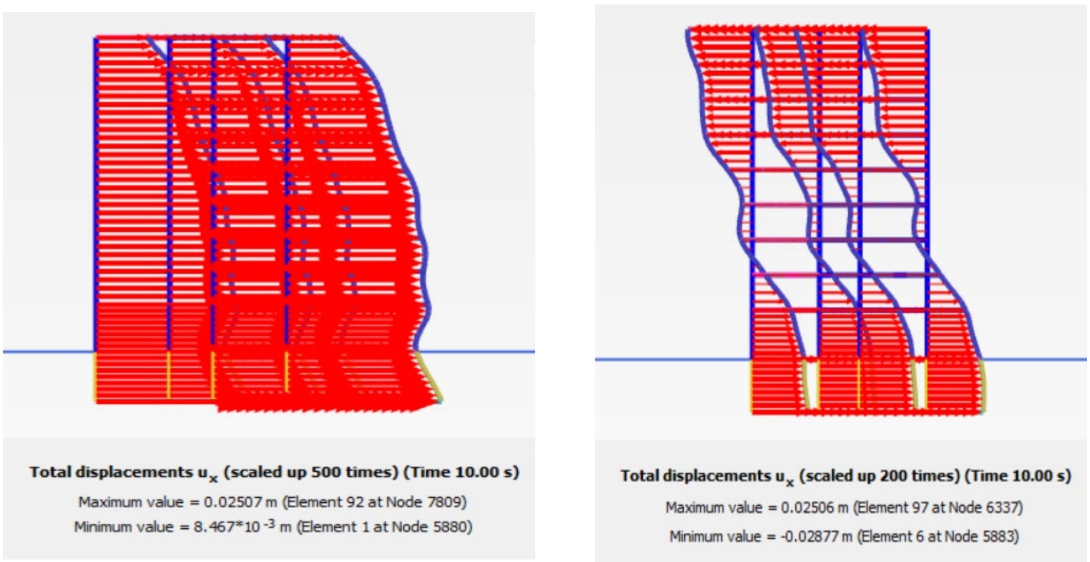
4 RESULTS AND DISCUSSION

To analyze the effectiveness of the software, validation calculations were performed based on real engineering-geological conditions and building projects in the Medeu district of Almaty. Computational models were considered using the Mohr-Coulomb and Hardening Soil Small models. The results of the calculations for normal force and moment are shown in the figure below. It can be observed that the results from the Mohr-Coulomb model almost agree with the analysis results. The linear elastoplastic Mohr-Coulomb model of ideal plasticity contains five input parameters: Young's modulus (E) and Poisson's ratio (ν) for soil elasticity, cohesion (c) for soil plasticity, the friction angle (φ), and the dilation angle (ψ). The Plaxis team recommends initially using this model to analyze existing problems. For each layer, an average constant stiffness is assessed. Due to this constant stiffness, calculations are generally completed relatively quickly, providing an initial estimate of deformations (**Merkulova et al., 2021**). On the other hand, the hardening soil model uses three types of stiffness (E50, Eur, Eoed), which depend on stress. E50 is resistant to the primary load, and its behavior at this level is highly nonlinear. Eur is the stiffness coefficient representing the stress path without load. Eoed is the oedometer modulus under the initial stress conditions. In addition to these stiffness values, cohesion (c), friction angle (φ), dilation angle (ψ), stress level (m), vur, K0nc, pref, and the initial conditions of the soil model are also used to determine the compaction behavior of the soil (**Jesus et al., 2015, Rafal et al., 2018**). It was found that the results of both models differed. Since the hardening soil model has additional parameters, it allows for more accurate and reliable results. In finite element analysis, appropriate stiffness values for the soil are required to provide a reasonable prediction of displacements. We observed that there are many differences between the two models. In the Mohr-Coulomb model, the deformed mesh or maximum displacement is 61.7×10^{-3} meters, as shown in Fig. 3. In the Hardening Soil Small model, the displacement of the deformed mesh is 52.3×10^{-3} meters, as shown in Fig. 4. Thus, we conclude that the mesh deformation or maximum displacement is smaller in the Hardening Soil Small model, which is associated with the stiffer behavior of the HS model (**Arjun et al., 2017**). Similarly, the total displacement of the building is 66.2 mm, as shown in Fig. 5, and 28.7 mm, as shown in Fig. 6, for the Mohr-Coulomb model and the Hardening Soil model, respectively. The negative sign indicates the direction (**Lina et al., 2018**).



