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Innovative Technologies and Prospects for Their Application in the Architecture of Kyrgyzstan

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Abstract

The study aimed to assess modern architectural technologies and their potential application in Kyrgyzstan, considering urbanization, environmental sustainability, and regional characteristics. It provided an overview of 21st-century architectural projects using visual materials, including satellite images, diagrams, and statistical data. International examples such as the Eastgate Centre, The Edge, and Al Bahar Towers were analyzed. Satellite imagery from Google Earth showed a significant increase in residential areas from 2005 to 2020. The study highlighted problems like chaotic urbanization, lack of infrastructure, and low energy efficiency, especially in new districts on the outskirts of Bishkek. These issues exacerbate environmental and social challenges, emphasizing the need for sustainable urban planning. The study recommended using local and recycled materials, such as pressed earth, clay blocks, reclaimed brick, and natural stone, along with energy-efficient technologies like solar panels and rainwater harvesting. Examples of successful projects in Bishkek and Osh, including the Olive Hotel and the American University of Central Asia campus, were presented. The study emphasized a systematic approach to introducing innovative technologies in Kyrgyzstan, combining sustainability, functionality, and energy efficiency. Its practical value lies in aiding architects, urban planners, and government agencies in modernizing the construction sector.

Keywords: *Byzantine, Byzantium, Arts, Early Church, Contemporary Christianity, Architecture, Arts.*

Introduction

In the 21st century, architecture is experiencing rapid development, turning into a complex and multifaceted system that integrates advanced technologies to create sustainable, functional and aesthetically pleasing spaces. Globalisation, accelerated urbanisation and the drive for sustainable development are having a significant impact on the modern architectural appearance of cities, setting new standards for construction. Kyrgyzstan is also actively seeking to introduce innovative technologies, such as energy-efficient construction and renewable energy sources, into architecture, which opens various prospects for the implementation of modern approaches to construction and strategic urban planning.

In Kyrgyzstan, which combines natural landscapes, cultural heritage and challenges related to climate, limited resources and rapid urbanisation, it is necessary to use modern approaches to create a comfortable and sustainable architectural environment. It is necessary to develop effective solutions that incorporate the specifics of the region. The organisation of society, demographic changes, economic and social factors, and people's lifestyles determine the type of buildings, their functionality and the structure of the urban environment.

The construction of new buildings and the modernisation of existing facilities have a direct impact on environmental performance, which is especially relevant in the context of accelerated urbanisation. T. Liu et al. [1] in their study of current achievements and future directions in the field of green building sustainability emphasise that green building is key in promoting sustainable development, minimising the environmental impact of the construction industry and adapting to climate change. H.F. Gholipour et. al [2] highlighted that to achieve the goals of decarbonisation, governments and the private sector around the world are actively implementing energy efficiency standards, developing new regulations and laws

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Kyrgyzstan is facing several challenges in the construction sector in the process of urbanisation and sustainable development, including environmental, social and infrastructural challenges. M. Alymbaev [3] studied the problems of urbanisation in Kyrgyzstan, emphasising the development of new settlements in Bishkek that have emerged since the end of the 1980s and concluded that they arose due to mass unauthorised resettlement from other parts of Kyrgyzstan, which led to subsequent legalisation, characterised by individual construction. C. Ormukov et al. [4], in analysis of the dynamics of land use in Bishkek based on a geographic information system, found that there is a lack of greenery in Bishkek due to dense development and low forest cover, which worsens air quality and increases temperature, especially in peripheral areas, the authors also identified a shortage of parks and public green spaces in Bishkek. G. Momosheva et al. [5] also analysed the lack of parks and public green spaces in Bishkek. E. Baybagyshov and N. Degembaeva [6] concluded in the study of the potential of renewable energy sources in Kyrgyzstan that their use remains limited. The main reasons for this are insufficient financing, lack of infrastructure and low level of implementation of modern technologies.

One of the most necessary areas of innovative technologies in Kyrgyzstan is the introduction of energy-efficient methods that help reduce energy consumption and increase the sustainability of the country's energy system. E. Boronbaev [7] explores ways to improve the energy efficiency of buildings in Kyrgyzstan and reduce their environmental impact, highlighting the use of local materials, which helps to reduce energy consumption and the carbon footprint of buildings. M.W. Akram et. al [8] concluded that the use of energy saving technologies, such as window replacement, improvement of the heating system and the use of automatic control of heating, ventilation and air conditioning systems, and the introduction of vertical greening systems, helps to significantly reduce energy consumption in buildings, which helps to minimise greenhouse gas emissions.

The studies are relevant in the identification of key challenges and opportunities related to the introduction of innovative technologies in the architectural sector of Kyrgyzstan. The study contributed to the research on how international experience and innovative approaches can be adapted to the specific conditions of the region. These papers emphasise that sustainable development of architecture is impossible without a comprehensive approach that includes both technical and socio-economic aspects.

However, despite the significant contribution of these studies, certain gaps remain. Further research is needed to analyse the feasibility of applying innovative technologies such as energy-saving systems, green buildings and digital solutions in the context of specific cities. Bishkek, as the capital and largest urban centre, is noteworthy. A detailed assessment of existing buildings and infrastructure should also be included to determine the level of energy efficiency, sustainability and accessibility.

The study aimed to explore the possibilities of introducing innovative technologies into architecture and construction in Kyrgyzstan, taking into account regional peculiarities, modern environmental challenges and urbanisation processes.

The main objectives of the study were to assess the state of architecture and construction in Kyrgyzstan at the beginning of the 21st century, including an analysis of existing technologies, materials and infrastructure. It was also necessary to study the prospects for the application of specific innovative solutions in different cities of the country, with a focus on large cities. This identified key areas for modernisation and determined the most appropriate technologies for their improvement.

Materials and methods

The study firstly analysed existing facilities that use innovative technologies in architecture. International experience in implementing such technologies, including Zimbabwe, the Netherlands, and the United Arab Emirates (UAE), was emphasised. Zimbabwe is an example of bioclimatic architecture, where passive cooling methods inspired by natural mechanisms are adapted to the hot climate. The Netherlands demonstrates advanced approaches to sustainable architecture through adaptive urban spaces and water settlements, while the UAE develops energy-efficient technologies in extreme climatic conditions. The study employed Internet resources, scientific articles, architectural catalogues and data from manufacturers of facade systems. The visualisation of architectural solutions is presented in the form of diagrams and illustrations demonstrating the process of designing and operating adaptive facades. Parametric design and computer modelling methods were used to optimise the shape of buildings and their energy efficiency. Architectural strategies for adapting façade systems to climatic conditions were also analysed.

