UDC 711.58:502.131.1(574)
IRSTI 67.25.25
REVIEW ARTICLE

MODERNIZATION OF RESIDENTIAL MICRODISTRICTS THROUGH THE INTEGRATION OF ECO-AGRO-ARCHITECTURAL ELEMENTS

I.I. Ostapenko[1], A.A. Bryantsev[1,2,*], T.A. Gvozdikova[1], N.Sh. Seitova[1], K.B. Bekturganova[1], O.L. Bantserova[3]

[1]International Educational Corporation, 050028, Almaty, Kazakhstan
[2]Scientific research institute «RAS Engineering», 050016, Almaty, Kazakhstan
[3]National Research Moscow State University of Civil Engineering, 129337, Moscow, Russia

Abstract. *Modern residential microdistricts in post-Soviet cities are characterized by building wear, a shortage of public spaces, high thermal loads, and an unstable water regime. The integration of eco-agro-architecture elements-courtyard vegetable gardens and orchards, green roofs, rooftop greenhouses, vertical farms, and nature-based stormwater infrastructure-is considered an engineering-architectural solution that combines climate adaptation, increased energy efficiency, and improvement of urban environmental quality. The aim of this study is to substantiate engineering-architectural approaches to the modernization of post-Soviet residential microdistricts through the integration of eco-agro-architecture elements and to determine the conditions for their effective and safe implementation in Kazakhstan. The research methodology includes a qualitative comparative analysis of "green" infrastructure solutions as well as a synthesis of design principles and a phased implementation model. The study results are presented as a three-step model-quick measures on existing roofs and courtyards; pilots on public buildings with monitoring of energy use and water drainage; scaling through municipal programs and standards. The practical significance lies in reducing peak stormwater runoff, mitigating thermal loads, and increasing the resource efficiency of buildings, as well as in forming social practices for the shared use of courtyard and rooftop spaces. The results are intended for akimats, designers, and management organizations and can be applied when preparing modernization passports and developing pilot projects.*

Keywords: *eco-agro architecture; urban agriculture; green roofs; rooftop greenhouses; vertical farms; microdistrict modernization.*

***Corresponding author**
Alexandr Bryantsev, e-mail: bryantsev@engineering.com.kz

https://doi.org/10.51488/1680-080X/2025.3-04
Received 04 July 2025; Revised 02 August 2025; Accepted 03 September 2025

ӘОЖ 711.58:502.131.1(574)
ҒТАМР 67.25.25
ШОЛУ МАҚАЛАСЫ

ЭКОАГРОАРХИТЕКТУРА ЭЛЕМЕНТТЕРІН ИНТЕГРАЦИЯЛАУ АРҚЫЛЫ ТҰРҒЫН ШАҒЫНАУДАНДАРДЫ ЖАҢҒЫРТУ

И.И. Остапенко[1], А.А. Брянцев[1,2,*], Т.А. Гвоздикова[1], Н.Ш. Сейітова[1], К.Б. Бектұрғанова [1], О.Л. Банцерова [3]

[1]Халықаралық білім беру корпорациясы, 050028, Алматы, Қазақстан
[2]Ғылыми-зерттеу институты «RAS Engineering», 050016, Алматы, Қазақстан
[3]Ұлттық зерттеу Мәскеу мемлекеттік құрылыс университеті, 129337, Мәскеу, Ресей

Аңдатпа. *Посткеңестік қалалардың заманауи тұрғын шағын аудандары ғимараттардың тозуы, қоғамдық кеңістіктер тапшылығы, жылулық жүктеменің жоғары болуы және су режімінің тұрақсыздығымен сипатталады. Экоагроархитектура элементтерін - аула бағалары мен бақтарын, жасыл шатырларды, шатыр жылыжайларын, тік агрофермаларды және табиғатқа ұқсас нөсерлік инфрақұрылымды - интеграциялау климатқа бейімделуді, энерготиімділікті арттыруды және қалалық ортаның сапасын көтеруді ұштастыратын инженерлік-сәулеттік шешім ретінде қарастырылады. Осы зерттеудің мақсаты - экоагроархитектура элементтерін интеграциялау арқылы посткеңестік тұрғын шағынаудандарды жаңғыртудың инженерлік-сәулеттік тәсілдерін негіздеу және оларды Қазақстанда тиімді әрі қауіпсіз енгізудің шарттарын айқындау. Әдістеме «жасыл» инфрақұрылым шешімдерінің сапалық салыстырмалы талдауын, сондай-ақ жобалау қағидаттары мен кезең-кезеңімен енгізу моделін синтездеуді қамтиды. Нәтижелер үшсатылы модель түрінде ұсынылған: бар шатырлар мен аулаларда жедел шаралар; энергия тұтынуы мен су бұрудың мониторингі бар қоғамдық ғимараттардағы пилоттар; қалалық бағдарламалар мен стандарттар арқылы ауқымдау. Типтік шешімдер үшін жүктемелер мен пайдалану талаптары бойынша бағдарлық мәндер келтірілді. Практикалық маңыздылығы - нөсерлік ағынның шоғырланған шыңдарын төмендету, жылулық жүктемені жұмсарту және ғимараттардың ресурс тиімділігін арттыру, сондай-ақ аулалық және шатырлық кеңістіктерді ортақ пайдалану бойынша әлеуметтік тәжірибелерді қалыптастыру. Нәтижелер әкімдіктерге, жобалаушыларға және басқарушы ұйымдарға арналған және жаңғырту паспорттарын дайындау мен пилоттық жобаларды әзірлеуде қолданылуы мүмкін.*

Түйін сөздер: *экоагроархитектура; қалалық ауыл шаруашылығы; жасыл шатырлар; шатыр жылыжайлары; тік агрофермалар; шағынаудандарды жаңғырту.*

***Автор-корреспондент**
Александр Брянцев, e-mail: bryantsev@engineering.com.kz

https://doi.org/10.51488/1680-080X/2025.3-04
Алынды 04 шілде 2025; Қайта қаралды 02 тамыз 2025; Қабылданды 03 қыркүйек 2025