(a) (b)

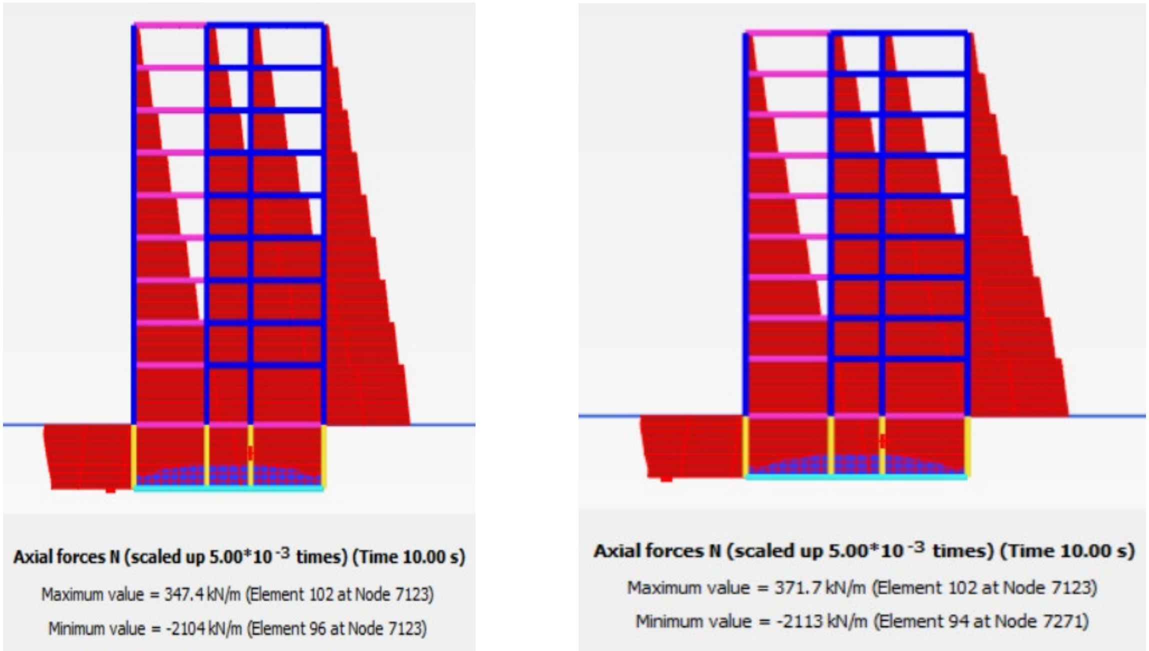
Figure 3 – (a) Deformed scheme by Mohr-Coulomb , (b) Deformed scheme by HSS (author's material).



(a) (b)

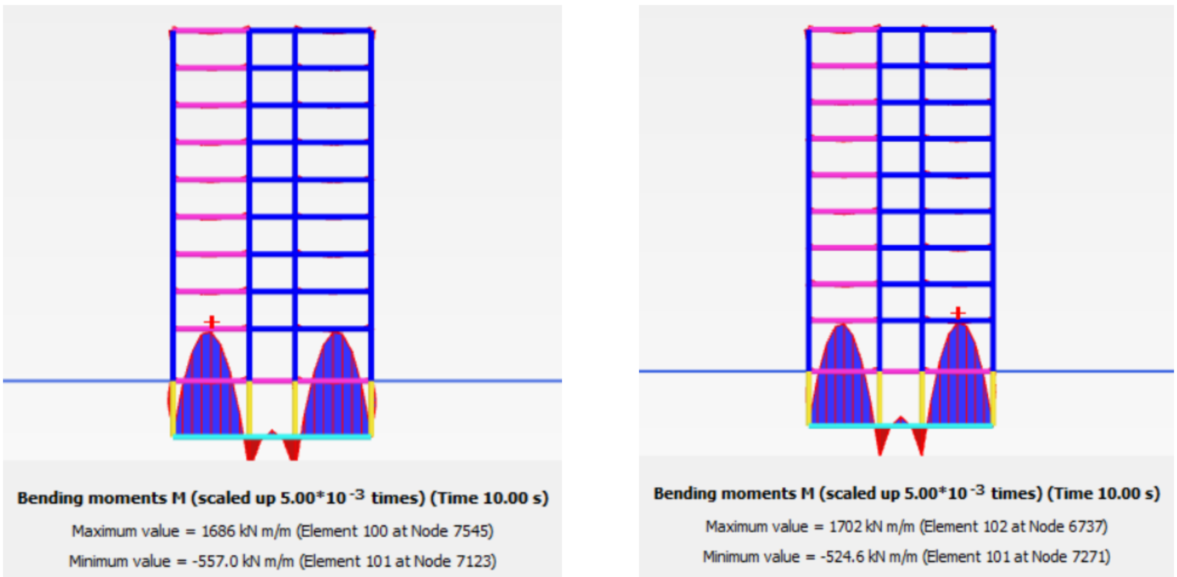
Figure 4 – (a) Mohr-Coulomb displacements, (б) HSS displacements (author's material).

