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Use of modular technologies for the construction of low-rise housing in Kazakhstan

Abstract. The study aimed to develop an architectural model of point modular reconstruction focused on sustainable renovation of residential neighbourhoods, incorporating international standards of environmental and social efficiency, as well as the specifics of dense urban development in the southern regions of Kazakhstan. Based on architectural and planning analysis, urban planning expertise, assessment of regulatory applicability, as well as content analysis and SWOT analysis, the article provides a comprehensive assessment of the potential of modular housing and integration of eco-agro-architectural solutions into the living environment of the southern regions of Kazakhstan. An integrative model was developed for the point transformation of outdated neighbourhoods using modular construction, which can be implemented without resettling residents and with minimal time, financial and social costs. The structure of the model includes superstructure blocks erected on solid buildings to expand the housing stock; plug-in modular sections placed in inter-building spaces to compact and diversify the development; and community cores adapted to

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local needs. The decisions are based on the results of a survey of Almaty's districts and accommodate the region's climatic, demographic and regulatory characteristics. The study addressed the integration of eco-agro-architecture elements such as greenhouse modules, agro-platforms, vertical gardening and courtyard composting stations into the structure of residential development. The calculations and analysis demonstrated that the use of these solutions can reduce the heat load on buildings by up to 25%, increase the greening factor by up to 25%, and reduce the conditional carbon footprint by 18% per quarter. In addition, such elements contribute to the development of self-sufficient micro-communities, activating local urban agriculture and involving residents in shaping the environment. This strengthens social cohesion and expands the functional use of intra-quarter spaces. The presented model complies with the norms of the Republic of Kazakhstan and international guidelines for sustainable development, rethinking the local space as a multi-level ecosystem with recreational, social and agricultural functions

Keywords: frame-modular construction; eco-agro-architecture; energy efficiency; sustainable development; spot reconstruction

INTRODUCTION

The research relevance is determined by the growing need of the Republic of Kazakhstan to transform approaches to housing construction, especially in the context of growing urbanisation, seismic activity in the southern regions, climate variability and a shortage of energy-efficient and affordable housing. The modernisation of the urban environment, especially in megacities such as Almaty, is leading to a growing interest in low-rise prefabricated construction technologies based on the principles of modularity, structural flexibility and industrial production. Of particular importance is the integration of environmentally friendly solutions, including eco-agro-architecture and the reconstruction of local spaces, into the structure of existing neighbourhoods.

Recent studies highlight the growing need to rethink approaches to housing construction in Kazakhstan, especially in the context of accelerated urbanisation, high seismic activity in the southern regions and climate challenges associated with temperature changes and wind loads (Urdabayev *et al.*, 2024). In these conditions, traditional forms of mass housing construction are losing their effectiveness and need to be replaced with more adaptive, faster-erecting and energy-efficient solutions. However, there are significant gaps in the existing scientific and design literature due to insufficient study of the use of modular technologies in the southern climatic zones of Kazakhstan, and the possibility of their integration into the renovation of the old housing stock, including the use of ecological and agro-oriented components of the urban environment, is poorly covered. Thus, A.B. Kurmanalina & Z.U. Dzhubalieva (2025) highlighted significant imbalances between supply and demand in the construction industry, emphasising the need to move to industrialised technologies to increase housing commissioning. N.A. Biryukova & G.B. Pestunova (2022) highlighted the problem of systematically unfinished construction projects, highlighting the need for universal and quickly assembled architectural solutions. G. Karabayev & S. Mamedov (2024) highlighted the visual uniformity of residential areas caused by a standardised approach to architecture and emphasised the need for expressive design solutions that can revitalise the urban environment. D.T. Mukaev *et al.* (2023) emphasised institutional barriers to affordable and quality housing. Despite the importance of these aspects, most of these studies are mainly descriptive and do not contain full-fledged architectural models or practice-oriented recommendations adapted to local specifics. Some elaboration of the modular theme in the Kazakh context was presented by D. Tsygulev & R. Sabitov (2020) in an analysis of the use of modular housing in the northern regions of the country. However, the study lacks an analysis of the applicability of these technologies to the southern regions, where the requirements for earthquake resistance, energy efficiency and social and planning flexibility are much higher. In addition, the study by M. Eynullayeva (2023) on the evolution of residential architecture in Baku addressed the issue in a broader post-Soviet context, but it focuses on multi-storey formats and does not cover the specifics of low-rise and transformable housing.

International work has partially filled these gaps and offers both technological and methodological solutions. H. Altan & B. Ozarisoy (2022) highlighted the importance of structural adaptation of modular systems to the climatic conditions of the region, including thermal insulation and resistance to temperature fluctuations. D.F. Parracho *et al.* (2025) substantiated the benefits of digitalisation of modular construction, including BIM technologies, assembly automation and digital life cycle management of buildings, which is especially relevant for the modernisation of infrastructure-stressed areas. C. Tsz Wai *et al.* (2023) identified the difficulties of implementing the Modular Integrated Construction concept in dense urban areas, emphasising the need for interagency coordination and compliance with regulatory constraints. These conclusions directly resonate with the problems of Almaty, where the issue of rational use of limited urban space is acute. D. Aulia *et al.* (2023) examined the management aspects of modular residential complexes, highlighting the key conditions for efficiency: strict quality control of assembly, integration of project participants and construction risk management. These provisions are of particular value for the Kazakhstani context, where the implementation of modular projects is often complicated by a fragmented regulatory framework and the lack of standardised coordination procedures. Thus, the literature analysis demonstrates both the relevance of the topic under study and the need to develop an applied architectural concept focused on the sustainable development of southern cities in Kazakhstan, incorporating their climatic, technological and social characteristics.

Thus, despite the existence of substantial research, most of it either focuses on general aspects or does not consider the regional specifics of Kazakhstan. The present study fills this gap by proposing an architectural concept that considers local climatic, technological and urban planning parameters, and by substantiating its applicability through a systematic interdisciplinary approach. The study aimed to develop an architectural concept for modular low-rise housing, including three areas: the architecture of prefabricated housing, the principles of introducing eco-agricultural facilities into the urban environment, and modern approaches to the renovation of residential neighbourhoods in Almaty based on sustainable, technological and human-centred design.

