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Modern principles of the formation of facilities for the production of crop products

Abstract. The relevance of this study is manifested in the need to adapt architectural solutions to changing climatic conditions and anthropogenic factors. The purpose of the study was to examine modern principles in the formation of structures for the production of crop products and identify critical aspects that are crucial for optimising this process. Methods of analysis, synthesis, deduction, and induction were used to achieve this goal. The findings indicate that architectural solutions must be adapted to varying climatic conditions in order to optimise plant growth. This necessitates adjustments to temperature control, lighting, and water management systems. Specific architectural examples, including the Urban Vertical Farm of Brightfood in Shanghai and Vertical Farm Beijing, are presented as case studies to demonstrate these principles. The Urban Vertical Farm incorporates terraces with edible plants, advanced hydroponic systems, and transparent materials that maximise sunlight. Similarly, Vertical Farm Beijing integrates a closed-loop water system and efficient LED lighting to minimise energy and water consumption, thereby promoting urban food security. These examples illustrate the importance of adapting architectural designs to environmental and urban constraints. The study provided an opportunity to understand the importance of architectural and engineering solutions in crop production, which can lead to the development of more efficient and sustainable plant-growing systems, which in turn can increase the productivity and quality of agricultural products

Keywords: yield optimisation; natural-climatic factors; innovative agrotechnologies; structures; cultivation systems

INTRODUCTION

Crop production facilities, such as greenhouses, play an essential role in ensuring food security and growing plants in various climatic conditions. These unique facilities create optimal conditions for plant production, which allows increasing yields and diversifying the range of products on the market. One of the critical advantages of greenhouses is the ability to control temperature, humidity, and indoor lighting. This is especially important in regions with cold winters or extreme climatic conditions where traditional field farming is limited. Such structures protect plants from adverse weather conditions and also help to extend the growing season, which allows crops to be grown year-round. The problem of the study is the need to adapt facilities for producing crop products to changing climatic

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conditions, resource instability, and urbanisation. Existing approaches to architectural solutions for crop production facilities are often insufficiently effective and do not always consider all aspects that affect the productivity and sustainability of crop production.

In the most recent publication by B.E. Singleton (2023), he addresses challenges in urban planning that are analogous to those encountered in agricultural policy, particularly the inadequate budgetary allocation for social spending, the geographical remoteness of agricultural regions from major markets, and the insufficient infrastructure for rural self-governance. The author emphasises the necessity for more robust governmental interventions to support these rural areas.

Z. Haghighi *et al*. (2021) examine the discrepancy between the financial resources required for rural development and the actual levels of funding available. They identify key challenges, such as the demand for comprehensive services in rural populations and the territorial access to vital services. This discrepancy between the elevated costs for agricultural producers and the necessity for social adaptation serves to illustrate the precarious state of food security. The authors also posit that the enhancement of rural infrastructure, including the establishment of specialised facilities for plant cultivation, is a crucial step in addressing these disparities and fostering agricultural growth.

W. Yang *et al*. (2024) investigate the role of innovation in agriculture, emphasising the significance of modern infrastructure that facilitates advanced technological developments. The authors put forth a series of pivotal strategies for fostering innovation, including the establishment of dedicated scientific and technological hubs, technoparks, and the implementation of incentives for investors. The authors posit that this approach could also be applied to the design and construction of controlled-environment buildings for plant production. Widespread innovation adoption would enable medium-sized agricultural enterprises to access cutting-edge equipment, expand operations, and modernise the agro-industrial complex, thereby enhancing sustainable development in the sector (Radchenko *et al*., 2023).

A. Amirbekova *et al*. (2023) place considerable emphasis on the importance of sustainable design in the context of residential and agricultural structures. The study demonstrates that architectural adaptations to environmental factors, particularly in the design of greenhouses and other plant-growing structures, can significantly enhance agricultural productivity. The research highlights the vital importance of sustainable development principles in the creation of resilient facilities that can withstand climate and resource challenges, thereby enhancing both the efficiency and resilience of agricultural systems.