We obtained higher stress values in the HSS model compared to the MC model. Additionally, several other results were found, such as the bending moment, which is 1686.0 kNm/m and 1702.0 kNm/m in the MC and HS models, respectively. The axial forces obtained in the HSS and MC models are -2104.0 kN/m and -2113.0 kN/m, respectively (the negative sign indicates the direction). All these values are shown in the figures, providing a more realistic comparison between both models (**Amjad et al., 2019, Endra et al., 2012**).



(a) (b)

Figure 5 – (a) Mohr-Coulomb axial force N, (b) axial force N by HSS (author's material).



(a) (b)

Figure 6 – (a) Bending moment M by Mohr-Coulomb, (b) Bending moment M by HSS (author's material).

To determine the maximum displacements, a point was selected for each floor. The graph shows a sharp increase observed on the sixth floor. From this, it can be concluded that the difference in maximum displacement is 33 percent (**Charles et al., 2021**).

Table 2
Maximum Floor Movements by Floor Level for Different Soil Models

Floors	Maximum floor movements, mm										
	basement	1	2	3	4	5	6	7	8	9	10
Mora-Coulomb	5,05	6,55	10,5	13,5	17,24	23,43	32,34	40,20	44,67	53,81	58,92
HSS	5,18	5,97	5,36	8,41	11,72	17,64	26,22	29,5	32,92	31,71	39,32

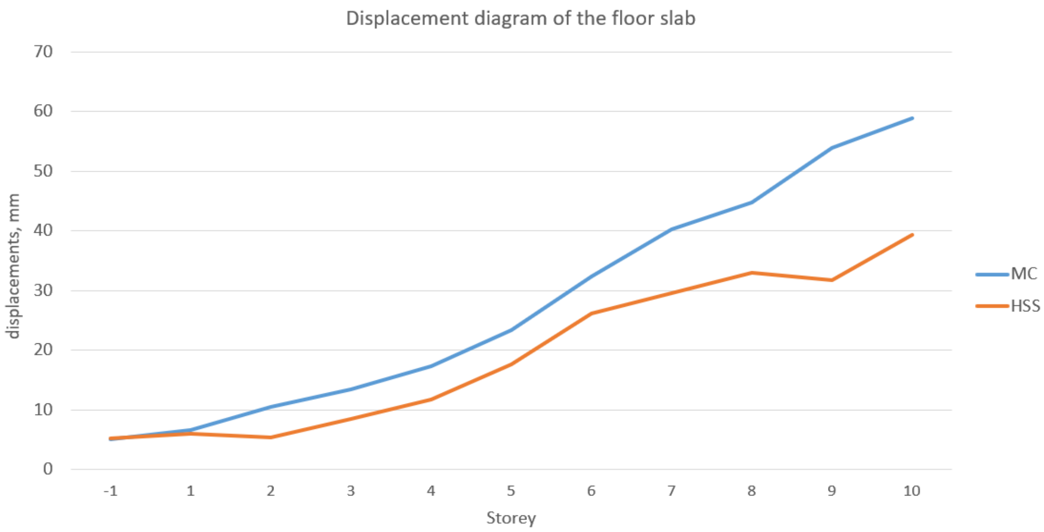


Figure 7 – Displacement diagram of the floor slab (author's material).

5 CONCLUSIONS

Ground movement under seismic impact on buildings is smaller in the HSS model compared to the MC model, which is due to differences in the unloading behavior of both models.

Stress-dependent stiffness in the behavioral model and the difference in stiffness between initial loading and unloading/reloading are critical aspects of modeling when discussing seismic impacts and play a significant role in predicting ground oscillations. Therefore, it is recommended that analysts use advanced models for seismic impact simulations.