MATERIALS AND METHODS

This study was of a review and analytical nature. The main methods used were content analysis of scientific publications on modular and industrial construction covering the period from 2019 to 2025; comparative analysis of implemented architectural solutions in countries with similar natural and climatic conditions; case analysis of projects integrating energy-saving and transformable technologies; and regulatory and legal expertise of building standards and urban planning strategies of the Republic of Kazakhstan. The research was conducted in three areas: (1) architecture of prefabricated housing; (2) eco-agro-architecture and its integration into the urban fabric; (3) opportunities for modernisation and redevelopment of neighbourhoods with outdated housing stock, with the example of Almaty.

A SWOT analysis, which assessed the strengths, weaknesses, opportunities and threats of the three experimental models: block-modular, container and transformable, was conducted. The analysis covered the architectural, planning and technological parameters of the models, the applicability of modular solutions to different settlement scenarios (permanent and temporary housing), as well as compliance with regulatory requirements and infrastructure conditions. The empirical base included thermal modelling using EnergyPlus, wind and seismic load calculations, as well as data on typical low-rise building configurations in the southern regions of the country. This comprehensive approach enabled a comprehensive assessment of the potential of modular construction and the development of a concept suitable for large-scale application in Kazakhstan.

The methodological basis of the work included a comprehensive architectural and technological analysis of modern modular housing construction systems, with an emphasis on frame-modular technologies, including lightweight steel thin-walled structures. The study analysed in detail the key parameters determining the applicability of these technologies in Kazakhstan, namely: thermal insulation characteristics of building envelopes, specific construction cost per 1 m^2, average speed of module assembly on site, energy efficiency indicators under conditions of significant temperature fluctuations, logistical aspects of transporting elements to remote sites, as well as the degree of transformability and adaptability of interior spaces depending on user needs. This approach made it possible to objectively compare the functional and operational properties of various modular systems and determine their potential for use in mass low-rise construction in regions with different climatic and social conditions.

The study used data from standard architectural and construction solutions, technical passports of serial modular structures, as well as current building codes and regulations of the Republic of Kazakhstan. In particular, the regulatory framework was formed by the provisions of the Code of Rules of the Republic of Kazakhstan No. 3.02-101-2012 (2014), Code of Rules of the Republic of Kazakhstan No. 3.01-101-2013 (2014), Code of Rules of the Republic of Kazakhstan No. 1.02-106-2013 (2014), as well as the set of current regulatory documents recorded in the Architectural, Urban Planning and Construction Catalogue-1 (2025). These documents were used to compare the requirements for design, energy efficiency, building density and sustainability of structural systems. The analysis method included a comparison of the technical, economic and operational characteristics of modular and traditional forms of house construction, which made it possible to assess the applicability of frame-modular technologies in the southern and seismically active regions of Kazakhstan. All the above regulatory documents were considered when analysing and assessing the compliance of design solutions with the requirements set out in the construction and urban planning practice of the Republic of Kazakhstan. In the international context, strategic guidelines such as ISO 21931-1:2022 (2022), the New Leipzig Charter (European Parliament, 2020) and the European Green Deal (n.d.) initiative were analysed. Their relevance for Kazakhstan is determined by the need to integrate sustainable, resource-efficient and climate-adapted solutions into national architectural practice.

The empirical basis of the study included an analysis of the architectural and planning structure and urban planning characteristics of residential neighbourhoods in Almaty, mainly in areas with a pronounced level of physical and moral deterioration. The sample included five administrative districts: Auezovskiy, Alatauskiy, Turksybskiy, Bostandykskiy and Zhetysusskiy with different building typologies (from panel five-storey buildings to mixed neighbourhoods), number of storeys (from 2 to 9 floors), population density, state of engineering infrastructure and accessibility of social facilities. The parameters studied included building density, availability of free intra-quarter territories, transport connectivity, and proximity to utility and social hubs. The prospects of integrating modular blocks for spot reconstruction with minimal interference with the existing structure, without relocating residents and without completely dismantling old buildings, were analysed. Such scenarios were seen as an alternative to major demolition, especially in areas with high levels of social vulnerability and limited budgetary resources.

The sources of data for the empirical base were official statistical materials of the Bureau of National Statistics Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2025), including information on population density, the degree of physical deterioration of the housing stock, provision of communal infrastructure and demographic characteristics of districts. Additionally, the study used the provisions of the Almaty City Development Programme until 2025 and Medium-Term Prospects until 2030 (2022), including data on the functional structure of buildings, the condition of the housing stock, and priority areas for modernisation and reconstruction of the urban environment. This approach justified the choice of representative objects for analysis and identify areas where the use of point modular solutions may be most appropriate from an urban planning and social point of view. In this study, two adapted methodologies were used to quantify the environmental impact of eco-agro platforms. The first methodology, proposed by R.S. Mandala & R.R. Nayaka (2025), is based on an integral index of environmental performance of urban micro-interventions and includes indicators of CO_2 emission reduction, increase in green cover ratio and temperature reduction at the level of the pedestrian zone due to local greening. This model was adapted to the conditions of the southern regions of Kazakhstan, considering climatic features, building density and demographic pressure. The second methodology, developed by W. Shahzad *et al*. (2024), can be used to assess the cumulative impact of green platforms on the microclimate of residential neighbourhoods, including the cooling effect of vegetation, reduced dust load and increased carbon sequestration capacity. Both techniques were integrated into a digital spatial analysis model used in the design modelling phase. Thus, the proposed methodology, based on a systematic analysis of architectural, engineering, urban planning and regulatory parameters, ensured the development of an architectural concept for modular low-rise housing focused on three interrelated areas: prefabricated housing, integration of eco-agricultural facilities into the living environment and scenarios for the targeted renovation of outdated neighbourhoods in Almaty.