УДК 711.58:502.131.1(574)
МРНТИ 67.25.25
ОБЗОРНАЯ СТАТЬЯ

МОДЕРНИЗАЦИЯ ЖИЛЫХ МИКРОРАЙОНОВ С ИНТЕГРАЦИЕЙ ЭЛЕМЕНТОВ ЭКОАГРОАРХИТЕКТУРЫ

И.И. Остапенко [1], А.А. Брянцев [1,2,*], Т.А. Гвоздикова[1], Н.Ш. Сеитова [1], К.Б. Бектурганова [1], О.Л. Банцерова [3]

[1]Международная образовательная корпорация, 050028, Алматы, Казахстан
[2]Научно-исследовательский институт «RAS Engineering», 050016, Алматы, Казахстан
[3]Национальный исследовательский Московский государственный строительный университет, 129337, Москва, Россия

Аннотация. *Современные жилые микрорайоны постсоветских городов характеризуются износом зданий, дефицитом общественных пространств, высокой тепловой нагрузкой и нестабильным водным режимом. Интеграция элементов экоагроархитектуры - дворовых огородов и садов, зелёных крыш, крышных теплиц, вертикальных ферм и природоподобной ливневой инфраструктуры - рассматривается как инженерно-архитектурное решение, совмещающее климатическую адаптацию, рост энергоэффективности и повышение качества городской среды. Целью данного исследования является обоснование инженерно-архитектурных подходов к модернизации постсоветских жилых микрорайонов путём интеграции элементов экоагроархитектуры и определение условия их эффективного и безопасного внедрения в Казахстане. Методология исследования включает качественный сравнительный анализ решений «зелёной» инфраструктуры, а также синтез проектных принципов и поэтапной модели внедрения. Результаты исследования представлены в виде сформированой трёхшаговой модели - быстрые меры на существующих кровлях и дворах; пилоты на общественных зданиях с мониторингом энергопотребления и водоотведения; масштабирование через городские программы и стандарты. Практическая значимость состоит в снижении пиков ливневого стока, смягчении тепловой нагрузки и повышении ресурсной эффективности зданий, а также в формировании социальных практик совместного использования дворовых и кровельных пространств. Результаты адресованы акиматам, проектировщикам и управляющим организациям и могут применяться при подготовке паспортов модернизации и разработке пилотных проектов.*

Ключевые слова: *экоагроархитектура; городское сельское хозяйство; зелёные крыши; крышные теплицы; вертикальные фермы; модернизация микрорайонов.*

***Автор-корреспондент**
Александр Брянцев, e-mail: bryantsev@engineering.com.kz

https://doi.org/10.51488/1680-080X/2025.3-04
Поступило 04 июля 2025; Пересмотрено 02 августа 2025; принято 03 Сентября 2025

ACKNOWLEDGEMENTS/SOURCE OF FUNDING

The research was conducted using private sources of funding.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

Residential districts formed during the Soviet and post-Soviet periods played a key role in providing affordable housing and shaping the urban structure. Their architectural and planning model was based on standardization and utilitarianism: typical panel and brick apartment blocks, a minimal set of social facilities and green areas, and a rigid functional hierarchy. This system made it possible to address the housing shortage of its time efficiently, yet under contemporary conditions its significant limitations have become evident.

A large share of the housing stock has now been in operation for more than 40-50 years, leading to structural deterioration, obsolescence of engineering systems, and reduced energy efficiency. Equally evident is the moral and functional obsolescence of planning solutions: standardized apartments and courtyard spaces no longer meet current demands for quality of life, functional diversity, and social expectations of urban residents.

An additional challenge is the shortage of public and recreational areas. Spaces originally designed as utilitarian or transit zones do little to stimulate resident interaction and fail to create conditions for local community building. The underdevelopment of ecological infrastructure further exacerbates the situation: systems for waste separation and recycling, rational water use, and energy conservation were either not envisaged or remain fragmented. This reinforces the social alienation typical of standardized environments, where people often remain anonymous users of space and feel neither attachment to nor responsibility for it.

The combination of these factors makes the modernization of residential districts one of the priority tasks of contemporary urban development. Importantly, this process cannot be reduced to building refurbishment or cosmetic landscaping. A comprehensive approach is required, one that reinterprets the residential district not merely as a place of dwelling but as a fully-fledged socio-ecological unit of the city-adaptive to new challenges, resilient in operation, and capable of ensuring high urban environmental quality.

The microdistrict model of development provided mass housing and basic infrastructure, yet today it requires profound modernization. The physical deterioration of envelopes and engineering systems, the obsolescence of courtyards, low energy efficiency, and climate vulnerability necessitate integrated solutions. Traditional measures (major repair, "cosmetic" landscaping) often fail to deliver sustainable improvements in quality of life. The integration of productive green solutions-eco-agroarchitectural elements-makes it possible to view the building and courtyard as a unified socio-ecological system with partially closed loops of energy, water, and materials.

This includes courtyard gardens and orchards, green roofs (extensive/intensive), rooftop greenhouses and vertical farms, as well as nature-based stormwater infrastructure (rain gardens, bioswales, rainwater harvesting). Such measures simultaneously improve the microclimate, reduce stormwater runoff, support biodiversity, and create new scenarios for the use of shared spaces. The social impact is reflected in the development of local communities, co-governance, and environmental education.

The present study systematizes international experience and scientific evidence, highlights engineering-ecological effects, organizational requirements and constraints, and proposes a phased implementation model for the context of Kazakhstan, oriented toward pilot projects, monitoring, and subsequent scaling up.

Residential districts of the Soviet and post-Soviet period in Kazakhstan are characterized by physical and functional obsolescence, low energy efficiency, and vulnerability to climatic and hydrological impacts. Traditional measures (capital repairs, cosmetic landscaping) deliver only limited and short-term improvements. Under these conditions, the integration of eco-agroarchitectural elements-green roofs (extensive and intensive), rooftop greenhouses, vertical farms, and nature-based stormwater infrastructure is considered a multifunctional strategy that simultaneously reduces peak stormwater runoff, mitigates urban overheating, increases the resource efficiency of buildings, and enhances resident engagement.

The scientific problem lies in the absence, within the Kazakhstani context, of systematized engineering and architectural principles and regulations for implementing such solutions, accounting for local snow, wind, and seismic loads, water and energy management, selection of resilient species, sanitation, operation, and co-governance models.

The aim of the study is to substantiate approaches to the modernization of residential districts through the integration of eco-agroarchitectural elements and to define the conditions for their effective and safe implementation in Kazakhstan.