Structural forces, such as axial and shear forces in the walls, are higher in the HSS model compared to the MC model. Similarly, stress values are greater in the HSS model than in the MC model, and the factor of safety in the HSS model is also higher than in the MC model. Practical examples have proven that for different types of soil models under seismic conditions, where unloading behavior of the soil is crucial, the Hardening Soil Small (HSS) model provides more realistic and accurate results than the Mohr-Coulomb (MC) model (**Semet, 2023**).

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RESEARCH ARTICLE

FORMATION OF A SET OF INITIAL DATA TO CREATE AN INFORMATION MODEL TO REDUCE THE CONCENTRATION OF RADON IN THE PREMISES

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Abstract. *The article is based on the synthesis of domestic and foreign data, shows the main sources and ways of radon in buildings, formulated the basic principles of their anti-radon protection, classifies methods and means of protection, outlines recommendations for their practical implementation in the design and construction of buildings. Today in Kazakhstan there are several laws aimed at ensuring radiation safety of the population, at the request of which epidemiological services conduct constant monitoring of facilities under construction and existing ones. According to current standards, the concentration of radon in existing buildings should not exceed 200 Bq/m^3, and during design – 100 Bq/m^3. When solving problems of anti-radon protection of buildings, the sources of radon are objects from which radon directly enters the premises, regardless of the nature of its appearance in these objects. It is necessary to understand that measures for anti-radon protection of a building, carried out at the stages of its design and construction, are more effective and require lower costs than measures to reduce radon in an already constructed building. Currently, there are no standardized methods for calculating the necessary parameters and determining the optimal type of radon protection. The procedure for this selection is heuristic and in each case is based on an analysis and qualitative assessment of a number of circumstances.*

Keywords: *radon, protection, safety, ventilation, civil engineering, activity.*

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ҒЫЛЫМИ МАҚАЛА

ҮЙ-ЖАЙЛАРДА РАДОН КОНЦЕНТРАЦИЯСЫН ТӨМЕНДЕТУ БОЙЫНША АҚПАРАТТЫҚ МОДЕЛЬ ҚҰРУ ҮШІН БАСТАПҚЫ ДЕРЕКТЕР КЕШЕНІН ҚАЛЫПТАСТЫРУ

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Аңдатпа. *Мақала отандық және шетелдік деректерді синтездеуге негізделген, радонның ғимараттарға түсуінің негізгі көздері мен жолдары көрсетілген, оларды радонға қарсы қорғаудың негізгі принциптері тұжырымдалған, қорғау әдістері мен құралдары жіктелген, ғимараттарды жобалау және салу кезінде оларды іс жүзінде енгізу бойынша ұсыныстар берілген. Бүгінгі таңда Қазақстанда халықтың радиациялық қауіпсіздігін қамтамасыз етуге бағытталған бірнеше заңдар қолданылады, олардың талабы бойынша эпидемиологиялық қызметтер салынып жатқан және жұмыс істеп тұрған объектілерге тұрақты мониторинг жүргізеді. Қолданыстағы нормалар бойынша жұмыс істеп тұрған ғимараттардағы радон концентрациясы 200 Бк/текше метрден, ал жобалау кезінде - 100 Бк/текше метрден аспауы тиіс. Ғимараттарды радонға қарсы қорғау мәселелерін шешу кезінде радонның көздері оның осы объектілерде пайда болу сипатына қарамастан, радон тікелей үй-жайларға түсетін объектілер болып табылады. Ғиматарры жобалау және салу кезеңдерінде жүргізілетін радонға қарсы қорғаныс шаралары қазірдің өзінде салынған ғимараттағы радонды азайту шараларына қарағанда тиімдірек және аз шығынды қажет ететінін түсіну қажет. Қазіргі уақытта қажетті параметрлерді есептеудің және радонға қарсы қорғаныстың оңтайлы түрін анықтаудың нормаланған әдістері жоқ. Бұл таңдау процедурасы эвристикалық болып табылады және әр жағдайда бірқатар жағдайларды талдауға және сапалы бағалауға негізделген.*

Түйін сөздер: *радон, қорғау, қауіпсіздік, желдету, азаматтық құрылыс, қызмет.*

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МРНТИ 87.24.27
НАУЧНАЯ СТАТЬЯ