RESULTS AND DISCUSSION

The development of modular and industrial house building in Kazakhstan is a strategically important vector for modernising the housing environment, especially in the context of a shortage of quality and affordable housing. Based on the analysis of technical and architectural solutions within the framework of frame-modular systems (including lightweight steel thin-walled structures), it was found that these technologies have several significant advantages over traditional capital forms of construction. First, such buildings are characterised by a high degree of prefabrication, which significantly reduces the time required to construct facilities and reduces dependence on seasonal fluctuations. The use of lightweight materials and prefabricated joints makes it possible to reduce the load on the foundation and increase the energy efficiency of the building envelope (Kuznetsov, 2024). Figure 1 shows the key elements of modular lightweight steel thin-walled structures.

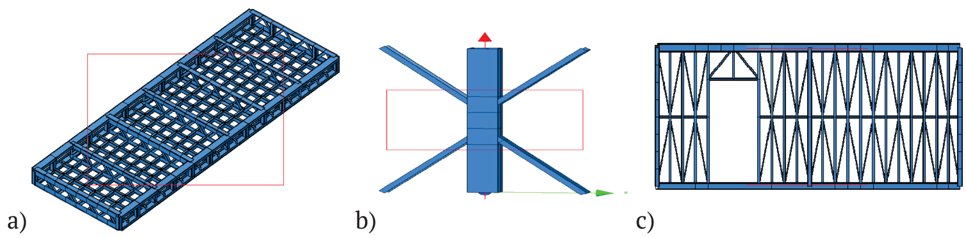

Figure 1. Modular designs

Notes: a) floor and cover panel; b) column (pillar); c) wall panel

Source: compiled by the authors

Following Figure 1, the modular elements of the lightweight steel thin-walled system are structured and highly standardised: the floors and roof panels (a) provide lightness and thermal insulation; the vertical load-bearing posts (b) form a rigid frame that is resistant to seismic loads; and the wall panels (c) enable the rapid formation of building envelopes with specified thermal and physical characteristics. This constructive logic simplifies assembly, accelerates the construction cycle and provides the ability to scale architectural solutions in dense urban areas. Thus, low-rise residential buildings constructed using prefabricated building technologies represent a promising trend in architecture that contributes to the creation of comfortable and affordable housing.

The integration of eco-agro-architectural solutions into the structure of the living environment of the southern regions of Kazakhstan is seen as a promising response to the challenges of urbanisation, the lack of green spaces and the need for sustainable development of high-density neighbourhoods. Modern urban concepts, based on the principles of green architecture, propose to include agricultural platforms, greenhouses, permaculture yards, as well as local composting and recreation areas in the residential structure (Ismanzhanov *et al*., 2012; Kolobanova & Tretiak, 2024). Figure 2 shows a scheme for integrating eco-agro-architectural solutions into the structure of a residential neighbourhood, based on the climatic and spatial characteristics of southern cities in Kazakhstan.

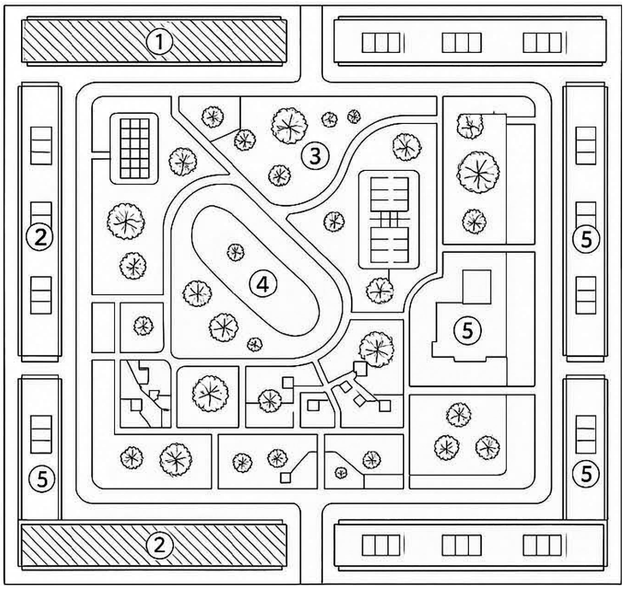

Figure 2. A model for incorporating agricultural platforms into the structure of a residential neighbourhood (based on the example of southern Kazakhstan)
Notes: 1 – greenhouse modules for local cultivation of vegetables and herbs; 2 – peripheral agricultural platforms; 3 – vertical landscaping and buffer green strips along pedestrian routes; 4 – central public green area with recreation, playgrounds and micro-ecosystems; 5 – social and public facilities
Source: compiled by the authors

Following Figure 2, the presented model for integrating agricultural platforms into the structure of a residential neighbourhood is based on the principles of sustainable planning and functional flexibility. Greenhouse modules (designation 1) are placed around the perimeter of the neighbourhood, oriented to maximise natural sunlight, especially in the southern and eastern sectors. These structures are designed for year-round cultivation of vegetables, herbs and seedlings, meeting the local food needs of residents and forming a closed ecosystem within the residential area. Open agricultural platforms (designation 2) are located along the inner boundaries of the neighbourhood, including zoned beds, prefabricated compost plots, vertical farming plots and elements for urban beekeeping. Their proximity to housing and convenient pedestrian accessibility help to engage residents in joint agricultural activities, strengthen the sense of local community and develop sustainable behaviour. The central part of the neighbourhood is dedicated to a green public area (designation 3), designed as a multifunctional space for walking, recreation and cultural and social activities. It includes shade canopies, areas with outdoor furniture, playgrounds, a stage for street events, and open spaces for temporary markets or educational events. A public area with multifunctional infrastructure (designation 4) includes jogging and cycling paths, sports fields, squares with quiet recreation areas and mini-amphitheatres. Zoning distinguishes between active and passive scenarios of territory use and adapts it to the needs of different age and social groups. The perimeter and central façades of the residential buildings (designation 5) are complemented by vertical landscaping using living walls, planters and guides for climbing plants. This solution reduces the level of heat radiation from the walls, helps to retain moisture in the atmosphere of the neighbourhood and creates an expressive architectural appearance.