M. Guth *et al*. (2020) concentrate on the part played by architectural design and spatial planning in promoting the economic sustainability of agricultural enterprises within the context of the European Union's Common Agricultural Policy. It is emphasised that architectural strategies integrated within CAP guidelines play a pivotal role in enhancing the resilience and adaptability of rural infrastructure. The adoption of analogous architectural and planning methodologies in Kazakhstan could serve to reinforce the structural integrity of its agricultural facilities, enhance resource efficiency, and facilitate the modernisation of rural areas. This would, in turn, reinforce productivity and competitiveness in the agricultural sector.

M. Hassan & H.H. Silleli (2024) believe that the designs of modern cultivation facilities should provide the necessary biological conditions for growing plants, contributing to the production of a large volume of products through the possibility of organising a mechanised labour process and meeting all operational requirements. The modern technologies listed in the authors' study complement each other and allow approaching such an ideal scheme in which the agricultural complex will become environmentally friendly, waste-free, and economically very profitable.

According to A. Askarova *et al*. (2020), the organisation of agricultural lands and their arrangement, considering their regional natural-climatic features, is of the greatest importance in the modern conditions of Kazakhstan. The authors believe that the organisation of crop rotations and the design of the main elements of their arrangement are especially relevant since the arrangement of the arable land is the territorial basis for introducing modern soil and water protection technologies. The orderly use of pastures to prevent their degradation is of great importance, therefore, the methodology of organising pasture rotations and their arrangement was considered.

The main purpose of the study was to examine modern methods of forming plant structures and develop them.

MATERIALS AND METHODS

The study is based on a comprehensive analysis of existing architectural solutions and methods of growing plants, as well as an examination of current trends in agriculture and architecture. A review of the literature, including academic papers, as well as architecture publication ArchDaily (Stouhi, 2021; Tovar, 2024), was undertaken to identify effective contemporary methods and architectural solutions in crop production. In order to situate this study within a practical context, two prominent architectural examples were examined: the Urban Vertical Farm of Brightfood and Vertical Farm Beijing. Both facilities exemplify innovative design that integrates environmental considerations with urban food production needs, demonstrating sustainable architectural approaches in high-density urban areas.

In this study, an analytical method was employed to systematically examine the interrelationship between natural climatic factors and the architectural solutions utilised in crop production facilities. Furthermore, the analysis method was employed to ascertain the interrelationship between internal factors, such as the types of plants cultivated and the methods of cultivation, and the architectural design of crop production facilities. The analysis method was employed to ascertain how architectural solutions might be adapted to accommodate these factors, taking into account the impact of urbanisation, environmental pollution, and resource availability.

An analysis of parameters such as temperature, precipitation, humidity, solar radiation, and wind conditions in the region under study was conducted to determine the impact of climatic factors on architectural solutions. An analysis was conducted to assess the impact of temperature changes, which allowed determining the need to adapt heating and air conditioning systems in crop production facilities. The study included an analysis of the amount and distribution of precipitation affecting water supply and drainage in crop production facilities. Architectural solutions that allow controlling humidity inside structures to ensure optimal conditions for plant growth and development were analysed. Methods for optimising the availability of sunlight, such as the use of transparent materials and orientation systems, were considered to ensure optimal conditions inside the structures.

In this study, the synthesis method was used to integrate various aspects and components related to the architectural design of structures for crop production to create a comprehensive and integrated methodology. As a result of the synthesis of climate data, engineering solutions aimed at solving problems related to climatic conditions were developed. The synthesis of all the data led to the creation of an integrated approach to the architectural design of structures for crop production. This synthesis method contributes to developing effective architectural solutions that optimally match climatic conditions and ensure sustainable and effective crop production in various regions.

The method of deduction was also used in the study; principles and theories were initially generalised, after which specific conclusions were derived from them. Initially, the general statement about the importance of architectural solutions in crop production was considered, and then this statement was deductively applied to the analysis of specific aspects, such as the influence of climatic factors, internal factors, and anthropogenic influences on the architecture of structures.

The induction method was used to identify general patterns and conclusions based on specific observations and data. The study analysed specific factors such as climatic conditions, internal factors, and anthropogenic influences and then inductively drew general conclusions about the importance of architectural solutions for optimising crop production facilities.

RESULTS

Architectural solutions of crop production facilities are crucial for the successful cultivation of plants, especially in a changing climate. Climatic factors such as temperature, precipitation, humidity, solar radiation, and wind conditions play a critical role in determining the efficiency and productivity of such structures (Muzdybayeva *et al.*, 2022).