ФОРМИРОВАНИЕ КОМПЛЕКСА ИСХОДНЫХ ДАННЫХ ДЛЯ СОЗДАНИЯ ИНФОРМАЦИОННОЙ МОДЕЛИ ПО СНИЖЕНИЮ КОНЦЕНТРАЦИИ РАДОНА В ПОМЕЩЕНИЯХ

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Аннотация. Статья основана на синтезе отечественных и зарубежных данных, показаны основные источники и пути поступления радона в здания, сформулированы основные принципы их противорадоновой защиты, классифицированы методы и средства защиты, изложены рекомендации по их практическому внедрению при проектировании и строительстве зданий. На сегодняшний день в Казахстане действует несколько законов, направленных на обеспечение радиационной безопасности населения, по требованию которых эпидемиологические службы ведут постоянный мониторинг строящихся и существующих объектов. По действующим нормам концентрация радона в действующих зданиях не должна превышать 200 Бк/м^3, а при проектировании - 100 Бк/м^3. При решении задач антирадоновой защиты зданий источниками радона являются объекты, из которых радон непосредственно попадает в помещения независимо от характера его появления в этих объектах. Необходимо понимать, что мероприятия по антирадоновой защите здания, проводимые на этапах его проектирования и строительства, более эффективны и требуют меньших затрат, чем мероприятия по снижению радона в уже построенном здании. В настоящее время не существует нормированных методов расчета необходимых параметров и определения оптимального типа противорадоновой защиты. Процедура этого выбора является эвристической и в каждом случае основана на анализе и качественной оценке ряда обстоятельств.

Ключевые слова: радон, защита, безопасность, вентиляция, гражданское строительство, деятельность.

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ / ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

According to the sanitary rules "Sanitary and epidemiological requirements for ensuring radiation safety", when selecting sites for the construction, residential houses and social and residential buildings are assigned to the areas with a gamma background not exceeding 0.3 μSv/h, and with the density of the radon flux from the surface of the soil is not more than 80 mBq/cm^2. According to p. 320 – in the building design a radon protection system (monolithic concrete pillow, improved insulation of the basement floor, etc.) is provided for the construction of a building on site with a radon flux density of more than 80 MBq/cm^2.

The purpose of anti-radon protection of buildings is to ensure compliance with the requirements of p. 4 subpar. 29 of the sanitary rules "Sanitary and epidemiological requirements for industrial buildings and structures, according to which the average annual equivalent equilibrium volumetric activity of radon isotopes in indoor air should not exceed 100 Bq/m^3.

In order to ensure the environmental safety of construction and increase the efficiency of the use of territories, more and more attention is paid to natural radioactivity. According to numerous studies of domestic and foreign scientists, the main radiation background on the planet is created by natural radiation sources, in particular, radon, which constitutes a significant (up to 60% or more) part of the total radiation dose.

The average world dose of irradiation of people due to all natural radiation sources is about 2.4 mSv/year with a typical dose range of 1.0-13 mSv/year.

The following values of effective doses characterize the relative degree of radiation safety of the population from natural radiation sources: at a dose of less than 2 mSv/year, it is considered that the irradiation does not exceed the average dose values from natural radiation sources; from 2 to 5 mSv/year - the irradiation refers to increased; more than 5 mSv/year – to a high level.

The main contribution to the irradiation of the population by natural sources of radiation is made by the short-lived isotopes progeny in indoor air (60-70%) and external irradiation (20-30%), while the remaining ones account for up to 10% of total doses. In 1988 the Congress of the World Health Organization and the International Agency for Research on Cancer, on the basis of numerous studies, recognized that the intake of radon into the human body is dangerous and can provoke lung cancer. Taking into account the fact that on average the urban resident spends almost 80% of the time indoors, there is a need to pay serious attention to the problem of protecting the health of the population from radon exposure in buildings.

2 LITERATURE REVIEW

With the acquisition of independence, Kazakhstan, using world experience, began to create the necessary regulations to ensure radiation protection.

The regulatory framework of Kazakhstan in the field of anti-radon protection meets the requirements of the International Committee on Radiation Protection **(Tapalova, 2018)**.

Methodological recommendations on radiation hygiene, sanitary rules and sanitary standards allow determining the concentration of radon gamma background of territories and premises provide recommendations on examination and requirements for radiation safety.

In general, there is no information on the distribution of radon radiation in Kazakhstan, and fragmentary studies by specialists in deliberately dangerous areas near developed uranium deposits have shown that citizens live in territories where radon radiation doses are many times higher than permissible, however, measures have not been taken by government agencies, citizens do not know about their rights.