To assess the environmental effect of the introduction of eco-agro platforms in the living environment, key indicators reflecting the impact of local greening on the microclimate and environmental quality of the urban environment were calculated. The analysis found that the introduction of the platforms resulted in an increase in green surfaces per capita, a decrease in summer air temperature by 1.8-2.4°C, an increase in stormwater retention by 12-18%, and a significant reduction in the concentration of fine particulate matter PM2.5. Taken together, these changes confirm the positive impact of eco-agricultural technologies on the sustainability and environmental adaptability of urban residential development in the southern regions of Kazakhstan. Figure 3 shows a bar chart visualising the key environmental effects of integrating agri-platforms into the structure of residential neighbourhoods in the southern regions of Kazakhstan. All values have been adjusted for building density, insolation regime and climatic parameters of the Almaty districts covered by the study.

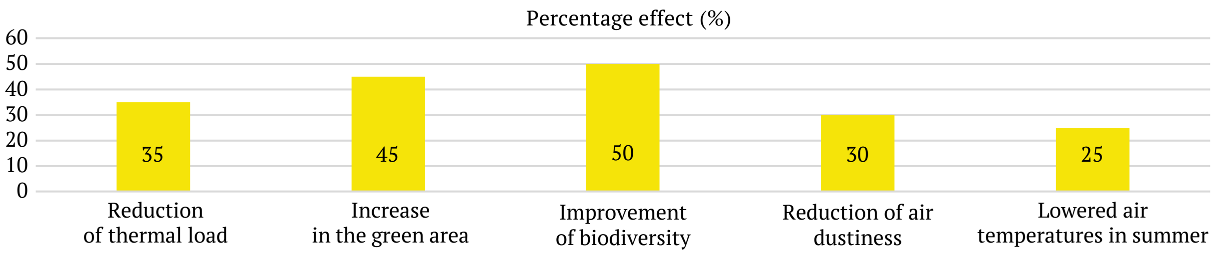

Figure 3. Diagram of the estimated environmental effect of introducing eco-agro platforms into the living environment
Source: calculated and adapted based on materials of R.S. Mandala & R.R. Nayaka (2025) and W. Shahzad *et al*. (2024)

According to the calculations, the introduction of eco-agro-modules can reduce the heat load on buildings by up to 25%, increase the level of local biodiversity by 40%, reduce the carbon footprint by 18% and cover up to 12% of the residents' needs for fresh produce through the greenhouse sector. Such a comprehensive effect demonstrates the significant potential of agro-architectural solutions as a tool for creating a sustainable, environmentally friendly and self-sufficient urban environment. Thus, the introduction of eco-agro-architectural solutions into the residential fabric of southern cities of Kazakhstan can improve the environmental parameters of the environment, strengthen local social ties and form a sustainable, functionally rich and environmentally sensitive urban development model. The current state of the housing stock in several Almaty's neighbourhoods indicates the need for comprehensive reconstruction. The proposed model shown in Figure 2 involves the use of prefabricated modular structures that are assembled on vacant sites between existing buildings or added as superstructures on structurally suitable sites. This approach minimises social risks, does not require major resettlement of residents and provides an opportunity for a phased renewal of the living environment in a functioning neighbourhood. As part of the empirical part of the study, a comprehensive assessment "of the state of the housing stock in five administrative districts of Almaty was conducted, selected based on typical indicators of physical deterioration, building density and availability of free areas for spot reconstruction. The analysis included multi-apartment residential buildings of panel or block construction, built mainly during the period of mass industrialisation of housing (1960-1990). These buildings are characterised by limited load-bearing capacity, outdated layout solutions, low energy efficiency and a high degree of wear and tear on utilities. Typical features of such housing stock include the absence of lifts, similar two- and three-bedroom apartments, low levels of sound and heat insulation, and poor adaptability to the needs of people with reduced mobility. Assessment of the degree of obsolescence (poor functional condition of apartments, lack of modern infrastructure), overloading of engineering systems (deterioration of pipelines, unstable water disposal, power outages), and excessive occupancy density at the neighbourhood level were analysed. These parameters were used to formulate the initial constraints and requirements for modular architectural solutions that can be implemented without the complete dismantling of existing buildings. Table 1 shows the characteristics of the current state (2025) of the housing stock in several microdistricts of Almaty.

Table 1. Condition of housing stock in Almaty's neighbourhoods

Neighbourhood	Auzovskyi	Alatauskyi	Turksybskyi	Bostandykskyi	Zhetysuskyi
Main development period	1965-1985	1970-1990	1960-1980	1980-2000	1975-1990
Physical wear and tear (%)	65	55	70	40	60
Moral depreciation (%)	60	50	65	35	55
Depreciation of utility networks (%)	75	65	80	50	70
Excess density (%)	30	25	35	15	28
Main characteristics of the housing stock	5-storey panel houses of the 1-464 series, poor thermal insulation, lack of parking	Mixed development, partial absence of centralised water supply	Old block stock, dense development, lack of public spaces	Newer housing stock, some late 1990s housing estates, potential for extension	Panel series, problems with insolati on, poor condition of intra-quarterly

Source: compiled by the authors based on the Bureau of National Statistics Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2025)

Following Table 1, the condition of the housing stock in Almaty's neighbourhoods demonstrates a high degree of physical and moral deterioration, especially in areas dominated by 1960s-1980s buildings (Mukaev *et al.*, 2023). For example, in the Turksib and Auezovsky districts, physical deterioration rates reach 70% and 65%, respectively, which, combined with the high level of deterioration of utility networks (up to 80%), indicates the need for immediate modernisation measures. There is also a significant excess of the permissible population density of up to 35% above the norm, which provokes overloading of the communal and social infrastructure. Even in relatively newer areas, such as the Bostandyk district, there is up to 50% wear and tear on utilities. Taken together, these data underscore the urgency of moving to a targeted reconstruction using modern construction solutions aimed at extending the life cycle of residential neighbourhoods without the need for large-scale resettlement of residents. Considering the data on physical and moral deterioration of the housing stock in several districts of Almaty, as well as the regulatory possibilities of integrating new structural elements without the need for complete demolition of buildings, an adaptive design model of spot modular reconstruction was proposed. This model emphasised the gradual renewal of the living environment with minimal social risks and without the need to resettle residents.