The Edge was studied in terms of the integration of intelligent control systems, energy-efficient solutions and building automation [9]. Al Bahar Towers was examined through the prism of adaptive façade systems based on the traditional mashrabiya technique, which reduces the heat load and the need for air conditioning [10].

The efficiency of the façade systems was assessed based on the ability of the façade to regulate sunlight, the impact on energy consumption, improvement of the internal climate, and integration with automated building management systems. Satellite images of Bishkek in 2005 and 2020 demonstrate the rapid growth of the urban area of Bishkek over 15 years. The study used Google Earth satellite imagery and Google Street View images to analyse the expansion of Bishkek's urban area over 15 years. Geospatial analysis was used to determine the extent of urbanisation and the transformation of the urban structure. A visual comparative analysis of the 2005 and 2020 images revealed the growth of residential areas, building densification and a lack of infrastructure [11]. Comparison of the images demonstrated changes that have taken place over 15 years. The socio-economic aspects of urbanisation, including migration and energy consumption, were also considered [12].

The analysis of the satellite image with the designated viewpoint for 33 Gagarin Street and 4 Altyn-Ordo Street improved the accuracy of the determination of the context and features of the area, which provided a broader picture of the neighbourhood layout and the location of the buildings, surrounding buildings and infrastructure. The selection of streets for analysis was based on their location in areas that are new or significantly densified, selective areas on the outskirts of Bishkek in the 21st century. The study also assessed building density, building type, green areas, transport infrastructure and street lighting. Together, the satellite image and panoramas based on Google Earth and Google Street View complement each other and provide a complete picture of the visual environment of the streets that emerged in the early 21st century [11, 13].

An image was also used, which is a fragment of an interactive map created using the Leaflet library, indicating the distances between houses in the area of 23 Arstanbek Duysheev Street, Bishkek, and providing quantitative data on the density of buildings and the location of buildings in this area [14]. This street is located on the outskirts of the Oktyabrsky district and belongs to the new selective territories formed on the periphery of Bishkek in the 21st century. In contrast to the areas where private houses predominate (e.g. Ak-Orgo and Altyn-Ordo), this area demonstrates a different type of housing, namely multi-storey buildings.

Further, the study is based on the analysis of real objects where innovative technologies are used in Kyrgyzstan, although the number of such examples and their coverage in the media space is limited. The data sources are publications and articles on the Internet, social networks and multimedia, such as Facebook [15, 16]. The collected information is used to assess the effectiveness of the technologies used. The effectiveness of the technologies used was assessed by analysing energy savings, environmental sustainability, economic feasibility, comfort and quality of life, as well as the scalability of solutions, incorporating data on energy consumption reduction, carbon footprint reduction, implementation costs and impact on user comfort.

The introduction of educational initiatives is considered, for example, cooperation between the State Agency for Architecture, Construction and Public Housing Utilities, Ikshak Razzakov Kyrgyz State Technical University and other institutions focuses on professional development [17]. The support of international organisations, including the International Development Association and the Swiss government, is considered, which is an example of international cooperation and funding [18].

The study also considered the use of innovative materials and technologies in companies engaged in the production of building materials and structures, in particular, the use of Emmedue technology, including the production of foam concrete blocks with improved thermal and sound insulation properties by Kyrgyzbetonkurulush Limited Liability Company (LLC) [19].

Thus, the study conducted a comprehensive analysis of international experience, as well as an assessment of the effectiveness of innovation, covering its environmental sustainability and economic feasibility, which is supported by the study of real objects, educational initiatives and international cooperation in the architecture of Kyrgyzstan.

Results

International experience in implementing environmental and energy-efficient technologies in modern architecture

Modern architecture is turning to environmentally friendly and sustainable technologies that improve the energy efficiency of buildings and reduce their carbon footprint. The carbon footprint refers to the total amount of greenhouse gas emissions generated at all stages of a building's life cycle, from the production of building materials and their transportation to operation and disposal. Even after the end of a building's service life, its demolition and processing of construction waste also lead to greenhouse gas emissions [20]. Energy-efficient buildings use advanced solutions to reduce energy and water consumption. This includes improved insulation, energy-efficient windows, automatic climate and lighting control, and the use of renewable energy sources through solar panels and geothermal pumps. Such buildings reduce the environmental footprint and reduce operating costs [21].

In addition, the use of recycled and environmentally friendly building materials such as recycled concrete, reused wood and low-carbon materials (wood, compressed earth, recycled bricks and concrete) is a relevant technology. These materials not only reduce waste but also contribute to the fight against climate change, as they reduce carbon dioxide emissions associated with the production of traditional building materials [22]. All of this is part of the green building concept, which implies designing buildings with sustainability and minimising environmental impact in mind [23].

The Eastgate Centre office complex in Harare, Zimbabwe, is an example of innovative technology in architecture. The building features a natural cooling system resembling a termite mound, which significantly reduces the need for air conditioning. Designed by architect Mick Pearce, the building uses ventilation and cooling, resulting in energy savings of up to 90% compared to traditional buildings [24]. A substantial feature is the use of concrete structures as heat stores, absorbing the sun's heat during the day and releasing it to the environment at night, creating a comfortable microclimate. This is similar to the daily temperature fluctuations in a termite farm and is particularly effective in the Harare climate, where temperature fluctuations are large, with temperatures reaching 28°C during the day and dropping to 8°C at night [25]. The design process involved local craftsmen and used readily available materials, which helped reduce construction costs and improve the local economy. Public spaces such as the central courtyard encourage social activity and interaction and support the concept of a sustainable city [26].

The main design concept for The Edge office building in Amsterdam, the Netherlands, is to create an intelligent space focused on user comfort, minimising environmental impact and improving workflows. The building is equipped with a mobile application that can simplify search for free workstations and meeting rooms, adjust lighting and temperature, and monitor energy consumption. The automatic control systems are based on sensors that monitor movement, light levels, temperature and humidity. The data obtained on employee movements, light levels, air temperature, humidity, occupancy of workplaces and meeting rooms, and energy consumption are used to adjust the operation of the building's engineering systems in real time, which reduces energy costs. Architectural solutions are also designed for improving energy efficiency. The atrium, located on the north side, provides natural light to the office space, reducing the need for artificial light. It also serves as a buffer zone between the interior and exterior, helping to maintain a stable temperature inside the building throughout the year (Figure 1).