An analysis of scientific sources shows that in many developed countries there is currently quite extensive information on the accumulation of radon, its distribution, diffusion, and emanation in residential and office premises.

Specialists in the field of radiation hygiene draw attention to the effects of radon in the environment as an etiological factor of respiratory diseases, including lung cancer, especially in non-smokers **(Grzywa-Celińska, 2020; Lorenzo-González, 2019; Al, 2018)**.

The concentration of radon in the premises is directly related to its concentration in the soils under houses and used building and decorative materials **(Pacheco-Torgal, 2012; Gandolfo, 2017; Singh, 2016)**.

What are the methods and recommendations for radon protection?

Foreign researchers suggest using various insulating materials to protect against radon. Moisture-proof or waterproof insulation laid over the entire surface of basement floors and walls in contact with the soil can prevent radon from entering buildings from the soil. These types of insulation can be considered as one of the most effective radon reduction systems in new homes **(Hůlka, 2001; Zhuk, 2019; Finne, 2019; Arvela, 2014; Jiránek, 2004; Gaskin, 2021; Rahman, 2009)**.

The methods developed in the UK are mainly based on passive radon barriers, which are inexpensive and easy to install **(Scivyer, 2001)**.

Japanese experts have tested a membrane permeability method for removing radon from the air using a hollow fiber module **(Iida, 2001)**.

In multi-storey buildings, the main source of radon intake is Ra-226 in building materials. At low air exchange rates, radon concentrations may exceed control levels. An increase in uncontrolled infiltration of fresh air while maintaining a normal ventilation regime (the duration of periods of active and passive ventilation) has a certain potential to reduce the concentration of radon in the room. Technically, such a corrective measure can be implemented by installing additional air ducts in enclosing structures, channels in window frames, etc. **(Singh, 2016; Tejado-Ramos, 2024)**.

Thus. It can be concluded that radon protection methods are scattered and insufficiently developed in terms of efficiency and effectiveness in the situation, the relevance of developing such methods increases with the widespread introduction of energy efficiency requirements in building construction. It is necessary to understand that measures for anti-radon protection of a building, carried out at the stages of its design and construction, are more effective and require less costs than measures to reduce radon in an already built building.

3 MATERIALS AND METHODS

When solving tasks of anti-radon protection of buildings, radon sources are objects from which radon directly enters the premises regardless of the nature of its appearance in these objects. The presence of radon in the air of a room may be due to its intake from the following sources:

– soils under the building;
– fencing structures made with the use of building materials from rocks;
– outside air;
– water from the building water supply system;
– fuel burned in the building.

Mechanisms and ways of radon entering the building. The average world values of volumetric activity (concentration) of radon in the outside air at a height of 1 m from the surface of the earth are from 7 to 12 Bq/m^3 (background value). In areas with saturated radon soils, this value can reach 50 Bq/m^3. There are areas where the radon activity in the outdoor air reaches 150 or more Bq/m^3. With the construction of the building site area is isolated from the surrounding space, therefore radon released from the underlying ground under the building can not be freely dispersed in the atmosphere, penetrates the building, and its concentration in the air of the premises becomes higher than in the outside air.

The inflow of soil radon into the premises is conditioned by its convective (along with air) transport through cracks, cracks, cavities and openings in the enclosing structures of the building, as well as diffusion transfer through the enclosing structures.

The main ways of radon entering the building are shown in **Figure 1**.

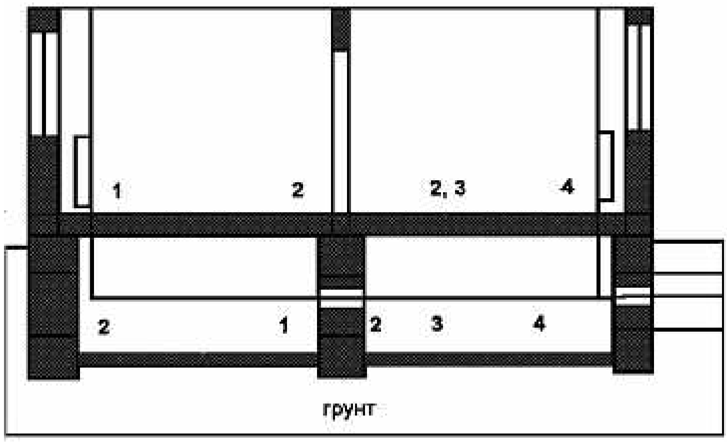

Figure 1 – The main ways of radon entering the building: 1 – isolation from the materials of enclosing structures; 2 – seams and joints between elements of enclosing structures; 3 – cracks and voids in the enclosing structures; 4 – openings for building utilities in the underground part of the building and basement floor (author's material).