To achieve this aim, the following objectives are addressed:

−to conduct a qualitative comparative analysis of typical interventions using a unified parameter matrix;

−to synthesize design principles and operational regulations;

−to propose a phased model (“quick measures - pilot projects - scaling up”) supported by target monitoring metrics;

−to refine load benchmarks and safety requirements.

A brief review of contemporary literature shows that green roofs and related solutions provide energy, hydrological, and ecosystem benefits when properly adapted to climate-specific construction and maintenance requirements, while integrated greenhouses and vertical farms demonstrate the potential for resource synergies between buildings and agro-systems. The success of implementation is determined by regulatory support, operational discipline, and resident participation.

2 LITERATURE REVIEW

Green roofs are considered a multifunctional ecosystem technology that combines climate adaptation with improvements to urban environmental quality. Studies by Oberndorfer, Lundholm, Bass, Mentens, Raes, Hermy **(Oberndorfer, Lundholm, Bass et al., 2007; Mentens, Raes & Hermy, 2006)** demonstrate in detail that the structure of the roof layers and the selection of vegetation determine the range of ecosystem services-from reducing peak stormwater runoff to mitigating the urban heat island effect in metropolitan areas.

The energy effect of green roofs is manifested in the reduction of summer heat gains and the lowering of building cooling loads. For accurate evaluation, researchers emphasize the need to calibrate numerical models with data from in-situ measurements on real buildings across different climatic regimes **(Jaffal, Ouldboukhitine & Belarbi, 2012)**.

The hydrological efficiency and long-term performance of green roofs depend on design and operational parameters. Reviews by Susca, Li, Babcock **(Susca, 2019; Li & Babcock, 2014)** systematize the influence of substrate depth and properties, drainage solutions, and maintenance regimes on stormwater retention and detention, including seasonal variability.

The biological composition of green roof systems requires conscious selection of plant species suited to specific climatic conditions and operational objectives. Research has shown that the resilience of plant communities and their contribution to microclimatic effects depend on diversity, life forms, and stress tolerance of species, as well as on maintenance strategies **(Shafique, Kim & Rafiq, 2018; Dvorak & Volder, 2010)**.

Rooftop urban agriculture confirms the practical feasibility of combining the technological and food-producing functions of rooftops. Whittinghill, Rowe, and Sanye-Mengual, Oliver-Sola, Montero, Rieradevall **(Whittinghill & Rowe, 2012; Sanye-Mengual, Oliver-Sola, Montero & Rieradevall, 2015)** describe requirements for sanitation, logistics, and product quality, and assess the environmental and economic consequences of integrating agricultural practices into the urban fabric using life-cycle assessment methods.

Building-integrated rooftop greenhouses (BIRG/I-RTG) utilize the exchange of heat and moisture between heated indoor spaces and the greenhouse volume. Several studies **(Sanjuan-Delmas, Rovira-Val, Nadal, Rieradevall & Josa, 2018; Nadal, Ceron-Palma, Cuerva et al., 2017)** demonstrate the potential for heat recovery, utilization of CO_2 from ventilation, and rainwater harvesting, which improve the energy performance and environmental profile of urban food production.

The organizational dimension of such projects requires cross-sectoral collaboration among municipalities, businesses, and residents. Research by Benis, Reinhart, Ferrao, and Specht, Siebert, Hartmann et al., **(Benis, Reinhart & Ferrao, 2018; Specht, Siebert, Hartmann et al., 2014)** emphasizes the importance of stakeholder mapping, early-stage communication, and overcoming institutional barriers-from rooftop access regulations to operational regimes and insurance requirements.

A systematic review of rooftop urban agriculture highlights typologies, governance models, and key barriers to implementation Kalantari, Tahir, Joni, Fatemi **(Kalantari, Tahir, Joni & Fatemi, 2018)**. It is noted that successful scaling depends on municipal support programs, standards, and cooperative forms of resident participation.

Vertical farming is evolving at the intersection of agricultural technology, microclimate engineering, and digital control. Studies by Al-Kodmany, and Beacham, Vickers, Monaghan 2019 **(Al-Kodmany, 2018; Beacham, Vickers & Monaghan, 2019)** underline the sensitivity of project economics to energy efficiency, tariffs, and the quality of thermal integration, as well as the importance of modular design.

LED-based horticultural lighting has become a key driver of productivity in controlled environments. Spectral tuning and dosing strategies allow optimization of photosynthesis and product quality while reducing specific energy consumption, as comprehensively reviewed by Pattison, Tsao, Brainard, Bugbee **(Pattison, Tsao, Brainard & Bugbee, 2018).**

Assessments of the food production potential of cities indicate that a significant share of vegetable output can be localized, provided that climate, building morphology, and sanitary-hygienic standards are properly considered. Such assessments are useful for scenario planning of urban food systems and logistics **(Payen, 2022).**

The ecological effects of green roofs include reductions in air and water pollution, as well as the filtration of dust and particulates **(Rowe, 2011; Van Mechelen, Dutoit & Hermy, 2015)**. At the same time, plant selection and the development of monitoring metrics for vegetation quality have a critical influence on the resilience of ecosystem services and the long-term performance of these systems.

The concept of "reconciliation ecology" applied to rooftops and walls emphasizes the compatibility of urban development with biodiversity. Operational reports underline the necessity of scheduled maintenance and condition monitoring, while long-term observation series are documented in studies by Francis, Lorimer, Liu, Minor **(Francis & Lorimer, 2011 and Liu & Minor, 2005).**

Empirical data confirm the contribution of green roofs to maintaining and enriching urban biodiversity **(Williams, Lundholm & MacIvor, 2014; Roehr & Kong, 2010)**. Parallel findings show a substantial reduction of surface runoff in temperate climates when design and operational requirements are met.