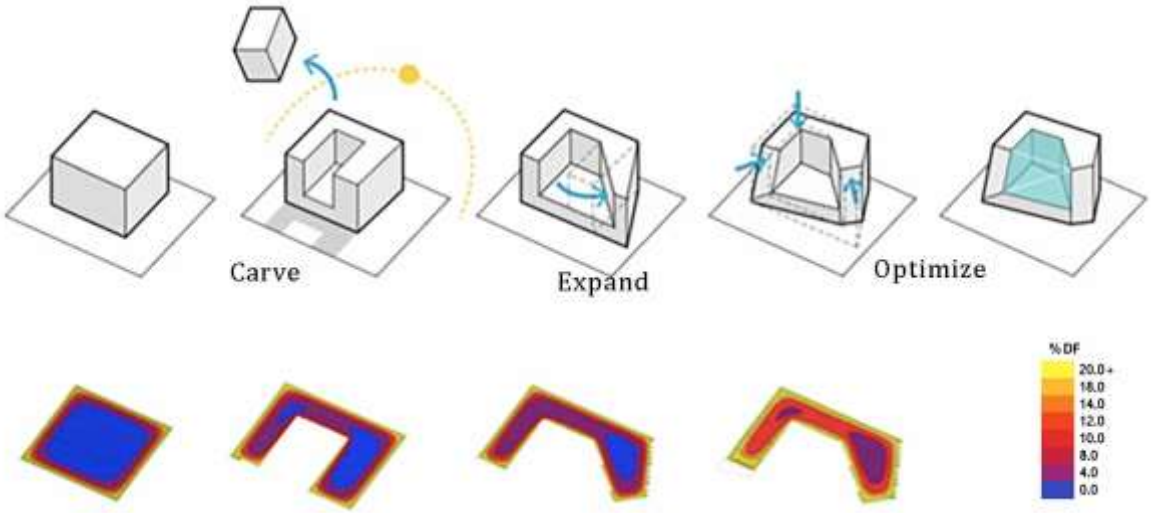

Figure 1. Schematic of the process of optimising the building form with an atrium to improve energy efficiency at The Edge, Amsterdam, the Netherlands

Source: [9].

The building's thermal mass and reduced window openings on the southern facades help reduce heat loss and prevent overheating. The building uses energy-neutral technologies, including solar panels for electricity generation and a rainwater harvesting system. The collected water is used to irrigate plants and flush toilets, which significantly reduces the load on water supply systems.

One of the principles of sustainable architecture is also the adaptability of buildings to climatic conditions, which minimises energy costs for their operation. Depending on the region, different strategies are applied, with special attention paid to solar protection and heat load reduction in hot, arid zones. The Al Bahar Towers in Abu Dhabi, UAE, use kinetic facades that adapt to solar radiation (Figure 2). The interactive facade panels automatically open and close depending on the level of sunlight, which helps reduce the heating of the premises and reduces the need for air conditioning [27].

Figure 2. Adaptive facades of Al Bahar Towers, Abu Dhabi, UAE

Source: [10].

The system is based on the traditional mashrabiya technique, adapted to the modern architectural context. This element not only improves the visual perception of the building, but also significantly reduces energy consumption. The mashrabiya built into the façade functions as a dynamic screen that reduces solar energy input by more than 50% [28]. The façade of Al Bahar Towers consists of many such elements that adjust to the movement of the sun. Depending on its position, these panels automatically open or close, regulating the amount of sunlight entering the building. This helps reduce the need for air conditioning and improves natural light inside the premises (Figure 3).

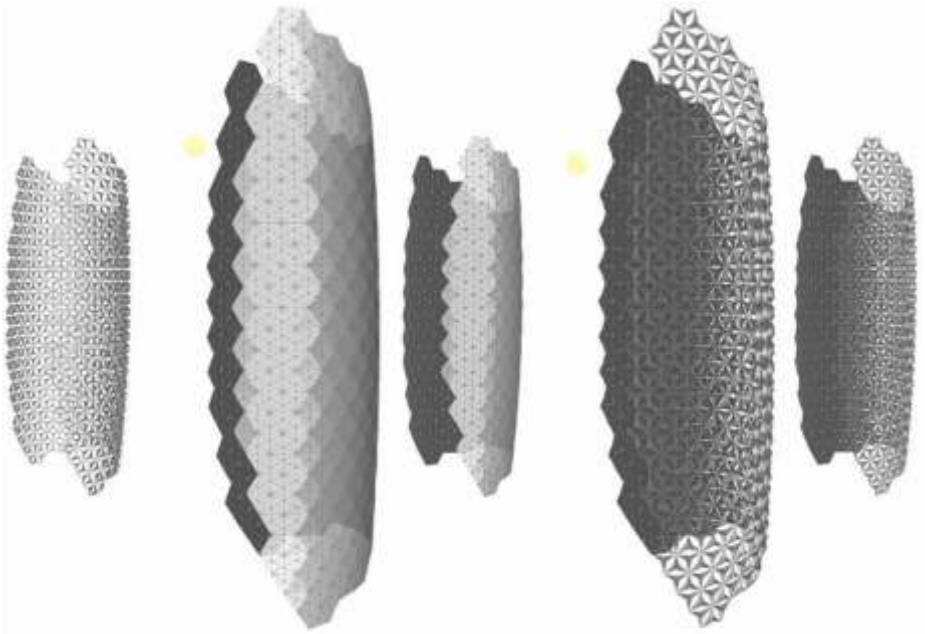

Figure 3. Adaptive façade system to protect the building from excessive solar radiation, Al Bahar Towers, Abu Dhabi, UAE

Source: [10].

The use of an adaptive screen employed naturally tinted glass, which contributes to greater penetration of daylight into the building and reduces the need for artificial lighting. The mashrabiyas are integrated into the façade using a computer system that synchronises their operation with the movement of the sun, providing effective protection against excessive solar radiation [29]. This adaptation of the façade to changing climatic conditions not only improves the energy efficiency of the building but also strengthens its connection with the cultural context of the region.

Challenges and prospects for the application of innovative technologies in the architecture of Kyrgyzstan

The architectural appearance of cities such as Bishkek and Osh was largely shaped by the Soviet school, which was dominated by standardised buildings, monumentality and functionality. In the Soviet era, architectural planning was based on a clear urban structure with residential, industrial and public zones. The use of standardised designs ensured mass housing construction, mainly in the form of multi-apartment panel buildings. Wide avenues, spacious courtyards and the availability of social infrastructure within walking distance were characteristic features of this period.