The temperature conditions in the region have an important impact on the architectural solutions of crop production facilities. Temperature changes may require the adaptation of heating and air conditioning systems in greenhouses and the selection of plants resistant to specific temperature conditions. The amount and distribution of precipitation affect water supply and drainage in crop production facilities. Consideration of the type and intensity of precipitation is essential to determine the need for water supply management systems such as rain collectors and artificial irrigation systems. Air and soil humidity play a crucial role in plant health. Architectural solutions should consider humidity control inside structures to ensure optimal conditions for plant growth and development (McClements & Grossmann, 2021). The intensity and duration of sunlight during the day affect photosynthesis and plant growth. It is essential that architectural solutions are designed in a way that enhances sunlight availability within crop production facilities, thereby ensuring optimal conditions for plant growth. This can be achieved through the judicious selection and placement of transparent materials, such as double-glazed glass, which provide thermal insulation while allowing maximum light penetration. The orientation of the structure should be designed in a manner that captures the highest amount of natural sunlight, taking into account the geographic location of the building. This can be achieved through the strategic angling of facades to maximise exposure during peak daylight hours. Furthermore, the utilisation of diverse glass types, such as low-emissivity glass, can be implemented in specific areas to regulate heat gain without impairing light transmission, thus maintaining an optimal indoor environment for plant growth across varying seasons and conditions.

The choice of materials for the construction of crop production facilities may depend on climatic conditions. For example, in cold regions, thermal insulation materials (e.g., polyurethane foam, mineral wool) may be necessary, and in hot regions – materials that protect from solar radiation (e.g., reflective coatings, UV-resistant glass) (Zhangabay *et al.*, 2023). In regions with cold winters or hot summers, heating and air conditioning systems may be necessary to maintain optimal temperatures inside structures (Kaletnik *et al.*, 2020). Water collection and distribution systems can regulate the availability of moisture to plants, especially in regions with limited rainfall. Artificial lighting can be used to compensate for the lack of sunlight, especially during periods of insufficient insolation. Architectural elements such as wind walls or barriers can be used to protect plants from strong winds. Climate change creates new challenges for crop production facilities. Extreme weather conditions, higher temperatures, and unstable precipitation may require more advanced architectural solutions. Effective management of climatic factors is becoming a key aspect of successful agriculture and crop production.

It is important to understand that internal factors such as the type of plants grown, care methods, production goals, resource availability, and technical capabilities substantially affect the form and function of these structures. Different types of plants have different requirements for the height of the premises. Tall plants, such as some tree species, may require tall greenhouses or other structures with a large volume for vertical growth. Growing field crops such as grains and vegetables may require flat or low structures to ensure maximum lighting and access to the soil. The use of hydroponic systems and vertical farming provides opportunities to optimise the use of space and may require specific architectural solutions, such as vertical cultivation systems. The use of artificial lighting to support plant growth may require special overhead lighting systems and optimal placement of light sources. Heating, air conditioning, and humidification systems may require certain architectural solutions to distribute heat and moisture evenly. Irrigation and water supply management systems should be integrated into the architecture of the structure to ensure efficient water consumption. Architectural solutions for commercial plant production can include maximising productivity and space efficiency. Facilities for scientific research of plants should be designed to provide controlled conditions and accurate measurements. In educational institutions, architectural solutions may include educational elements that allow students to study the processes of growing plants.

The implementation of innovative architectural designs in the construction of crop production facilities exemplifies the feasibility of integrating sustainable design principles with the practical aspects of food production in urban settings. The global array of vertical farming structures exemplifies the efficacy of integrating architectural and environmental solutions to address the challenges posed by urban density, resource limitations, and climate conditions. Two noteworthy projects serve to exemplify these principles in practice: the Urban Vertical Farm of Brightfood in Shanghai, China, and Vertical Farm Beijing, situated in the heart of the Chinese capital (Shao *et al.*, 2021).