Extensive green roofs in several cities have demonstrated reductions in energy consumption and improvements in indoor thermal comfort. In addition, attenuation of the urban heat island effect has been recorded at the neighborhood and microclimate levels **(Getter & Rowe, 2006; Alvarez & Velasco, 2020).**

Regional research within the post-Soviet context, including case studies in Almaty, highlights the importance of regulatory support and the inclusion of green solutions in modernization roadmaps. The influence of renovation governance regimes on the success of green infrastructure implementation is discussed in comparative works by Murzabayeva, Lapshina, Tuyakayeva, and Khmelnitskaya, Ihalainen, **(Murzabayeva, Lapshina & Tuyakayeva, 2022; Khmelnitskaya & Ihalainen, 2021).**

Design recommendations for rooftop agriculture establish requirements for access, safety, and operation, including rainwater harvesting and the management of organic waste. Long-term observations of rooftop vegetation clarify successional trajectories, resilience, and maintenance volumes **(Daneshyar, 2024; Kohler, 2006).**

Socioeconomic assessments demonstrate that when externalities are accounted for (microclimate, runoff, health, community effects), the benefits of green roofs increase significantly **(Bianchini & Hewage, 2012; Lundholm, 2006)**. The "habitat template" approach provides a framework for linking architecture and biodiversity, setting design guidelines for façades and rooftops.

3 MATERIALS AND METHODS

The comparative method involved a qualitative analysis of typical interventions-extensive and intensive green roofs, rooftop greenhouses, vertical farms, and nature-based stormwater infrastructure-using a unified parameter matrix. The parameters included:

−Design loads and verification of load-bearing capacity (including snow, wind, and seismic actions);

−Structural nodes and detailing;

−Water and energy management (rainwater harvesting, heat recovery/utilization);

−Operational and maintenance requirements;

−Sanitation and safety standards;

−Indicative CAPEX/OPEX values, where available.

Based on the resulting intervention profiles, a synthesis of design principles and a phased implementation model was developed, tailored to the conditions of residential district modernization.

3.1 Main directions of modernization

The modernization of residential districts implies a comprehensive set of transformations that affect not only the architectural and spatial organization of development but also its engineering, environmental, and social dimensions. One of the priority directions is the renewal of the housing stock: façade reconstruction, thermal insulation of building envelopes, replacement of outdated engineering networks, and the implementation of modern energy-efficient technologies. These measures can significantly reduce operating costs, improve comfort levels, and extend the service life of buildings.

It is also important to reconsider attics, basements, and technical floors, which previously served exclusively utilitarian purposes: they may be adapted for household and public functions, cultural venues, and educational spaces.

Equally important is the creation of new public and recreational areas. Courtyard territories, once perceived as secondary or transit spaces, acquire multifunctional roles during modernization: they become places for recreation, sports, cultural activities, and resident interaction. Such transformation redefines the district from a collection of individual buildings into a cohesive social space that strengthens horizontal connections and fosters local identity.

Special attention is given to environmental aspects. In modern cities, modernization is impossible without systems for rational water use, waste separation and recycling, the application of renewable energy sources, and the enhancement of ecological resilience in urban development. Architectural and engineering solutions must be integrated into a single concept in which buildings and courtyards function as interconnected elements of a unified environment.

Ultimately, the modernization of residential districts becomes a tool for shaping a qualitatively new urban environment, where architectural, engineering, and social transformations reinforce one another and are directed toward creating a sustainable, comfortable, and adaptive living space.

3.2 Integration of eco-agroarchitecture into modernization processes

A key principle of such transformation is multifunctionality. Spaces previously regarded as purely utilitari

an or secondary (courtyards, passage zones, parking areas) can be reimagined as places for shared living and activity. Here, gardening communities may emerge: residents cultivate greens, organize workshops, host lectures, festivals, and neighborhood gatherings. The user becomes a co-author of the environment, which increases engagement and responsibility, strengthens horizontal ties, and supports local identity.

In conditions of dense urban development and a shortage of available land, the importance of vertical greening and green roofs grows considerably. These solutions compensate for land scarcity, provide additional recreational areas, and deliver a wide range of benefits: reducing air and noise pollution, improving building insulation, and contributing to energy savings. When integrated with systems for rainwater harvesting, organic waste recycling, and smart sensor technologies, green roofs and façades become elements of closed ecological cycles: each building functions as a miniature “living organism” embedded within the microdistrict system.

Small-scale agricultural production represents another essential component. International experience demonstrates that urban food cultivation is both possible and effective, offering significant educational and therapeutic potential. Under contemporary conditions, such practices evolve through rooftop and basement greenhouses, modular farms, micro-facilities for organic waste processing, and compost production. These facilities may operate as community initiatives, cooperatives, or social enterprises, simultaneously stimulating the local economy, creating jobs, and reducing dependence on external food supplies.

Particular attention is also given to ecological water infrastructure. Traditional engineering solutions for stormwater drainage are gradually giving way to nature-based systems: rain gardens, bio-ponds, and water-retentive landscape forms. These reduce the load on urban sewer systems, prevent localized flooding, and create aesthetically appealing and comfortable recreational spaces. In the context of climate change and increasingly frequent extreme precipitation events, such solutions become critically important, shaping a resilient system of interaction between the urban fabric and natural processes.

A significant direction is the architectural adaptation of existing buildings. Attics, technical floors, and other “dead zones” can be converted into greenhouses, conservatories, co-working spaces, or cultural pavilions, thereby activating previously unused areas. The addition of photovoltaic panels, rainwater harvesting systems, composters, and household waste processing units renders buildings partially autonomous and resource-efficient, reducing operating costs and enhancing the resilience of the urban environment.

New practices require not only engineering but also cultural change. Programs of “green education” are essential for raising environmental literacy, developing skills in gardening and sustainable consumption. Resident engagement through educational initiatives, joint projects, and volunteering not only broadens knowledge but also fosters a responsible attitude toward the environment, laying the foundation for long-term transformation of urban lifestyles.

Thus, the eco-agroarchitectural approach spans all levels of the urban environment-from individual courtyards and buildings to entire blocks. Its implementation reduces ecological pressures, strengthens climate resilience, develops social connections, and supports the local economy. Importantly, this is not merely a technical modernization, but a large-scale socio-cultural process in which every resident plays an active role: the city of the future is born from the synergy of engineering solutions and collective efforts striving for harmony between people and nature.

3.3 Case example

Havana (Cuba). The urban organopónicos system, covering areas of up to several hectares across sites of varying scale, emerged during a food crisis and demonstrated the effectiveness of utilizing vacant land-along streets, on rooftops, and in courtyards-for organic vegetable cultivation with minimal resource inputs **(Figure 1)**. By 1998, Havana hosted more than 8,000 urban farms, supplying a substantial share of the residents’ vegetable.