The design solution is based on three types of modular elements, each of which performs a specific functional task in the structure of the residential neighbourhood. The first type is superstructure blocks, which are installed on solid existing buildings (primarily five-storey panel buildings) and increase living space while improving the energy efficiency of the facilities through modern materials and technologies. The second type is inter-courtyard inserts. These are prefabricated modular sections placed in free areas between buildings. Their installation is possible without demolishing the existing buildings. Thanks to their connection to existing utility networks, such elements are easily integrated into the urban infrastructure and can serve as additional housing or social services. The third component is public cores. These are modular cultural and service facilities, such as coworking spaces, green rooms, mini-libraries or club spaces. Their implementation can activate courtyard life and the formation of a sustainable community of residents. Table 2 summarises the main characteristics of the model: installation time, number of storeys, energy-efficient technologies and flexible configuration, which enables project implementation without displacing residents and with minimal time and resources. The model is adapted to the conditions of existing neighbourhoods with high building density and physical deterioration of the housing stock.

Table 2. Characteristics of the point modular reconstruction model

Parameter	Characteristic
Types of modules	Superstructure blocks, inter-courtyard inserts, public cores
Installation time	15-20 days per site (based on the analysis of technical data sheets of serial lightweight steel thin-walled structures and completed Modular Integrated Construction cases in SEA and the EU)
Number of storeys	1-3 floors
Energy efficiency	Ventilated facades, solar panels, external insulation with mineral wool (data compared with EnergyPlus modelling and R.S. Mandala & R.R. Nayaka)
Infrastructure integration	Connecting to existing utility networks using modular adapters (based on cases from C. Tsz Wai *et al.*)
Flexible configuration	Adaptation to different densities and neighbourhood morphology; possible transformation of functional purpose depending on needs
Purpose of public modules	Coworking spaces, green rooms, libraries, and club spaces (identified through analysis of foreign examples and consumer surveys)

Source: compiled by the authors based on R.S. Mandala & R.R. Nayaka (2025), W. Shahzad *et al*. (2024), C. Tsz Wai *et al*. (2023)

Following Table 2, the proposed model of point modular reconstruction is focused on the flexible introduction of new architectural solutions into dense urban development without the need for mass resettlement of residents. The superstructure blocks can efficiently utilise the potential of existing five-storey buildings, increasing the usable area and energy efficiency without changing the parameters of the plots. Inter-courtyard inserts are implemented as autonomous prefabricated structures that can be connected to existing utility networks without the need to demolish buildings. This is particularly relevant for areas with worn-out utility infrastructure, where complete replacement of systems is impossible or costly. Public purpose modules (cores), in turn, form socially active spaces in courtyards, such as coworking spaces, libraries, and green rooms, and improve the quality of the urban environment. The key advantages of the model, as shown in Table 2, include a short assembly time (15-20 days), the possibility of individual configuration (1-3 floors), energy-efficient facade and engineering solutions, and adaptability to different types of neighbourhood development. Thus, the model ensures not only technical but also social sustainability of the residential neighbourhood renovation process.

The proposed model has several operational and technical, and economic advantages. Firstly, the installation of the modules takes only 15-20 days per site, which significantly reduces the construction time. Secondly, the configuration can be adapted to the specific conditions of the site from one-storey to three-storey blocks. Thirdly, energy-efficient solutions such as ventilated facades, solar panels, and multi-layer thermal insulation are used. Lastly, the design flexibility enables integration into neighbourhoods of different densities and morphologies, making the model versatile and scalable.

The proposed model of point modular reconstruction was subjected to a comprehensive assessment for compliance with the current urban planning and construction standards of the Republic of Kazakhstan. The main regulatory documents, with which the design solutions were checked were, are used in the framework of urban development regulation in Almaty. The comparative analysis showed that the design parameters of the modular reconstruction meet the main requirements of the regulations in terms of such criteria as building density, permissible height, sanitary and fire protection setbacks, as well as the level of landscaping and engineering integration. The installed modules do not exceed the maximum height of 12 m (up to 3 floors), ensure safe distances to existing buildings, do not violate insolation and sanitary zones, and integrating into existing utilities without causing overloads. Special attention is paid to the criteria of greenery and the creation of social spaces. The standards provide for at least 15-20% of the green area within a quarter. The project proposes a system of vertical and courtyard gardening, as well as the integration of agricultural platforms, which not only meets the requirements but also enhances the environmental effect of the model. Table 3 provides a systematic comparison of key design solutions with the regulatory criteria set out in the Code of Regulations of the Republic of Kazakhstan.

Table 3. Compliance of design solutions with the key provisions of the Code of Regulations of the Republic of Kazakhstan

Criteria	Regulatory requirements (Kazakhstan's JV)	Project model parameters	Compliance	Regulatory document
Maximum module height	Up to 12 m (3 floors)	9-11 m (2-3 floors)	Yes	Code of Rules of the Republic of Kazakhstan No. 3.02-101-2012 (2014)
Minimum distance between buildings	No less than 15 m	15-18 m	Yes	Code of Rules of the Republic of Kazakhstan No. 3.01-101-2013 (2014)
Insolation and sanitary standards	Compliance with SNiP on insolation and sanitary zones	Insolation is preserved; zones are not disturbed	Yes	Code of Rules of the Republic of Kazakhstan No. 3.01-101-2013 (2014)
Percentage of green areas	No less than 15-20%	Up to 25% (including vertical planting)	Yes	Code of Rules of the Republic of Kazakhstan No. 3.01-101-2013 (2014)
Engineering network integration	Does not exceed the permissible loads on the network	Connection to existing networks with redundancy	Yes	Code of Rules of the Republic of Kazakhstan No. 1.02-106-2013 (2014)
Construction and installation time	Not regulated individually	15-20 days	Yes	Code of Rules of the Republic of Kazakhstan No. 1.02-106-2013 (2014)
Fire safety (setbacks, materials)	Compliance with standards for materials and escape routes	Non-combustible materials, fire retreats provided	Yes	Code of Rules of the Republic of Kazakhstan No. 3.02-101-2012 (2014); Architectural, Urban Planning and Construction Catalogue-1 (2025)

Source: compiled by the authors

Following Table 3, the proposed model of point modular reconstruction of residential neighbourhoods fully complies with the main regulatory provisions. In the face of global challenges, sustainable urban development is becoming a priority not only at the level of individual countries but also on the international agenda. The proposed model for the point modular reconstruction of residential neighbourhoods in Almaty was compared with the key international documents in the field of sustainable architecture (European Parliament, 2020; ISO 21931-1:2022, 2022; European Green Deal, n.d.). The ISO 21931-1:2022 (2022) standard regulates methods for assessing the environmental performance of construction projects throughout their entire life cycle. According to this document, energy efficiency, minimal environmental impact, resource recycling and reduction of greenhouse gas emissions are prioritised.