The Urban Vertical Farm of Brightfood, designed by Stefano Boeri and situated in Shanghai, China, represents a significant urban agriculture initiative that integrates food production with urban spaces, with the objective of addressing the challenges inherent to urbanisation (Fig. 1). The structure, which covers approximately 110,000 square meters, embodies the concept of a "vertical forest", with terraces and balconies planted with fruits and vegetables. This enhances biodiversity and creates visual appeal in the cityscape. The 12 terraced greenhouses, constructed from ETFE film, a lightweight and recyclable material, are orientated to maximise sunlight exposure for optimal plant growth within the urban environment. The integration of greenhouses with office spaces engenders a distinctive synergy between work and agriculture, enabling employees to engage directly in the farming process and develop a stronger connection to food sources.

Figure 1. Urban Vertical Farm of Brightfood

Source: D. Stouhi (2021)

Furthermore, the Urban Vertical Farm of Brightfood exemplifies notable environmental benefits. The implementation of advanced hydroponic systems within the farm has the potential to reduce water usage by up to 90% in comparison to conventional agricultural practices. Furthermore, by situating the food production process within the city limits, this project serves to enhance local food security while simultaneously reducing the carbon footprint associated with long-distance food transport. As a pioneering urban agriculture initiative, the Urban Vertical Farm of Brightfood serves as a model for sustainable practices in both urban planning and food production. It responds effectively to the challenges of urban density while promoting ecological resilience.

The Vertical Farm Beijing, situated on the campus of the Chinese Academy of Agricultural Sciences (CAAS) in central Beijing, is an urban agricultural project designed by Van Bergen Kolpa Architects in collaboration with AgriGarden and CAAS (Fig. 2). The facility, which spans 3,500 square meters, serves as both an educational and a production centre for urban horticulture. The architectural design incorporates a faceted glass façade, which serves to create a distinctive visual presence within the urban environment. This facade allows natural light to permeate the interior while also offering views of the cultivation areas. The facility is organised around a central atrium, with three floors dedicated to the cultivation of different crops. The first two floors utilise purple LED lighting for the cultivation of fruits, berries and leafy vegetables, while the third floor relies on natural daylight for the growth of tomatoes and cucumbers. An educational route within the building provides an insight into the diverse cultivation methods employed, including automated vertical lettuce systems and open-ground fruit trees. This allows visitors to observe innovative agricultural practices in action (Xu, 2024).

Figure 2. Vertical Farm Beijing

Source: E. Tovar (2024)

Sustainability is a fundamental aspect of the Vertical Farm Beijing project. The facility utilises a closed-loop water system, whereby irrigation water is recycled and reused, thereby reducing the generation of waste. The climate control system is managed through the use of natural ventilation and evaporative cooling, with passive heat extraction from sunlight and residual heat from LED lighting employed to regulate temperature. Furthermore, the building exemplifies resource efficiency through the capture of nutrients from sewage and carbon dioxide from the atmosphere, thereby promoting a circular economy approach to urban agriculture. Vertical Farm Beijing represents a significant advancement in sustainable urban food production, demonstrating how cities can integrate food production within urban landscapes to meet local demands and address ecological challenges.

The available budget may limit the choice of materials and technical solutions when designing crop production facilities. The qualifications of staff and their knowledge in the field of plant cultivation can influence architectural decisions, as complex systems may require more advanced knowledge and skills. Local anthropogenic factors, including urban development, air pollution, changes in land use, and resource availability, can affect the architecture and functionality of crop production facilities. Air pollution from emissions and transport may require special filtration and ventilation systems to ensure clean air inside structures. The availability of high-quality water for irrigation and hydroponic systems is a key aspect of the design of crop production facilities, especially in polluted water conditions. Climate change may require updating architectural solutions to adapt to new temperature conditions, precipitation levels, and extreme weather events. Crop production facilities may require additional safety measures, such as protection from hurricanes, floods, and other natural disasters (Xu *et al.*, 2022).

Solving the problem of air pollution and providing quality water for crop production facilities may include the following steps. Development and implementation of highly efficient filtration and ventilation systems for structures to minimise the impact of emissions and transport pollution. This may include the use of innovative air filtration technologies and low-emission ventilation systems. Implementation of water purification systems to ensure the availability of high-quality water for irrigation and hydroponic systems. Using advanced water purification and recycling technologies can mitigate the problems associated with contaminated water (Dovgal *et al.*, 2024). Updating architectural solutions of crop production facilities considering climate changes. This may include the development of buildings with more efficient thermoregulation adapted to new temperature conditions and extreme weather events. The introduction of additional security measures, such as protective systems against hurricanes, floods, and other natural disasters. The development and implementation of infrastructure capable of coping with extreme environmental conditions can reduce the risks to crop production facilities. Energy supply for heating, air conditioning, and lighting systems may require effective solutions to reduce costs and environmental impacts. The treatment and disposal of waste from crop production facilities is becoming an important aspect of sustainable agricultural production. Protected soil crop production enterprises are essential in providing food in a changing climate and urbanisation (Ozpinar, 2023). They are modern agrotechnical systems, including greenhouses, where plants are grown under controlled conditions.