Figure 1 - Rows of the "Organopónico Plaza" area with seasonal greens: lettuce, spring onion, and others **(Cuba's organic revolution, 2008)**

Bosco Verticale (Milan, Italy). A residential complex with vertical façade greening: more than 90 plant species, including trees and shrubs, integrated into the architecture to enhance biodiversity and microclimate **(Figure 2)**.

Figure 2 - Greened loggias of Stefano Boeri's iconic building Bosco Verticale. **(Boeri Studio's Bosco Verticale was the most significant building of 2014, 2025)**

One Central Park (Sydney, Australia). A multifunctional building developed as part of the Central Park redevelopment project. The skyscraper features a "hanging garden" façade, LED illumination, and an integrated irrigation system within the framework of sustainable architecture. It was recognized as one of the world's best high-rise residential complexes in 2014. At 116 meters in height, the building's façades present challenging conditions for vegetation due to strong winds and intense solar radiation (despite its orientation away from the south). For this reason, 350 plant species capable of withstanding such stresses were selected for greening. Irrigation is supplied by the complex's wastewater, treated on-site through its own filtration system **(Figure 3)**.

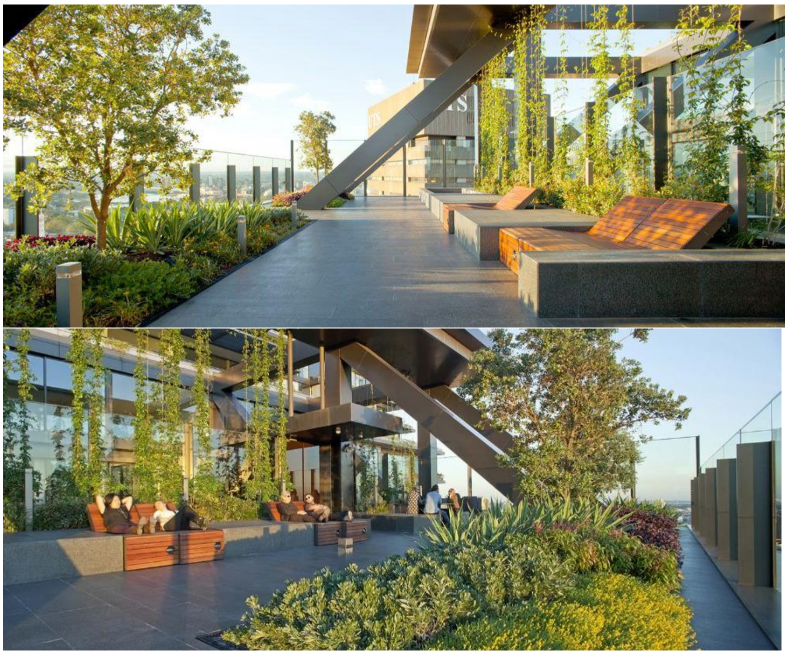

Figure 3 - Terrace of the residential complex planted with vegetation. **(N.Frolova, 2014)**

Lufa Farms (Montreal, Canada). Commercial greenhouses located on the rooftops of industrial buildings, supplying the city’s population with fresh vegetables while minimizing logistics and enhancing food system resilience **(Figure 4).**

Figure 4 - The largest greenhouse located on the rooftop of Lufa Farms’ wholesale distribution center **(Top 5 samyh bol'shih teplic v mire, 2024**)

Figure 5 diagram classifying solutions: courtyard gardens/orchards, green roofs (extensive/intensive), rooftop greenhouses, vertical farms, and nature-based stormwater infrastructure. For each typology, the diagram illustrates placement zones and key construction details (root-resistant waterproofing, drainage and filter layers, structural frames/anchoring, water supply and access points). Minimum requirements for engineering interfaces (irrigation, drainage, power supply) and load limitations are indicated. The scheme is intended to support the selection of configurations according to the baseline conditions of a given site.

Figure 5 - Typologies of eco-agroarchitectural element integration (authors' material)

Figure 6 - Three-phase model: quick interventions on existing roofs/courtyards; pilot projects on public buildings with baseline monitoring; and scaling-up based on standards and programs. For each phase, the inputs (structural assessment, utilities), target metrics (runoff retention, ΔT, energy consumption), and decision points are indicated. The structure of the phases is aligned with scheduling, resources, and management risks.

Figure 6 - Phased model for implementing solutions in residential districts (authors' material)

Table 1 presents additional permanent loads, indicative capital and operating expenditures, as well as expected effects and constraints for each type of solution. For green roofs, load benchmarks are given in the water-saturated state: extensive ~ 0.6-1.2 kN/m^2, intensive ≥1.5 kN/m^2; for rooftop greenhouses, the self-weight of glazing/structural frames together with wind and snow actions are considered; for vertical farms, the weight of equipment and water is taken into account.

The consolidated indicators are intended for pre-design structural capacity checks, preliminary selection of construction solutions, and high-level budgeting (CAPEX/OPEX). At the same time, operational constraints (access, sanitary requirements, energy demand) are recorded, to be further detailed at the project documentation stage.

Table 1
Comparison of Solutions by Loads, Costs, and Characteristics (author's material)

Solution	Additional Load	Capital Expenditures	Operating Expenditures	Key Effects	Constraints
Courtyard Gardens	Low	Low	Low	Community building, educational effect, local microclimate improvement	Need for plot management and water supply
Extensive Green Roof	0.6-1.2 kN/m² (saturated condition)	Low-Medium	Low	Reduction of surface runoff, mitigation of overheating, increase in biodiversity	Maintenance of substrate and drainage elements
Intensive Green Roof	≥ 1.5 kN/m²	Medium-High	Medium	Food production, climatic and recreational benefits	Requirements for load-bearing structures and irrigation system
Building-Integrated Rooftop Greenhouse (BIRG)	Medium (weight of frame and glazing)	High	Medium-High	Food production, integration of closed resource cycles	Increased energy demand, sanitary requirements
Vertical Farm	Low-Medium (equipment and water weight)	High	High	High yield and year-round production	Increased energy demand, need for specialized expertise

Table 2 systematizes elements of nature-based water infrastructure (rain garden, bioswale, rainwater storage tank, composting, and PV-green roof combination), indicating their target functions, maintenance requirements, and typical locations.