After the collapse of the Union of Soviet Socialist Republics (USSR), the weakening of state control over land use and zoning led to chaotic and heterogeneous development [30]. Kyrgyzstan, similarly to many post-Soviet countries, is experiencing an intense urbanisation process in the 21st century, with a concentration of population in and around the capital, as well as significant movement from rural to urban areas. This has led to the relocation of entire families from rural areas to more prosperous and developed cities, where there are better living conditions and access to electricity, water and other amenities. A comparison of satellite images of Bishkek in 2005 and 2020 shows a significant expansion of the urban area, especially on the outskirts of the city. The satellite imagery shows how the

area of residential areas and new settlements occupying former agricultural land and undeveloped territories has increased over 15 years (Figure 4).

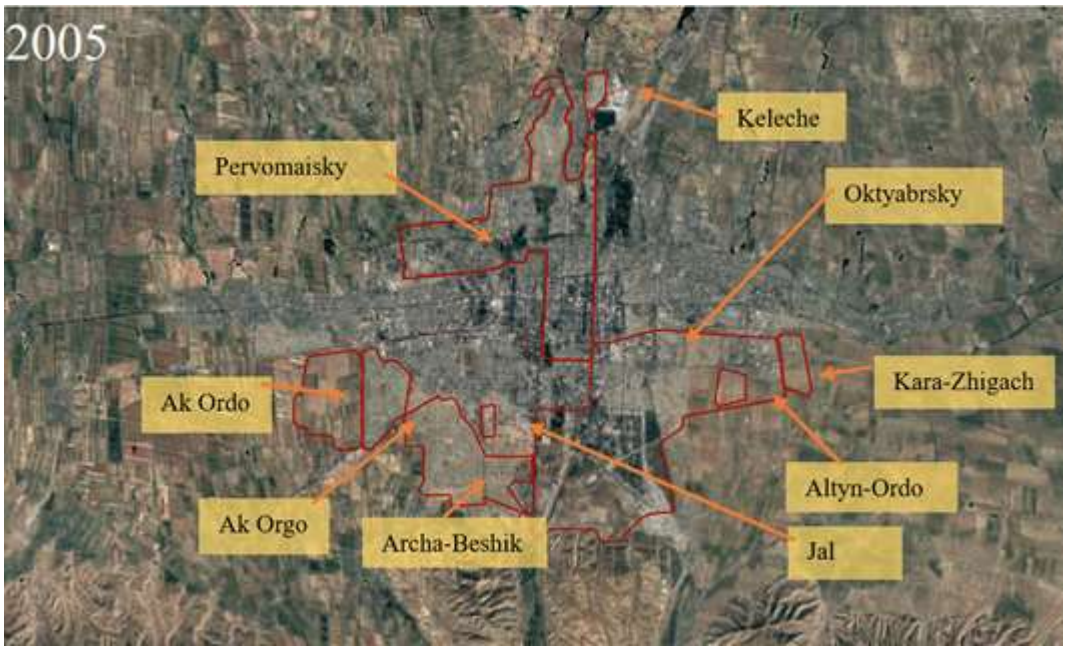

Figure 4. Satellite images of Bishkek in a) 2005 and b) 2020

Note: provides the latest up-to-date information on Google Earth satellite imagery at a scale covering all relevant areas.

Source: compiled by the author based on [11].

Suburban and urban areas, such as Ak-Orgo, Ak-Ordo, Altyn-Ordo, Archa-Beshyk, Djal, Kara-Jygach, Kelechek, and the outskirts of Pervomaisky and Oktyabrsky districts, have significantly expanded and densified. The southern regions of Kyrgyzstan, such as Osh and Jalal-Abad, are characterised by high population density and poverty, which forced residents to move to Bishkek [3].

The 2.4% increase in the percentage of urban population from 2012 to 2023 indicates the ongoing urbanisation process in Kyrgyzstan [12]. With 37% of the population urbanised, Kyrgyzstan has a larger rural population, which mainly lives in mountainous areas and small towns. Most of the population does not have access to modern architectural solutions and infrastructure. In contrast, large cities have access to advanced technologies, experienced professionals and investment resources, which facilitates faster innovation. Developed infrastructure simplifies the implementation of innovative projects, while in less urbanised areas, such resources are often lacking, slowing down the process of introducing new solutions.

Rapid population growth and migration flows, driven by economic, social and geographical factors, have created a high demand for housing, which is often met spontaneously. People build houses on available land plots, often without the involvement of professional architects and regard to urban planning standards. The main problems of new neighbourhoods in the south of Bishkek are the lack of an integrated approach to planning and insufficient attention to environmental aspects. The design of these areas often focuses on mass housing, which leads to a lack of attention to the visual environment and deterioration of the ecological situation. There are no green areas, no trees or shrubs along the road, no lawns or landscaped green areas. There are no sidewalks, and pedestrians have to walk along the roadside. There are no curbs or dividing elements between the road and the adjacent territory. The infrastructure appears underdeveloped, and there are no elements of urban furniture (benches, lighting, bins) (Figure 5).

Figure 5. Visual environment 33 Gagarin Street, Bishkek

Source: compiled by the author based on [13].

The Altyn-Ordo and Ak-Orgo districts are characterised by high-density residential development (Figure 6). The predominant housing type is private residential buildings on small plots. The streets are not wide and intersect at right angles, and the plots have irregular shapes. There are also no well-designed pedestrian areas or small cultural centres that could contribute to the local urban environment. This approach to development is directly linked to the process of uncontrolled urbanisation.

Figure 6. Fragment of the area from the satellite, 33 Gagarin Street, Bishkek

Source: compiled by the author based on [11].

In the southeast of the city, Altyn-Ordo is also characterised by a predominance of private houses, often one or two storeys (Figure 7). The houses are constructed of various materials such as brick, adobe, and cinder block. There are no or poorly maintained sidewalks, a lack of street lighting, and the road surface quality is inconsistent.

Figure 7. Visual environment 4 Altyn-Ordo Street

Source: compiled by the author based on [13].

Almost every house has a small garden plot, or none at all (Figure 8). This limits their use for growing crops, keeping pets or simply for recreation. The streets are mostly perpendicular to each other, forming a rectangular grid.