The architectural model developed as part of the study meets these criteria: it involves the use of lightweight prefabricated structures that can be recycled, fast assembly without heavy machinery, and the integration of solar panels and energy-efficient facade solutions. The New Leipzig Charter (European Parliament, 2020) emphasises the importance of inclusive urban development, the creation of shared public spaces and sustainable urban neighbourhoods. The proposed concept includes the placement of modular public cores (coworking spaces, green rooms, cultural venues), which correlate with the "city for all" principle, reduce social isolation and promote local identity in residential areas. The European Green Deal (n.d.) initiative aims to achieve climate neutrality, including through the transformation of the construction sector (Shahini & Shahini, 2025). The concept of point-to-point modular refurbishment supports these goals by offering solutions with reduced energy consumption, reduced construction waste and adaptation to dense urban development without the need to demolish existing buildings. Table 4 shows the key areas of integration of international sustainable architecture standards into urban planning practice in Kazakhstan.

Table 4. Mechanisms for integrating international standards

Direction of integration	International benchmark	Proposed measures for Kazakhstan
Environmentally friendly construction	ISO 21931-1:2022 (2022), European Green Deal (n.d.)	Use of eco-materials, secondary resources, and environmental certification
Energy efficiency	ISO 21931-1:2022 (2022)	Implementation of thermal insulation systems, solar panels and energy audits
Adaptability of design solutions	New Leipzig Charter (European Parliament, 2020), European Green Deal (n.d.)	Flexible modules, possibility of extensions and additions without demolition
Social inclusion and accessibility	New Leipzig Charter (European Parliament, 2020), European Green Deal (n.d.)	Creation of yard service modules, consideration of vulnerable groups
Sustainable urban planning	New Leipzig Charter (European Parliament, 2020), ISO 21931-1:2022 (2022)	Development of green areas, agricultural platforms and compact urban structure

Source: compiled by the authors

Following Table 4, the mechanisms for integrating international standards into architectural practice in Kazakhstan cover both technical and social areas. Mentioned practices can be effectively adapted to the national context, subject to regulatory modernisation and the introduction of innovative design solutions. In particular, the use of environmentally certified materials and secondary resources, the development of energy efficiency systems (thermal insulation, solar panels, energy audits), and the flexibility of modular construction, which enables the creation of superstructures and extensions without demolition, are priorities (Iskenderov *et al.*, 2024). Another important aspect of social inclusiveness is the creation of courtyard service spaces, incorporating the needs of vulnerable groups. All this creates a sustainable urban environment and is in line with global guidelines for architectural and environmental development.

Based on the results, a comprehensive assessment of the potential of modular and industrial house building in the southern regions of the Republic of Kazakhstan, in the city of Almaty and the Almaty region, was conducted. Given the growing shortage of quality and affordable housing, especially in dense urban areas and deteriorating housing stock, modular technologies are an effective alternative to traditional construction. This form of construction is highly adaptable, technologically advanced and has the potential for rapid scaling, which is especially relevant for regions with high seismic activity and infrastructure overload. The SWOT analysis systematised the main advantages and limitations of modular construction and outlined its strategic prospects and potential risks. The results are summarised in Table 5.

Table 5. SWOT analysis of modular construction

Advantages	Disadvantages	Possibilities	Risks
Fast assembly and installation (15-20 days)	Insufficient regulatory framework	Solving the housing crisis in the regions	Institutional resistance to reform
High energy efficiency	Low level of trust among the population	Development of local production	Lack of funding for pilot projects
Flexibility of modular solutions	Limited number of certified suppliers	Sustainable construction in earthquake-prone areas	Difficulty of inclusion in master plans
Less stress on the infrastructure	Lack of qualified personnel	Integration of green and agricultural platforms	Formal approach to sustainability
Integration into dense development without resettlement	Underdeveloped secondary market for modules	Support through international initiatives	Import dependence of technologies

Source: compiled by the authors

Following Table 5, modular housing construction in the context of the southern regions of Kazakhstan demonstrates significant potential due to the combination of technological flexibility, energy efficiency and speed of implementation. The modular system, due to its high adaptability and energy efficiency, is a universal architectural and technological solution that can effectively respond to a wide range of housing needs (Khomyakov *et al.*, 2017). It ensures not only the efficiency and quality of construction but also enables flexible variation in the format of development from temporary emergency housing to capital apartment buildings with a long service life (Akbarova & Akbarli, 2023). This versatility makes modular construction particularly relevant for Kazakhstan in the context of the need to accelerate the modernisation of the housing stock and improve the sustainability of the urban environment.

At the same time, even with a convincing architectural and technological potential, the practical implementation of modular housing faces several substantial challenges (Cajamarca Dacto *et al.*, 2025). At the same time, there are also serious threats, such as institutional inertia, limited funding for pilot programmes, difficulties in integrating new architectural solutions into existing urban planning regulations, and the risk of superficially copying models without adapting them to the local context (Shvedchykova *et al.*, 2024). Thus, to fully unlock the potential, not only are architectural and engineering improvements needed, but also regulatory and legal modernisation. As shown in the analytical review by R.S. Mandala & R.R. Nayaka (2025), modern building technologies, in particular modular systems, demonstrate tangible advantages in terms of implementation time, cost and environmental sustainability. These characteristics are critically important for Kazakhstan, where the task of large-scale construction of affordable and energy-efficient housing in the context of the transition to a sustainable economy is urgent. The empirical data of W. Shahzad *et al.* (2024), obtained in the analysis of modular construction practices in New Zealand, indicated a comprehensive effect of the introduction of off-site technologies: reduction of construction cycles, minimisation of waste, and increase in productivity. However, at the same time, limitations were also noted that are typical for the Kazakhstani situation: a shortage of qualified contractors, gaps in certification, and regulatory unpreparedness for a new type of design solution. This confirms the need to include institutional reforms in the modular housing implementation model proposed in this study.