Operational regimes include periodic removal of sediment, inspection of filters and overflows, checks of pumping equipment, and seasonal care of vegetation. The information provided defines the composition of the stormwater management chain and the operational practices required to ensure the designed hydraulic efficiency.

A unified parameter format ensures comparability of alternatives when developing operation and maintenance regulations.

Table 2
Elements of Water Infrastructure and Maintenance Requirements (author's material)

Intervention	Maintenance	Typical Locations
Rain Garden	Seasonal plant care, removal of sediment	Courtyard spaces
Bioretention System (Bioswale / Biofilter)	Regular removal of debris and sediment, inspection of inlets/outlets	Edges of pedestrian paths and parking areas
Rainwater Harvesting Tank	Filter and pump maintenance, tank flushing	Rooftop or basement areas
Composting	Periodic aeration and mixing, moisture control	Courtyards and service areas
Photovoltaic Panels Combined with Green Roof	Regular cleaning and monitoring of panels and vegetation layer	Accessible/operated rooftops

4 RESULTS AND DISCUSSION

The challenge of modernizing residential districts today extends far beyond engineering and technical solutions. Contemporary cities face environmental, social, and food-security pressures, and only comprehensive approaches can deliver durable outcomes. Integrating eco-agroarchitectural elements into residential environments appears to be a promising direction that simultaneously enhances the quality of urban infrastructure and creates new opportunities for residents.

Although Kazakhstan currently lacks examples of the systematic integration of agro-ecological solutions into microdistrict development, international practice demonstrates successful models of urban agriculture: rooftop greenhouses and farms, vertical farms, and community agro-spaces have been implemented and operate stably in major metropolitan areas. Moreover, academic studies and peer-reviewed publications offer methodological guidance for designing such systems in residential settings, forming a basis for adaptation to the Kazakhstani context.

Thus, the modernization of residential districts with the integration of eco-agroarchitectural elements can become one of the key directions in the development of Kazakhstan's urban environment. This approach would not only improve the energy performance and environmental quality of the housing stock, but also foster new forms of social activity, strengthen local food security, and move cities closer to a sustainable development model. The absence of domestic precedents should not be viewed as a constraint; on the contrary, it opens opportunities for pioneering projects capable of setting new standards for the design and operation of the residential microdistricts of the future.

The analysis of sources confirms that combining green roofs with nature-based stormwater infrastructure consistently reduces both total volumes and peak stormwater flows, while simultaneously improving the microclimate through evaporative cooling and increased thermal inertia of the building envelope. These measures help mitigate the urban heat-island effect and, with appropriate substrate and plant selection, enhance the structural and species diversity of urban biotopes. For durable outcomes, not only the types of interventions matter, but also their coordination: rain gardens, bioretention systems, rainwater storage, composting, and green roofs must operate as a unified courtyard- and block-scale ecosystem.

The hydrological effect manifests through two mechanisms: retention and detention. Green roofs and rain gardens "cut" peak runoff by redistributing flows over time, thereby reducing loads on existing storm sewers and lowering the likelihood of courtyard flooding. Biologically based stormwater systems (bioswales, biofilters) improve water quality via filtration through vegetative and mineral layers and promote infiltration where geotechnical conditions allow. Rainwater tanks enable partial capture of precipitation for subsequent irrigation, reducing potable-water demand and stabilizing vegetation water regimes during dry periods. The effectiveness of these measures depends on proper hydrologic siting within courtyard topography, the specified share of pervious surfaces, and the overflow capacity during peak rainfall.

The microclimatic effect is expressed in lower surface temperatures of roofs and pavements due to evaporation and shading, which improves pedestrian-level thermal comfort and decreases building cooling loads in warm seasons. Green roofs additionally shield roofing assemblies from extreme temperature swings and ultraviolet exposure, extending the service life of waterproofing. At the block scale, a mosaic approach is important: alternating green elements with pervious coverings and tree-shrub groupings creates heat-resilient micro-zones and improves the aeration of courtyard spaces.

Biodiversity support is achieved through careful selection of substrate and plant species. Practice shows that the use of native and drought-tolerant species reduces irrigation demand, increases stress resistance, and promotes the formation of stable trophic networks (pollinators, entomofauna, urban birds). Gradual development is important: first establishing a resilient baseline floristic composition, then introducing continuous-bloom flowerbeds and "pockets" with seed-bearing plants to enable natural self-seeding. At the same time, invasive species must be excluded, and allergenicity requirements must be considered.

4.1 Productive solutions

Rooftop greenhouses and vertical farms-add new value but impose higher requirements on engineering integration. Rooftop greenhouses effectively utilize surplus building heat and solar radiation; with recovery systems, it is possible to stabilize thermal regimes and reduce auxiliary heating costs. Vertical farms typically require precise control of artificial lighting and microclimate, which imposes demands on power supply, heat removal from light sources, and water treatment systems. In both cases, sanitary regulations are mandatory: monitoring water quality for irrigation, maintaining hygienic working conditions, pest management without toxic agents, ensuring adequate ventilation, and preventing condensation that could damage building envelopes. Without these measures, productive systems risk becoming sources of operational problems.

For post-Soviet microdistricts, structural capacity assessment and operational safety are critical. Before implementing a green roof or greenhouse, load-bearing structures must be verified: accounting for permanent loads from water-saturated substrate, snow and wind actions, and dynamic loads from maintenance. Fire-safety measures (fire breaks, fire-service access), safe roof access, and maintenance protocols that avoid damage to waterproofing are essential. At the courtyard scale, existing networks, slopes, and potential internal flooding zones must be considered; bioswales and rain gardens should be placed to avoid soaking building foundations and to ensure safe overflow discharge.

4.2 Operation and maintenance are key determinants of long-term performance.

For green roofs, this includes seasonal servicing of the vegetative layer, inspection of gutters, drains, and gravel firebreaks, and restoration of mulch. For biobased stormwater systems, routine removal of debris and sediment is required, along with inspection of filter layers and re-establishment of turf after extreme rainfall. Rainwater tanks require filter and pump checks, preventive flushing, and water-quality monitoring. Introducing composting closes the organic loop: green waste from courtyards and roofs becomes a resource for substrates and mulch. Effectiveness increases when a responsibility matrix defines the roles of the homeowners' association/management company, landscaping contractors, and active residents, as well as baseline service levels and response times to events (drought, heavy downpour, windthrow).