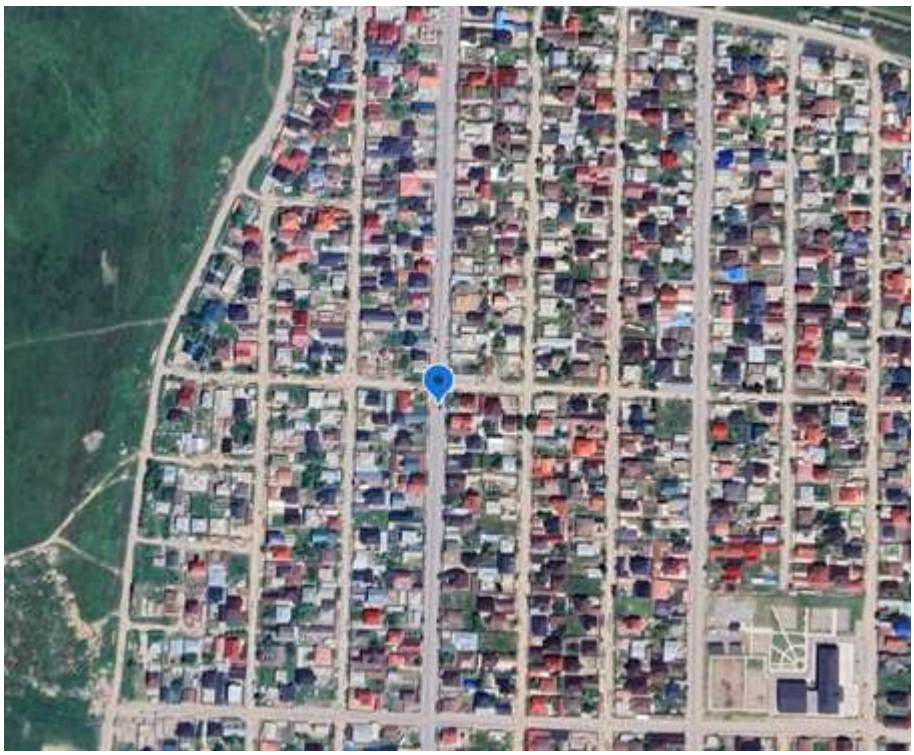

Figure 8. Satellite image of the area, 4 Altyn-Ordo Street, Bishkek

Source: compiled by the author based on [11].

To improve the situation in areas such as Altyn-Ordo and Ak-Ordo, unique tactics need to be developed that incorporate the local context. To improve the situation in existing neighbourhoods, it is necessary to create small community centres that act as points of attraction for residents, improve the visual environment and provide places for recreation and socialisation. Adding functional and

aesthetically pleasing spaces to the neighbourhood will improve the overall appearance of the area. The use of solar panels and rainwater harvesting systems is also an optimal solution; the integration of these technologies can be used for the provision of energy and water to housing, reducing dependence on centralised systems and reducing the load on them.

Sustainable development of residential areas and modernisation of infrastructure in Kyrgyzstan

A sharp increase in the urban population and internal migration from rural areas has led to an increase in demand for housing, which in turn has put additional strain on the country's energy system. For instance, in 2023, electricity consumption in the construction industry in Kyrgyzstan increased by 10.4% compared to 2022 [31].

According to Nurzat Abdyrasulova, President of Unison Group, about 40% of all emissions in the country are due to inefficient use of energy in construction, with about 60% of energy lost during the operation of buildings. The Unison Group is a professional, expert, and analytical organisation founded in 2002, specialising in providing sustainable solutions in the areas of energy management, renewable energy supply, energy efficiency, green technologies, green finance, climate change mitigation, water resources and environmental protection [32]. However, the introduction of energy-efficient technologies and the modernisation of the sector can significantly reduce emissions. According to forecasts, these measures will reduce Kyrgyzstan's contribution to CO_2 emissions by about 40% by 2030 [33].

Issues arising from the outdated residential and public housing stock built during the Soviet period significantly affect the national energy system. Around 70% of heat losses and low energy efficiency are attributed to insufficient insulation of facades, roofs and windows, as well as the use of old heating systems. As a result, energy consumption per square metre in Kyrgyzstan is 3-5 times higher than in countries with similar climatic conditions in the European Union [34]. Old and traditional buildings have little or no insulation, which significantly increases the need for heating. This need is often met by burning coal and firewood, which creates environmental and social problems. The burning of coal and wood for heating in old and traditional buildings without thermal insulation leads to air pollution, an increase in greenhouse gases, deforestation for fuel, and the accumulation of toxic ash. The low efficiency of these energy sources, especially in the case of old stoves, causes air pollution both indoors and in the environment, which significantly worsens living conditions in rural areas [35].

According to the technical assistance programme for Kyrgyzstan [36], materials that combine low carbon footprint, high energy efficiency and suitability for the climate and economic conditions of the region should be selected. For example, compressed earth, which effectively retains heat and reduces the carbon footprint due to minimal transport. Clay blocks with straw provide excellent thermal insulation and ease of production. Straw bales used for wall insulation are environmentally friendly and economical. Local stone, which is resistant to climatic conditions, is ideal for foundations and finishing, providing durability and strength. Wood from renewable sources is ideal for frame structures and decorative elements.

In addition, recycled materials are substantial in construction. Reclaimed bricks, obtained from old buildings after cleaning and sorting, can be reused in construction for facades and load-bearing structures, and crushed concrete can be used as aggregate for new buildings. Recycled steel produced by melting down old metal products, such as scraps or decommissioned structures, to reuse them in construction is used in frames and roofs, and ground blast furnace slag is used to replace natural aggregates in concrete. Energy-efficient insulation materials include mineral wool, which is suitable for walls, roofs and floors, and foam glass, which combines lightness, environmental friendliness and durability.

For instance, the use of local stone for foundations and building cladding not only reduces transport costs but also increases the durability of structures. This is especially relevant in the context of seismic activity in the region, where the reliability and stability of building structures are central. Wood from renewable sources used for frames, floors and decorative elements can be used for the construction of buildings with a reduced carbon footprint and more expressive aesthetics [37]. Recycled materials, such as crushed concrete and reclaimed bricks, are suitable for street improvements, paving and low-rise construction. Their use contributes to the development of sustainable construction, especially in the context of resource scarcity and rapid growth in the suburbs of Bishkek and rural areas of Kyrgyzstan.

The construction of Park Avenue, English Quarter, German Quarter and adjacent buildings in Oktyabrsky District began in 2017 in the southern part of the city and is an example of a multi-storey

development. The facades of the buildings are designed in a style that interprets the neoclassical style. The architectural solutions include elements typical of the classical tradition, such as strict symmetry of the facades, rustication at the ground floor level, porticoes with columns in the design of entrance groups, as well as decorative elements imitating columns and pilasters. Such techniques are used to create a visual effect of elegance and stability without reproducing specific historical prototypes, but rather an interpretation adapted to modern conditions and needs. This solution emphasises the status of the area, creates an atmosphere of solidity and respectability, as developers position this housing as premium or business class. Nemetsky Kvartal is a residential complex built of brick, which is a substantial factor in optimising the energy efficiency of buildings. Brick, as a building material, has high thermal insulation characteristics, which help to preserve heat in the cold season and protect against overheating in the summer.