It is necessary to understand that the measures for anti-radon protection of the building, carried out at the stages of its design and construction, are more effective and require fewer expenses than measures to reduce radon in the already constructed building.

At present, there are no normalized methods for calculating the required parameters and determining the optimal type of anti-radon protection. The procedure for this choice is heuristic and in each case is based on the analysis and qualitative assessment of a number of circumstances. The effectiveness of a solution of anti-radon protection depends on how in each specific case these circumstances and the types of technical solutions used combine.

The most effective combination of several technical solutions of anti-radon protection in one construction. When choosing technical solutions for anti-radon protection, it is recommended to consider the following factors and circumstances:

The intensity of radon emissions in the construction site. The higher the intensity of radon emissions from the ground at the construction site and the lower the allowable radon content in the building's premises, the higher the effectiveness of anti-radon protection.

Depth of the building. The greater the depth of the building, the higher the probability of increased radon supply through the floor and the basement walls.

Characteristics of the geological section. In the case where the upper layers of the geological section are composed of dense, low gas permeability rocks, their removal during excavation can lead to an increase in radon load on the underground part of the building.

Ground water level. With a high level of groundwater and the need for a drainage system, it, having the properties of a collector of soil gas, can have both a positive and negative impact on the radon situation at the base of the building.

The purpose of the premises of the basement floor and the characteristics of its ventilation system. At the device of poorly ventilated cellars and undergrounds the radon-insulating ability of their floor and overlapping should be raised.

The layout of the openings for input-output of utility communications in the underground enclosing structures of the building. The dispersal and large number of such openings increases the likelihood of radon penetrating them through the building.

Quality of construction works. The radon-insulating ability of the enclosing structures depends critically on the quality of the construction work. The use of poor-quality materials and the violation of their technology can lead to zero effectiveness of anti-radon protection.

Recommendations for design

Ventilation of premises – The possibility of reducing the concentration of radon in indoor air due to their ventilation by external air is limited by the maximum permissible (or economically justified) magnitude of the air exchange rate. Therefore, ventilation should be considered only as an auxiliary tool, complementary to other solutions. The intensification of ventilation leads to an increase in energy consumption for heating the building.

The best is a well-balanced system of supply and exhaust ventilation, providing the hygienic reasons for the air exchange in the rooms and the minimum pressure difference between the basement and upper rooms.

Impregnation – The sealing impregnating compound is a suspension or emulsion on bitumen, latex, polymer, etc. basis. Impregnations are recommended to reduce the radon permeability of finely dispersed materials such as clay and sand in unexploited subterranean buildings with a slight deeper penetration.

Coating – Coatings can be used in the insulation device on the outer or inner surface of the enclosing structure, as well as between its elements.

Membrane – Radon-insulating membranes are used in the construction of foundation slabs, walls and floors of cellars of monolithic reinforced concrete or prefabricated reinforced concrete elements to prevent radon transport through pores, cracks, joints and air cavities in these structures.

When the membrane is installed, it is important to ensure its continuity within the protected area of the structure and the possibility of elastoplastic deformation during the movements of the supporting structure.

4 RESULTS AND DISCUSSIONS

Barrier – The anti-radon barrier is made in the form of a solid, monolithic reinforced concrete slab, which can serve as the foundation of the house, the floor or the ceiling of the basement. The effectiveness of the barrier is greatly enhanced by creating the possibility for a free exit (natural drawing) of radon from the ground beneath the building to the surrounding space. For this purpose, a device is recommended under the barrier of the radon collector in the form of a layer of coarse-grained, freely conductive gas of piling and a pipe serving for the discharge of radon from the piling into the atmosphere **(Figure 2)**.