Co-governance models and resident participation enhance system resilience.

Pilot plots can be assigned to courtyard communities under the guidance of professional curators: residents participate in species selection and conduct simple end-to-end monitoring (e.g., sediment gauges, visual checklists), while the management company handles high-risk professional tasks (pump maintenance, waterproofing repairs). Public displays and digital panels at building entrances that show accumulated rainwater volumes, the number of irrigation events without potable water, and surface-temperature trends make results visible and build trust.

A phased strategy reduces risks and builds datasets for scaling.

Phase 1 (quick wins): low-risk interventions-rain gardens in flow-accumulation zones, localized biofilters along parking edges, small tanks for landscape irrigation.

Phase 2: extensive green roofs on technical areas with easy access and minimal additional weight.

Phase 3: integration of photovoltaic panels with green roofs to improve energy and microclimatic performance.

Phase 4: productive solutions-rooftop greenhouses and compact vertical farms-in buildings with verified structural reserve and ready engineering infrastructure.

Each phase is accompanied by monitoring and iterative refinement of O&M protocols.

Monitoring should be structured as an evidence-based management system. Core indicators include: the proportion of runoff reduced and frequency of overflows, surface temperature of roofs and pavements, substrate moisture, plant survival rates, maintenance costs, and number of complaints. Additional indicators may cover biodiversity (pollinator and bird counts), while for productive systems they include yield and specific energy intensity. Data collected over at least one full hydrological year enables adjustments to design solutions, optimization of maintenance schedules, and evidence-based scaling of successful prototypes to adjacent courtyards and rooftops.

The economic dimension consists of initial capital investments and operating expenditures. Operating costs can be reduced through deliberate selection of durable materials, standardization of details, and training of staff and residents in simple maintenance protocols. Additional value is created by the "stacking of effects": water savings from storage tanks, reduced cooling costs, extended service life of waterproofing, localized production of fresh produce, and the enhancement of courtyard "social capital." The presence of a clear co-financing model (municipal programs, grants, business partnerships) accelerates scaling, but it is critical that each solution remains viable within realistic budgets and load conditions.

Taken together, the results demonstrate that the integration of green roofs, nature-based stormwater infrastructure, and productive agro-elements into post-Soviet residential districts is technically feasible and managerially achievable, provided phased implementation, strict adherence to O&M regulations, and transparent monitoring are in place. This approach mitigates climatic and hydrological risks, enhances the quality of the urban environment, and generates sustainable added value for both residents and management organizations.

5 CONCLUSIONS

1. Integrating eco-agroarchitectural elements in the modernization of residential districts simultaneously addresses environmental, social, and food-security objectives while improving energy efficiency and overall urban environmental quality.
2. The absence of Kazakhstani precedents is not a barrier: drawing on international practice and scholarly guidance enables the launch of pilot projects that can establish new standards for design and operation.
3. Eco-agroarchitecture functions as a truly multidisciplinary modernization tool: it reduces stormwater risks and urban overheating, enhances thermal comfort and biodiversity, and stimulates a local care economy and resident cooperation. The effect is robust when solutions are integrated into a unified courtyard - block system.
4. Starter measures - extensive green roofs, rain gardens, and community gardens - deliver "quick wins" with moderate costs and low risk. They cut peak runoff, improve the microclimate, and raise social engagement; simple O&M regulations and clear roles for responsible parties are essential.
5. Rooftop greenhouses and vertical farms should be introduced as pilots on public buildings. Load calculations, integration with heat and lighting systems, and sanitary requirements are mandatory. Energy and water monitoring ($kWh/kg, L/kg$) enables rapid process adjustment and cost control.
6. System resilience rests on three pillars: reliable structural calculations and details; clear O&M protocols (seasonal inspections, cleaning, safe access); and co-governance models with resident participation, formalized through a responsibility matrix and a dedicated budget.
7. For Kazakhstan, an optimal pathway is a phased model - "quick effects - pilots - scaling up" within municipal programs and standards: typified solutions, procurement criteria, target monitoring indicators, and funding for maintenance ensure reproducibility and the wide replication of best practices.

REFERENCES

1. **Oberndorfer, E., Lundholm, J., Bass, B., et al.** (2007). Green roofs as urban ecosystems: Ecological structures, functions, and services. BioScience, 57(10), 823-833. https://www.researchgate.net/publication/232694304_Green_Roofs_As_Urban_Ecosystems_Ecological_Structures_Functions_And_Services