Agriculture and crop production play an important role in ensuring food security and meeting the needs of the population. Modern architectural and design solutions that consider the features of crop production facilities are needed for the efficient production of crops. This study considers the modern principles of the formation of structures for the production of crop products and the features of architectural and constructive solutions that correspond to them (Weingaertner & Moberg, 2014). Various types of structures are used for growing crops, including greenhouses and warehouses for storing crops and machinery. Each of them requires specific architectural and design solutions (Table 1).

Table 1. Types of structures and their architectural-design features

Type of system	Semi-closed	Closed	Closed
Irrigation system	Land irrigation	Hydroponics	Hydroponics
Light source	Natural and artificial light	Artificial light	Artificial light
Spatial distribution	Horizontal	Horizontal and vertical	Vertical
Climate management	Ventilation and heating	Automated climate control	Automated climate control
Energy costs	Medium	High	High
Water use efficiency	Medium	High	High
Efficiency	Medium	High	High
Spatial efficiency	Medium	High	Very high
The complexity of the service	Medium	High	High

Source: compiled by the authors

Modern requirements for sustainability and energy efficiency have an impact on architectural and structural solutions in crop production facilities. For example, the use of insulation materials and specialised materials to reduce energy consumption and create more stable climatic conditions; the use of solar panels and other alternative energy sources to reduce dependence on conventional energy sources; the use of water treatment and recycling systems to reduce water consumption and negative environmental impacts. Modern crop production facilities also include automated control systems that help optimise production processes and control the conditions for plant growth. The use of monitoring and control systems for temperature, humidity, lighting, and other parameters. Automatic irrigation, fertilisation, and cleaning systems are used. Integration of management systems into digital platforms for data monitoring and analysis for more effective decision-making. An important aspect of achieving efficiency and sustainability in crop production is the development of modern architectural-structural solutions that consider the engineering infrastructure and its impact on the spatial planning solutions of the main buildings.

The choice of location for agricultural facilities and crop production enterprises depends on the availability of engineering infrastructure such as water, electricity, and sewerage systems. This affects spatial planning solutions, as the availability of communications and resources determines the possibilities for expansion and development of production. Engineering water supply and irrigation infrastructure is crucial for successful crop production. Modern architectural and design solutions include systems for collecting, storing and distributing water and innovative irrigation methods such as drip irrigation, which efficiently use water resources and provide plants with water in exact quantities (Bacon *et al.*, 2012). The engineering infrastructure includes energy supply and energy management systems. Modern crop production facilities actively use alternative energy sources such as solar panels and wind turbines to reduce dependence on conventional sources and the environmental footprint. The engineering infrastructure includes air quality control systems, critically important for preventing plant diseases and ensuring high yields. Filtration and ventilation systems provide optimal conditions for plant growth and reduce the risk of infections. The engineering infrastructure also includes digital technologies and automation systems that allow monitoring, managing production, and resource optimisation. This affects spatial planning solutions, as modern structures must be ready for integration with digital systems.

Urban planning placement of crop production facilities in the structure of a settlement poses a number of tasks related to the optimal use of land resources, considering the needs of the population and ensuring environmental sustainability. The basic principle of urban planning of plant-growing enterprises is to consider the needs of the population in terms of products and their accessibility. The location of crop production enterprises is close to populated areas can substantially reduce transportation costs and increase the availability of fresh products (Xue *et al.*, 2024). It also contributes to the development of the local economy and job creation. Urban planning of crop production facilities near settlements has the advantage of minimising transportation costs. This is important to reduce CO_2 emissions and environmental impacts, save resources, and reduce product costs. When placing crop production enterprises in the structure of settlements, it is important to consider the principles of sustainable development and environmental protection. The use of modern technologies and methods, such as green roofs, wastewater treatment, and reduction of soil pollution, helps to reduce the negative impact on nature and neighbouring settlements (Czyżewski *et al.*, 2019).