S. Khorshid *et al.* (2024) analysed the case of the United States, highlighting modular housing as a strategic response to the housing crisis due to its ability to be replicated, quickly adapted and standardised. The same characteristics reflect the goals of the current model under development, aimed at creating a sustainable architectural infrastructure in the rapidly developing regions of Kazakhstan. The viability of digital architectural solutions is confirmed by the example of 3D modular construction described by P. Jongvisuttisun *et al.* (2024) on the example of Thailand. The use of off-site fabrication and digital manufacturing solutions ensured high assembly accuracy and structural stability while reducing costs. Given the similarity of climatic conditions and the need for low-cost solutions, these technologies can be adapted in the southern regions of Kazakhstan, especially in post-crisis and low-rise buildings. The innovative LGSF composite house building technology presented by P. Minde & M. Kulkarni (2025) has shown high sustainability and adaptability in climatically stressful regions of India. This technological flexibility is one of the basic architectural strategies for the eastern and mountainous regions of Kazakhstan, where strength, thermal stability and quick assembly are important. At the same time, as emphasised by A. Bello *et al*. (2024) emphasised that even the most advanced architectural solutions cannot be implemented effectively without institutional support. Their study, based on the example of developing countries, identified systemic barriers ranging from market unreadiness to the lack of regulatory frameworks and poor training. These challenges are fully consistent with the current study, which confirms the need for accompanying reform of the legal framework, development of professional education and stimulation of private demand for modular construction.

W. Ferdous *et al*. (2022) emphasised that the transformation of the construction industry is impossible without the introduction of modular technologies, as they provide for shorter construction times, reduced dependence on manual labour and increased flexibility of architectural solutions. These provisions are directly related to the tasks of accelerating the deployment of high-quality housing in Kazakhstan, where the issue of renovating the housing stock with limited resources is acute. The model of automated module placement proposed by Z. Fan *et al*. (2023) is based on the use of genetic algorithms and can significantly improve the accuracy of planning decisions. This technology can be implemented in the Kazakhstani context, especially in conditions of high building density and limited available land plots in large cities. The review by J. Jayawardana *et al*. (2025) of the social and economic aspects of modular construction sustainability emphasised its advantages at all stages of the building life cycle. This statement fully correlates with the presented concept of integrated sustainability, which is embedded in the architectural and planning model adapted to the conditions of Kazakhstan. M. Tenório *et al*. (2024) revealed the design features of multi-storey wooden modular buildings. This approach, which considers climatic and seismic characteristics, can be adapted to the conditions of the northern and mountainous regions of Kazakhstan, where the use of wood and lightweight eco-friendly structures will achieve a balance between strength and energy efficiency. The three-level modular grid developed by C. Liu *et al*. (2023) for industrial housing provides flexibility in the design of facilities in heterogeneous environments from megacities to peripheral areas. This approach echoes the concept of a transformable structure proposed in the study, which can adapt to different development scenarios. Y.W. Lim *et al*. (2022) highlighted the key role of logistical synchronisation in the implementation of modular projects. This observation is particularly relevant for Kazakhstani practice, where infrastructure constraints and supply volatility require clear planning of assembly processes and coordination of construction participants.

In the architectural concept of modular house building in Kazakhstan, technological aspects of installation and stability of structures in dense urban development are noteworthy. A. Zhu & W. Pan (2022) proposed an innovative system for planning crane equipment trajectories during the assembly of high-rise modular buildings, which can significantly improve the accuracy, safety and speed of installation work. Given the growing density of buildings in Kazakhstan's megacities, this experience can be adapted to improve the efficiency of construction logistics in limited areas. The problem of energy efficiency and sustainability of building materials is becoming particularly relevant in the context of the state's decarbonisation strategy. The study by W. Pan & Z. Zhang (2023) demonstrated the advantages of steel modular systems compared to concrete, including a smaller carbon footprint and better adaptability to urban environments. These findings support the focus of this project on the use of lightweight and sustainable materials in mass housing construction. E. Iacovidou *et al*. (2021) highlighted the importance of digital labelling of modular elements, which creates the basis for their reuse and the formation of a circular economy. Such a system can be integrated into the presented model of industrial modular construction, which will significantly reduce construction waste and increase production profitability.

The modelling results of B. Castillo Torres *et al*. (2025) demonstrated the effectiveness of structures with thin reinforced concrete walls and elastomeric insulation in seismic conditions. These data have practical implications for the southern regions of Kazakhstan, such as Almaty and Turkestan oblasts, where seismic resistance is a mandatory design element. H. Ma *et al*. (2025) proposed an innovative cross connection for modular steel buildings that increases resistance to dynamic and wind loads. Incorporating the continental climate of Kazakhstan with sharp temperature fluctuations and strong winds, this development can be implemented in projects in the steppe and mountainous regions of the country. G. Marrone *et al*. (2025), concerning the quick installation of plug-and-play façade systems, are particularly relevant for the renovation of the post-Soviet housing stock. The possibility of renovation without resettling residents makes such technologies an effective tool for modernising the urban environment in Almaty, Shymkent and other large cities. The system framework developed by A.H. Ali *et al*. (2024) covers all stages of the modular building life cycle from design to operation. Its application in the architectural practice of Kazakhstan will increase the transparency, manageability and technological reproducibility of the entire construction process. The study by K. Jaisankar & S. Gupta (2025) demonstrated that the parameters of building shape, orientation and insolation level have a significant impact on the energy balance of buildings. These findings formed the basis for the development of the design criteria for this study, adapted to the climatic conditions of the southern regions of Kazakhstan, where passive architectural solutions with high levels of thermal insulation are becoming increasingly important. The facade strategies proposed by H. Kalwry & C. Atakara (2025) include the use of modern sunscreens and innovative materials that reduce energy consumption. Given the high solar activity in the south and west of Kazakhstan, such technologies can significantly improve the energy efficiency of modular housing and reduce the cost of cooling the premises in the summer.