2. **Mentens, J., Raes, D., & Hermy, M.** (2006). Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landscape and Urban Planning, 77(3), 217-226. https://doi.org/10.1016/j.landurbplan.2005.02.010
3. **Jaffal, I., Ouldboukhitine, S.-E., & Belarbi, R.** (2012). A comprehensive study of the impact of green roofs on building energy performance. Renewable Energy, 43, 157-164. https://doi.org/10.1016/j.renene.2011.12.004
4. **Susca, T.** (2019). Green roofs to reduce building energy use? A review on key structural factors of green roofs and their effects on urban climate. Building and Environment, 162, 106273. https://doi.org/10.1016/j.buildenv.2019.106273
5. **Li, Y., & Babcock, R. W**. (2014). Green roof hydrologic performance and modeling: A review. Water Science and Technology, 69, 727-738. https://doi.org/10.2166/wst.2013.734
6. **Shafique, M., Kim, R., & Rafiq, M.** (2018). Green roof benefits, opportunities and challenges-A review. Renewable and Sustainable Energy Reviews, 90, 757-773. https://doi.org/10.1016/j.rser.2018.04.006
7. **Dvorak, B., & Volder, A.** (2010). Green roof vegetation for North American ecoregions: A literature review. Landscape and Urban Planning, 96(4), 197-213. https://doi.org/10.1016/j.landurbplan.2010.03.005
8. **Whittinghill, L. J., & Rowe, D. B.** (2012). The role of green roof technology in urban agriculture. Renewable Agriculture and Food Systems, 27(4), 314-322. https://doi.org/10.1017/S174217051100038X
9. **Sanyé-Mengual, E., Oliver-Solà, J., Montero, J. I., & Rieradevall, J.** (2015). An environmental and economic life cycle assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. The International Journal of Life Cycle Assessment, 20(3), 350-366. https://doi.org/10.1007/s11367-014-0836-9
10. **Sanjuan-Delmás, D., Rovira-Val, M. R., Nadal, A., Rieradevall, J., & Josa, A.** (2018). Environmental assessment of an integrated rooftop greenhouse for food production in cities. Journal of Cleaner Production, 177, 326-337. https://doi.org/10.1016/j.jclepro.2017.12.147
11. **Nadal, A., Cerón-Palma, I., Cuerva, E., et al.** (2017). Building-integrated rooftop greenhouses: An energy and environmental assessment. Applied Energy, 187, 338-351. https://doi.org/10.1016/j.apenergy.2016.11.022
12. **Benis, K., Reinhart, C. F., & Ferrão, P.** (2018). Development of a simulation-based decision support workflow for the implementation of rooftop greenhouses. Journal of Industrial Ecology, 22(1), 138-152. https://www.sciencedirect.com/science/article/abs/pii/S0959652617301452
13. **Specht, K., Siebert, R., Hartmann, I., et al.** (2014). Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. Agriculture and Human Values, 31, 33-51. https://doi.org/10.1007/s10460-013-9448-4
14. **Kalantari, F., Tahir, O. M., Joni, R. A., & Fatemi, E.** (2018). Opportunities and challenges of rooftop urban agriculture: A systematic review of literature and stakeholders' analysis. Journal of Cleaner Production, 197, 1039-1056. https://doi.org/10.1016/j.jclepro.2018.06.052
15. **Al-Kodmany, K.** (2018). The vertical farm: A review of developments and implications for the vertical city. Buildings, 8(2), 24. https://doi.org/10.3390/buildings8020024
16. **Beacham, A. M., Vickers, L. H., & Monaghan, J. M.** (2019). Vertical farming: A summary of approaches to growing skywards. The Journal of Horticultural Science and Biotechnology, 94(3), 277-283. https://www.researchgate.net/publication/331130061_Vertical_farming_a_summary_of_approaches_to_growing_skywards
17. **Pattison, P. M., Tsao, J. Y., Brainard, G. C., & Bugbee, B.** (2018). LEDs for photons, physiology and food. Nature, 563(7732), 493-500. https://doi.org/10.1038/s41586-018-0706-x
18. **Payen, F. T.,** (2022). How much food can we grow in urban areas? Food production and consumption potential in any city worldwide. Earth's Future, 10(5), e2022EF002748. https://pubmed.ncbi.nlm.nih.gov/36246543/

19. **Rowe, D. B.** (2011). Green roofs as a means of pollution abatement. Environmental Pollution, 159(8-9), 2100-2110. https://doi.org/10.1016/j.envpol.2010.10.029
20. **Van Mechelen, C., Dutoit, T., & Hermy, M.** (2015). Qualitative parameters for urban green roof vegetation. Landscape and Urban Planning, 143, 121-133.
21. **Francis, R. A., & Lorimer, J.** (2011). Urban reconciliation ecology: The potential of living roofs and walls. Journal of Environmental Management, 92(6), 1429-1437. https://www.sciencedirect.com/science/article/abs/pii/S0301479711000132
22. **Liu, K., & Minor, J.** (2005). Performance evaluation of an extensive green roof. Greening Rooftops for Sustainable Communities, Washington, D.C., pp. 1-11, https://sustainabletechnologies.ca/app/uploads/2013/03/NRC_EastviewGRrept.pdf
23. **Williams, N. S. G., Lundholm, J., & MacIvor, J. S.** (2014). Do green roofs help urban biodiversity conservation?. Journal of Applied Ecology, 51(6), 1643-1649. https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2664.12333.
24. **Roehr, D., & Kong, Y.** (2010). Runoff reduction effects of green roofs in Vancouver. Urban Water Journal, 7(6), 407-418. https://doi.org/10.4296/cwrj3501053
25. **Getter, K. L., & Rowe, D. B.** (2006). The role of extensive green roofs in sustainable development. HortScience, 41(5), 1276-1285. https://doi.org/10.21273/HORTSCI.41.5.1276
26. **Álvarez, A. E., & Velasco, E.** (2020). Mitigating urban heat island through green roofs. Urban Climate, 34, 100700.
27. **Murzabayeva, K., Lapshina, E., & Tuyakayeva, A.** (2022). Modernization of the living environment space using the example of an urban array of residential buildings from the Soviet period in Almaty. Buildings, 12(7), 1042. https://doi.org/10.3390/buildings12071042
28. **Khmelnitskaya, M., & Ihalainen, E.** (2021). Urban Governance in Russia: The Case of Moscow Territorial Development and Housing Renovation. Europe-Asia Studies, 73(6), 1149-1175. https://www.tandfonline.com/doi/full/10.1080/09668136.2021.1937573
29. **Daneshyar, E.** (2024). Residential Rooftop Urban Agriculture: Architectural Design Recommendations. Sustainability, 16(5), 1881. https://doi.org/10.3390/su16051881
30. **Köhler, M.** (2006). Long-term vegetation research on two extensive green roofs in Berlin. Urban Habitats, 4(1), 3-26.
31. **Bianchini, F., & Hewage, K.** (2012). Probabilistic social cost-benefit analysis for green roofs. Building and Environment, 58, 152-162. https://doi.org/10.1016/j.buildenv.2012.07.005
32. **Lundholm, J.** (2006). Green roofs and facades: A habitat template approach. Urban Habitats, 4(1), 87-101.
33. **Boeri Studio's Bosco Verticale was the most significant building of 2014** (2025). Dezeen. https://www.dezeen.com/2025/01/20/bosco-verticale-stefano-boeri-21st-century-architecture
34. **Frolova, N. (2014).** *"Zelenaya" arkhitektura nalitso* ["Green" architecture in sight]. *Archi.ru.* https://archi.ru/world/58450/zelenaya-arkhitektura-nalico (In Russ.).
35. *Top 5 samykh bol'shikh teplits v mire* [Top 5 largest greenhouses in the world]. (2024). *Svoefermerstvo.ru.* https://svoefermerstvo.ru/svoemedia/articles/top-5-samyh-bol-shih-teplic-v-mire (In Russ.).
36. *Cuba's organic revolution.* (2008, April 4). *The Guardian.* https://www.theguardian.com/environment/2008/apr/04/organics.food