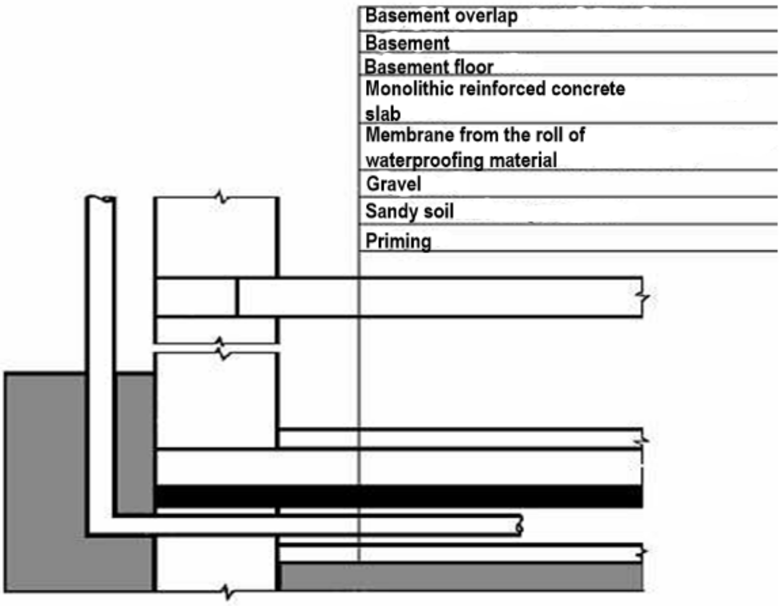

Figure 2 – Radon collector, membrane, barrier (author's material)

Depending on the area of the house, pipes in the gravel layer can be laid along the axes of the protected area or along the foundations.

Depression of the soil base – The greatest effect of anti-radon protection of the building is achieved with a depression (creating a low-pressure zone) of the basement floor basement.

Depression is provided when the radon collector is supplemented with a special system of forced exhaust ventilation, which is completely unrelated to the ventilation of the premises.

When using forced drawing, the effective operation of the protection system is ensured by installing one underground pipe at a rate of 100-120 Bq/m^3 of protected area and using a low-pressure fan with a capacity of 150 to 250 Bq/m^3. Fans should have a sealed enclosure and be located in the vertical part of the pipes as close as possible to the point of release of soil gas into the atmosphere.

It is recommended to mount the fan with removable fasteners and flexible hermetic connection of the housing with the pipe. Installation of fans in the basement and other premises of the building, except for the attic, is not allowed.

The soil is ventilated due to a natural stack effect and wind interaction with the exhaust pipe on the roof of the building. If the activity of radon in the building exceeds the permissible levels, an exhaust fan located in the attic can easily be installed on the existing air duct system in the building. If the results of the study show that in an erected building an elevated level of radon is unlikely, or it will be decided not to install a soil ventilation system, then after installing the pipes to connect the air ducts to the foundation plate, their necks are carefully sealed. In this case, it is desirable that the construction of the building allows, if necessary, quickly and economically to install the entire system of exhaust or discharge ducts.

One of the most effective is the method of removing radon from under the floors of the first floor. Air from under the slabs is diverted by means of special ventilation ducts outside the buildings. At the same time, depending on the construction of the building, various air discharge schemes are used (by placement of ventilation ducts and air ducts). Reducing the concentration of radon in buildings allows the use of radon wells. The radon well is a well dug to a depth of 4 m at a distance of 10-60 m from the house. A powerful fan is installed in the well, which removes radon from the soil outside. Radon wells can reduce the level of radon concentration by 92% within 60 m from the well provided high soil permeability. Reducing the concentration of radon allows the application of the radon-collecting system under the foundation and the sealing of the foundation and overlap.

The principle of the radon-collecting system is as follows. In the space under the foundation with the help of a centrifugal fan, air pressure is reduced compared to the rooms. At the same time radon released from the soil is released into the atmosphere. The commissioning of the radon-collecting system, consisting of five air intakes, allows reducing radon concentrations in the premises of the first floor by 10 or more times.

5 CONCLUSIONS

In the presence of high radon concentrations in soils in order to exclude or limit radon intake from the technical underground, cellar or basement of the building, special anti-radon measures are necessary, including:

– ventilation of basement premises;
– screening of the basement using special materials (impregnation, coating);
– application of radon-insulating membranes and anti-radon barriers;
– organization of radon collectors;
– creation of a zone of low pressure (depression) of the ground basement of the basement floor;
– sealing joints, joints and openings;
– application of radon suppression systems;
– sealing cracks, cracks, communication openings of floor slabs of the first floor with the use of self-adhesive, plastic, elastic, foaming, etc. materials;
– the device of special vapor barrier insulation above the basement, etc.

The above examples clearly demonstrate that the use of these or those measures effectively reduces the radon and thoron content in indoor air. The choice of concrete measures is largely determined by the amount of funding for repair and construction and ventilation.

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