Most buildings are designed in a single style, which visually unites the development. The construction of high-rise buildings contributes to the efficient use of urban land, saving land resources and expanding space for residential and commercial facilities. However, despite this, in some places, there is an imbalance in the perception of the urban environment. The main factor behind this is the high density of buildings, with a distance of 15-20 metres between houses (Figure 9).

Figure 9. Fragment of the area, interactive map, 23/1 Arstanbek Duysheev Street, Bishkek

Source: compiled by the author based on [14].

This distance is perceived to be insufficient, as the number of storeys in most buildings exceeds 10, creating a sense of crampedness and visual bulkiness that negatively affects the comfort of the environment for residents (Figure 10). In addition, the limited space available for green spaces and infrastructure for residents further reinforces this impression.

Figure 10. Visual environment 23/1 Arstanbek Duysheev Street

Source: compiled by the author based on [13].

The area has a well-developed infrastructure. Within a radius of 500 metres from the residential complex, there is Heydar Aliyev Park and the Gazprom Kyrgyzstan school, which is one of the examples of the principles of barrier-free and sustainable school construction in Kyrgyzstan. The Heydar Aliyev Park is a central recreational facility that provides residents with access to green areas for recreation and walking. The appearance of the school building has features of neoclassicism and eclecticism, which is manifested in the symmetry of the facade, the use of columns, porticoes, pediments and other decorative elements typical of classical architecture.

Other significant objects are located at a distance of about a kilometre: Victory Park, American University of Central Asia and Nursery School No. 94 [11]. Victory Park performs a central function in terms of cultural and environmental improvement of the area, used as a place for recreation and events. The neighbourhood is surrounded by many catering establishments, shops and other commercial facilities, providing residents with access to the goods and services they need.

The combination of residential and public buildings creates a comfortable environment for living, working and recreation. However, high building density, a lack of green spaces and narrow passageways between buildings highlight the need to revise urban planning solutions. Implementation of the concept of sustainable urban development, with an emphasis on new recreational spaces and environmental improvements, will significantly improve the comfort of living in the area.

Environmental degradation of green areas and integration of sustainable energy technologies into urban and construction development in Kyrgyzstan

The problem of environmental degradation covers all districts of Bishkek. Since 2000, the deterioration of vegetation cover has begun, caused by the development of adjacent territories. From 2015 to 2020, there was a significant reduction in vegetation both within the city limits and in the surrounding areas. Since the collapse of the USSR, the Bishkek administration has maintained green areas only in the central part of the city, while parkland in other areas has changed.

An example of degradation is the Ata-Turk Park, which since 2005 has decreased from 350 hectares to 131 hectares by 2010, and to 121 hectares by 2022. A similar situation is observed with Elm Grove Park, whose area decreased from 253 hectares in 2005 to 150 hectares in 2020 [4]. In 2020, the absence of green areas within walking distance, within a radius of 500 metres, was recorded for 63% of Bishkek residents [38]. These changes illustrate the overall process of degradation of Bishkek's green areas, much of which has been given over to private development.

Green spaces act as natural filters, cleaning the air from pollutants and reducing the effect of the urban heat island, which helps to improve the environmental situation and stabilise the temperature regime in the urban environment [39]. The lack of green spaces worsens the environmental situation, which, over time, has a negative impact on human health. The lack of public spaces, such as parks,

squares and alleys, reduces the level of social interaction among residents, weakening the sense of unity and local identity [40]. Not only is the quantity of public spaces relevant in for the development of mental health, but also their physical and socio-spatial quality [41]. The design and accessibility of these spaces affect inclusiveness and civic engagement, which are crucial for community identity [42]. Central city districts that have better living conditions due to the presence of green spaces become more attractive and expensive, which increases social stratification. Peripheral areas without such spaces become less comfortable to live in. Thus, solving the problems of uncontrolled urbanisation requires a systematic approach are designed for developing a harmonious, environmentally friendly and functional urban environment.

Due to the high level of solar radiation in most regions of Kyrgyzstan, solar energy is a promising solution, especially for remote areas not connected to centralised grids. Solar panels can not only provide electricity, but also be used to heat water, which significantly improves living conditions in areas where heating and hot water are problematic in winter. This technology has great potential for sustainable development and helps to reduce carbon emissions, as evidenced by successful examples of its use in Kyrgyzstan [6].

For instance, the Olive Hotel in Bishkek is an environmentally efficient building. Vacuum solar collectors are used to heat water, providing up to 70% energy savings. Six solar collectors fully cover the hotel's hot water needs (Figure 11). Air-to-air heat pumps collect heat from the outside air and concentrate it to heat the rooms. A single pump consumes only 3.5 kW, but produces 14 kW of heat, which provides heating for the first two floors of the building (300 m²). Environmentally friendly equipment reduces the environmental impact and significantly reduces operating costs [15].

Figure 11. Solar collectors on the roof of the Olive Hotel

Source: [16].

The campus of the American University of Central Asia, built in 2015, is an example of the efficient use of renewable energy sources. The 18,000 m² building is equipped with a geothermal heating and cooling system that significantly reduces energy consumption by only 15% of what is required for similar facilities with traditional heating systems [36]. Geothermal energy provides stability and independence from external factors such as weather and fuel availability, making it environmentally friendly and economical. In addition, the campus has solar collectors that provide additional energy and help to use resources efficiently. To minimise energy consumption, the building has efficient natural light, and windows with UV absorption systems not only protect students' health but also help maintain a comfortable indoor temperature [43].

The Dasmia Fitness Family fitness centre is equipped with solar collectors that cover the entire roof of the building, providing hot water, heating, and heating for the pool and showers (Figure 12).

Figure 12. Solar collectors on the roof of the Dasmia Fitness Family fitness centre

Source: [44].

The Art Hotel in Osh introduces innovative technologies in architecture, including the use of 100 mm thick mineral wool to reduce heat loss and insulate the ceilings. All lighting fixtures have been replaced with energy-efficient LED lamps, and motion sensors have been installed to automatically control lighting and reduce energy consumption. There are plans to install a solar collector for hot water and build a solar power plant to provide lighting [45].

The technologies presented in the Art Hotel in Osh, the Olive Hotel, and the Dasmiya Fitness Family fitness centre are examples of optimising small and medium-sized architectural objects. These solutions have great potential to be replicated in Kyrgyzstan, as their implementation requires fewer resources than large-scale infrastructure projects or large buildings, making them more affordable. There is a trend towards the use of green and energy-efficient technologies to attract visitors and promote the city [46].