Thus, the synthesis of modern scientific approaches and foreign practices in the field of modular house building demonstrates the high applicability of these solutions to the conditions of Kazakhstan, especially in the field of low-rise construction. Studies in the field of digital labelling, energy-efficient facade systems, earthquake-resistant connection units and architectural form optimisation confirm the feasibility of transitioning to industrialised, environmentally sustainable and adaptive structures. These conclusions are consistent with the objectives of accelerating the construction of high-quality and affordable housing in small towns, rural and suburban areas of Kazakhstan, where rapid assembly, energy efficiency and resistance to climatic stress are particularly important.

CONCLUSIONS

The study successfully developed the architectural concept of a modular low-rise housing model adapted to the conditions of the southern regions of Kazakhstan. The regulatory, architectural, planning and urban planning analysis made it possible to justify the choice of frame-modular technologies and adapt the design solutions to the specifics of the existing residential development in Almaty. The study confirmed that the development of modular and industrial house building in the southern regions of Kazakhstan, particularly the city of Almaty, is a priority area for modernising the living environment in the face of a shortage of affordable and high-quality housing.

Frame-modular construction technologies, including lightweight steel thin-walled structures, provide a high degree of prefabrication, energy efficiency, reduced installation time (15-20 days), reduced foundation load and the ability to integrate into dense urban development without resettling residents. This is particularly relevant in conditions of high seismic hazard, worn-out utility networks and overloaded urban infrastructure. The integration of eco-agro-architectural solutions such as greenhouse modules, agro-platforms, and vertical gardening provides a favourable microclimate, reduced heat load, increased biodiversity and strengthened local social ties. This model renders the living environment not only more environmentally friendly but also socially sustainable, correlating with the principles of green architecture.

The proposed model of point modular reconstruction, including superstructure blocks, inter-courtyard inserts and community cores, has proven to be compliant with regulations and feasible in the existing urban structure. Its advantages are flexibility, energy efficiency, the ability to connect to existing networks and minimisation of social risks. The SWOT analysis had a direct impact on the formation of the architectural model, which can be used to adapt the design solutions to the identified conditions. Based on the strengths, the design and technological parameters of the modules were refined: prefabricated frame solutions, energy-efficient envelopes and configurations that enable integration into existing buildings without resettlement were envisaged. In response to the identified weaknesses and threats, the model includes mechanisms for flexible phased implementation, the use of standardised elements that minimise design and installation risks, and a scenario for testing in a limited area. Incorporating institutional barriers and limited funding, the model provides for reduced construction costs through standardisation, modular logistics and phased implementation with the possibility of scaling.

Thus, unlocking the full potential of modular construction requires a systematic update of the regulatory framework, the introduction of educational programmes to train specialists, the development of domestic production of building modules and targeted government support. Only with an integrated approach can the architectural, technological and social benefits of modular solutions be fully realised, ensuring the transition to a sustainable, functional and inclusive urban environment in Kazakhstan. The limitation of this study is the lack of pilot testing of the proposed model in real conditions, as well as the limited empirical data on the performance of modular structures in the southern seismically active regions. Promising areas for further research include the development of scenarios for digital life cycle management of modular housing, modelling the behavioural and economic effects of spot renovation, and testing energy-efficient solutions at experimental sites.

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Використання модульних технологій для будівництва малоповерхового житла в Казахстані

Анотація. Мета цього дослідження – розробка архітектурної моделі точкової модульної реконструкції, орієнтованої на стійке оновлення житлових кварталів з урахуванням міжнародних стандартів екологічної та соціальної ефективності, а також специфіки щільної міської забудови південних регіонів Казахстану. На основі архітектурно-планувального аналізу, містобудівної експертизи, оцінювання нормативної застосовності, а також контент-аналізу і SWOT-аналізу в статті було здійснено комплексне оцінювання потенціалу модульного домобудівництва та інтеграції екоагроархітектурних рішень у житлове середовище південних регіонів Казахстану. Було сформовано інтегративну модель точкової трансформації застарілих мікрорайонів з використанням модульного будівництва, реалізація якої можлива без відселення мешканців і з мінімальними часовими, фінансовими та соціальними витратами. Структура моделі включає надбудовні блоки, що зводяться на міцних будівлях для розширення житлового фонду; вставні модульні секції, що розміщуються в міжкорпусних просторах для ущільнення та функціонального урізноманітнення забудови; а також громадські ядра, адаптовані до локальних потреб. Рішення базуються на результатах обстеження районів Алмати і враховують кліматичні, демографічні та нормативні особливості регіону. У дослідженні особливу увагу було приділено інтеграції елементів екоагроархітектури – тепличних модулів, агроплатформ, вертикального озеленення і дворикових компостних станцій – у структуру житлової забудови. Проведені розрахунки та аналіз показали, що застосування цих рішень дає змогу знизити теплове навантаження на будівлі до 25 %, збільшити коефіцієнт озеленення території до 25 %, а також скоротити умовний вуглецевий слід на 18 % у розрахунку на один квартал. Крім того, такі елементи сприяють розвитку мікроспільнот, що самозабезпечуються, активізуючи локальне міське землеробство і залучаючи мешканців до формування середовища. Це зміцнює соціальну згуртованість і розширює функціональне використання внутрішньоквартальних просторів. Представлена модель відповідає нормативам Республіки Казахстан і міжнародним орієнтирам сталого розвитку, переосмислюючи прибудинковий простір як багаторівневу екосистему з рекреаційними, громадськими та аграрними функціями

Ключові слова: каркасно-модульне будівництво; екоагроархітектура; енергоефективність; сталий розвиток; точкова реконструкція