The State Agency for Architecture, Construction and Public Housing Utilities and Ikshak Razzakov Kyrgyz State Technical University have signed a memorandum of understanding that marks the beginning of a new phase of cooperation. This partnership aims to develop engineering sciences and technologies and improve the construction industry in Kyrgyzstan. One of the main areas of focus was the professional development of inspectors of the state architectural and construction control. A two-day course on earthquake-resistant construction was organised at the Nasirdin Isanov Kyrgyz Civil Engineering Institute, including training in the latest inspection methods and modern construction technologies, which ensured high-quality training for specialists. Training sessions were also held to provide participants with additional skills in architecture and construction [17].

This initiative demonstrates the strategic importance of combining the efforts of educational and governmental structures to improve the level of competence of specialists and introduce innovative approaches in the architectural and construction sector of Kyrgyzstan.

The Heat Supply Improvement project, which has been running since 2019, aims to improve the energy efficiency and earthquake resistance of public buildings such as schools, kindergartens and hospitals built during the Soviet era. These buildings often face problems of poor insulation, low winter temperatures and insufficient ventilation, which compromise the comfort and safety of users. The project is supported by the Kyrgyz government, the International Development Association and the Swiss government and covers different regions of the country. As part of the project, 21 buildings were selected for energy efficiency improvements. Old windows and doors have been replaced with modern energy-

efficient windows with double or triple glazing, which helps to retain heat and improve insulation. In addition, energy-saving lighting was used in the project, with incandescent lamps replaced with LEDs, which significantly reduces energy consumption. One of the substantial steps was the introduction of energy-efficient heating and ventilation systems, such as heat pumps and ventilation recuperators, which reduce energy costs and provide comfortable indoor conditions.

In addition, heat recovery systems have been introduced as part of the modernisation of buildings to capture heat removed from the premises and use it to heat the cold outside air. This is especially relevant in winter, when heat loss through ventilation significantly increases heating costs [18].

Kyrgyzbetonkurulush is an example of the introduction of modern construction technologies in Kyrgyzstan. The plant, which opened in August 2022, focuses on the production of expanded polystyrene panels for house construction using Emmedue technology. This innovative technique can be used for the construction of high-quality buildings with minimal costs and high energy efficiency. The technology is based on a modular system, where the key element is the panels, which are two galvanised meshes filled with concrete, ensuring their strength and lightness. These panels are used to build walls, floors, roofs and partitions [19].

Emmedue technology has several substantial advantages, including reduced construction costs due to optimised assembly and transport processes, as well as flexibility in design. It provides excellent thermal and noise insulation, earthquake resistance, and reduces the consumption of building materials and construction time. Convenience and speed of installation, together with high energy efficiency, contribute to the creation of durable and cost-effective buildings, which makes a significant contribution to the development of the construction industry in Kyrgyzstan.

These examples of the integration of architectural technologies in Kyrgyzstan demonstrate the desire to introduce innovative and energy-efficient solutions, as well as to improve the quality of construction and modernise old facilities. This helps to create sustainable and cost-effective buildings, improve infrastructure and raise people's living standards. However, some barriers prevent the wider use of innovative technologies in architecture and construction.

It is necessary to address the existing problems, including limited accessibility and infrastructure, environmental and climate challenges and strive for sustainable urbanisation, which will accelerate implementation of innovative solutions in architecture and construction in Kyrgyzstan. The focus of sustainable urbanisation should be on the integration of innovative technologies concerning environmental sustainability, optimisation of resource consumption and minimisation of harmful environmental impact. At the same time, it is necessary to develop the infrastructure that will support such technologies, ensuring their accessibility and effective use in real-world conditions. Sustainable urban development should be the basis for the implementation of environmentally friendly, energy-efficient and technologically advanced solutions that meet modern challenges. Striving for a balanced development of the urban environment will help not only improve the quality of life of the population, but also create the basis for further investment in innovation.

Discussion

During the Soviet period, the development of residential areas in Bishkek prioritised fulfilling ideological and functional objectives, such as mass housing, monumental objects and public spaces, which were supposed to ensure an even distribution of the population and the creation of a socialist space. The city was designed as a single structure with a clear hierarchy reflecting the socialist ideals of collectivity, sustainability and equality.

However, in the 21st century, Kyrgyzstan is witnessing a shift in urban development priorities: the search for innovative building solutions designed to improve the energy efficiency and ergonomics of buildings is becoming more urgent. This is due to the growing demands for energy efficiency, environmental sustainability and improved quality of life in the context of a rapidly growing urban population and climate change. Given the high level of energy dependence and resource scarcity, efficient energy use in buildings is becoming a substantial factor for sustainable development.

M. Sadykov et al [47] emphasised that solar energy has a high potential in Kyrgyzstan, especially in areas with high insolation; however, energy production is limited in winter due to cloudiness and low solar radiation. The study emphasised that the development of hybrid systems combining different energy sources can increase the efficiency of renewable resources.

This correlates with the results of the current study, which demonstrates the potential of solar panels and innovative energy-saving materials to improve the energy efficiency of buildings in Kyrgyzstan. In particular, the introduction of solar panels in combination with energy-efficient building solutions such as thermal insulation, LED lighting and energy management systems will help to significantly reduce energy consumption and minimise the carbon footprint.

The growth of cities through an increase in area and population, without proper infrastructure development and functional balance, leads to a number of problems. Cities such as Bishkek have the resources to implement innovative projects, but it is difficult to spread them to remote areas.

E. Nasritdinov [48] argued that in urbanised countries, there are usually strict building codes and standards are designed for the safety, sustainability and energy efficiency of buildings. These regulations often encourage the use of innovative materials and technologies. In countries with a low level of urbanisation, regulations are less developed, which limits the introduction of innovative solutions.

Rapid population growth and internal migration create a high demand for housing, which is often met by spontaneous construction without the involvement of professionals. In the south of Bishkek, for example, the Altyn-Ordo and Ak-Orgo districts are being developed without a harmonious urban planning approach, resulting in poor visual quality and environmental problems. The low percentage of urbanised population (37%) limits rural residents' access to innovation and modern infrastructure. K. Mehta et al [49] emphasised that it is necessary to develop individual sustainable development strategies for each city, incorporating its unique environmental and economic conditions.

The current study also emphasises that government policy should support these processes by focusing on the development of not only the capital's areas, but also other regions, which will help to balance the pace of urbanisation and create a more even distribution of the population across the country. Regulation of migration processes through the development of infrastructure and jobs in less urbanised areas will not only reduce the burden on Bishkek but also improve the quality of life throughout Kyrgyzstan.

Raising awareness, both among citizens and construction organisations, is helping to strengthen the demand for sustainable projects. This increases interest in implementing existing concepts and stimulates the search for new approaches and technologies. Y. Li et al [50] emphasised that mass promotion and advertising are key in the popularisation and development of green building, helping to raise awareness, change public opinion and create demand for environmentally sustainable solutions.

J. Beringer et al. [51] also emphasise that despite the obvious advantages of such insulation materials as sheep wool, straw bales and reed panels, they are not recognised as official insulation materials in Kyrgyzstan. The study emphasised that this requires active information efforts for explaining their potential, economic and environmental benefits, as well as training residents in their use. O. Iwuanyanwu et al. [52] noted that the use of environmentally friendly materials contributes not only to solving urgent environmental problems, such as reducing carbon dioxide emissions and reducing the amount of construction waste, but also to achieving economic benefits.

Information work also includes the dissemination of green technologies, including through self-promotion, which helps to raise awareness of their benefits and encourage the use of sustainable solutions. For construction companies, the promotion of green buildings is becoming a tool for increasing competitiveness. By promoting projects certified to international standards, companies demonstrate their commitment to sustainable development, which attracts environmentally conscious customers. This tactic is relevant for Kyrgyzstan, for example, the website of the Olive Hotel in Bishkek highlights environmental technologies, confirming the effectiveness of this approach [48]. By attracting customers through an emphasis on sustainability, energy efficiency and aesthetics, companies create a positive image and stimulate interest in environmental initiatives.

To achieve sustainable urban development in Kyrgyzstan, a comprehensive approach that incorporates environmental, economic and social aspects is needed. Adopting policies that incorporate all of these factors will ensure long-term sustainability and improve the quality of life.

A. Tleuken et al. [53] discussed various barriers and opportunities for the introduction of Design for Disassembly (DfD) in the construction sector in Central Asia, i.e. a design approach that aims to create structures and buildings in such a way that they can be easily disassembled and recycled at the end of their life cycle. However, this study insufficiently addressed the local challenges and prospects

for DfD in Kyrgyzstan. In particular, there is no in-depth analysis of the specific local conditions that could affect the adoption of this building technology in Kyrgyzstan.

It is necessary to introduce building technologies in stages, depending on their suitability for current conditions. Start with technologies that can be easily integrated into existing building practices, such as improved insulation, use of local materials and energy-efficient solutions. The transition to more sophisticated technologies should be gradual, incorporating the readiness of infrastructure, technologies and regulations. This approach will ensure sustainability and reduce risks in adapting to new building technologies.

In the 21st century, the construction industry in Kyrgyzstan faces several significant obstacles to the integration of innovative technologies. These obstacles include both economic and social ones, such as a lack of funding, limited access to modern equipment, and low levels of personnel qualifications in the field of new technologies. Nevertheless, since 2010, there has been noticeable progress in the introduction of innovative construction technologies in the more urbanised areas of Kyrgyzstan. Private companies, to improve the quality of construction, have begun to actively introduce new materials and methods, such as energy-saving technologies, solar panels, energy-efficient lighting and modern thermal insulation materials. Government agencies have also begun to support projects designed for improving the sustainability of urban infrastructure, including projects to improve building insulation and use renewable energy sources, as well as the involvement of educational institutions in this area.

The key point is that, given the uneven development of all of Kyrgyzstan's territories, there is significant potential for further introduction of innovative technologies, especially in more urbanised areas. The development and implementation of more affordable and locally adapted technologies contribute to improving the quality of life and sustainable development of the region. The prospects lie in building a system of innovation that incorporates both economic and environmental factors, as well as the specific cultural and social aspects of different regions of the country.

Conclusions

The assessment of global experience of implemented technologies in architecture considered the Eastgate Centre office complex in Zimbabwe, the Edge office building in the Netherlands, and Al Bahar Towers in the UAE, demonstrating an approach where energy-saving solutions are integrated with environmental and social aspects.

Analysis of satellite images of Bishkek for 2005 and 2020 shows a significant expansion of the urban area. Ak-Orgo, Archa-Beshyk, Djal, and Kara-Jygach are actively developing on former agricultural land, while Kelechek has emerged as a result of migration flows to Bishkek from the southern regions of Kyrgyzstan. Infrastructure problems, chaotic land use and a lack of planning make it difficult to create a sustainable urban environment in the new areas.

The visual environment in 4 Altyn-Ordo Street in the south-east of Bishkek and 33 Gagarin Street in the south-west of the city is characterised by monotonous architectural solutions, high building density, and a lack of green spaces, which leads to a deterioration in air quality and an increase in temperature in urban areas.

The creation of small community centres will be an effective tool for improving the quality of life in these areas. The integration of modern technologies, including solar panels and rainwater harvesting systems, can reduce the burden on centralised power and water supply networks. The use of local materials such as pressed earth, clay blocks, straw bales and recycled resources such as crushed concrete and reclaimed bricks, the use of local stone for foundations and wood from renewable sources will increase the energy efficiency and sustainability of the development and reduce the carbon footprint.

In the Arstanbek Duysheev Street area, architectural solutions in new residential complexes, such as the German Quarter and Park Avenue residential complexes, demonstrate a desire for visual harmony through the use of brick and neoclassical decorative elements. However, the distance between buildings is only 15-20 metres, which impairs visual perception, but the area demonstrates a higher level of infrastructure development.

Although the introduction of innovations in construction in Kyrgyzstan is still at a developmental stage, there are successful examples of modern technologies. At the Olive Hotel in Bishkek, solar collectors cover up to 70% of the hot water demand, and air-to-air heat pumps provide heating for an area of 300 m². At the Dasmiya Fitness Family fitness centre, solar collectors provide hot water, heating

and pool heating. The campus of the American University of Central Asia, built in 2015, demonstrates the successful use of geothermal energy. The Art Hotel in Osh has implemented mineral wool insulation technology and LED lighting. The Heat Supply Improvement project, which has been implemented since 2019, has covered 21 social infrastructure facilities, improving their energy efficiency and thermal insulation. Kyrgyzbetonkurulush is actively implementing Emmedue technology in Kyrgyzstan.

Among the factors limiting the study are the limited availability of municipal documentation for different years in the public domain, as well as the lack of foreign research on the use of innovative technologies in Kyrgyzstan.

Further research is needed to assess the effectiveness of innovative technologies and to develop strategies for modernising the existing infrastructure.

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