The climatic and natural conditions of a particular region should be considered in the formation of the structure. This includes determining optimal planting seasons, microclimatic features, and landscape features. For example, greenhouse complexes can be located in such a way as to maximise the use of solar energy in the region. Rational master plans should ensure the maximum use of land resources. This includes choosing the optimal locations for planting areas, minimising crop losses, and maximising yields per unit area. The preparation of master plans also includes the structuring of production processes. For example, observing crop rotation and planning places for storing crops and equipment. Optimisation of transport routes and logistics is also an important aspect. Rational master plans should include consideration of modern technologies and innovations. This includes using automation, digital technologies, and control and monitoring systems to optimise production processes and increase efficiency.

The examination of architectural solutions in crop production and their adaptation to climatic conditions is of great importance, especially in light of climate change. The approach to designing buildings for crop production should consider factors such as temperature, humidity, and lighting to ensure optimal conditions for plant growth and yield. An analysis of the influence of these climatic factors on the architectural parameters of structures was conducted, and a new design methodology is proposed. High temperatures may require cooling, ventilation, and thermal insulation systems inside greenhouses or other crop production facilities. Cold climates require effective insulation, heat pumps, and air heating (Mysak *et al.*, 2016). Humidity control inside structures plays an important role in preventing plant diseases and creating optimal conditions for their growth. Humidification and drainage systems may be necessary to regulate humidity inside structures. Depending on the climate and time of year, artificial lighting may be required to ensure the necessary daylight hours for plants. Architectural solutions should consider the placement of windows and transparent walls and the possibility of using LED lighting. A new design methodology that considers climatic factors may include the following elements:

1. Integrated climate control systems: automatic temperature, humidity, and lighting control systems can be configured to optimise growth conditions in real-time, depending on climate data.

2. Effective insulation and ventilation: using modern insulation and ventilation materials can help maintain stable conditions inside the structure.

3. Renewable energy use: the integration of solar panels and other renewable energy sources can reduce energy costs and make climate management systems more sustainable.

4. Modularity and flexibility: structures should be modular to adapt to different climatic conditions and plant species.

5. Data monitoring and analysis: it is important to collect data on climatic conditions and plant growth to continuously improve the design methodology.

By synthesising these elements, it is possible to develop architectural solutions that optimally match climatic conditions, ensuring sustainable and efficient crop production in different regions. This may include creating multifunctional greenhouses, using innovative materials and technologies, and active resource management to minimise adverse environmental impacts.

DISCUSSION

The study highlights the necessity for implementing adaptive architectural solutions in crop production facilities to facilitate resilience in the context of evolving climatic conditions and urbanisation trends. The study's principal conclusions highlight the necessity of climate-sensitive architectural designs and the incorporation of green technologies to guarantee the sustainability of crop production. Similarly, as demonstrated by D. Karamanis *et al.* (2024), the incorporation of green building elements, such as photovoltaic panels and greenery, can enhance urban sustainability. The present study also suggests crop production facilities could benefit from such integration to improve environmental performance and energy efficiency. Such an approach would not only optimise the use of sunlight but also assist in regulating internal temperatures, particularly in regions characterised by extreme climates.

By the findings of Z. Wu *et al.* (2024), which indicated that the integration of green spaces within urban infrastructure could serve to mitigate the Urban Heat Island effect, the study proposes that crop production facilities should consider the incorporation of analogous architectural elements to maintain optimal internal climates. The installation of green roofs and walls could assist in stabilising temperatures, reducing cooling costs and providing additional insulation, which is of paramount importance in maintaining a stable environment for crop growth.

Moreover, Um-e-Habiba *et al.* (2024) emphasise the significance of integrating smart systems to enhance energy efficiency in buildings. Similarly, the study lends support to the integration of smart technologies, such as automated climate control systems and LED lighting, to improve energy management within crop production facilities. The implementation of these technologies has the potential to markedly reduce energy expenditure and advance sustainable practices in agriculture, particularly in urban and semi-urban regions where resource efficiency is of paramount importance. This study is also in accordance with the findings of A. Gamal *et al.* (2023), who presented a framework for vertical greening systems to enhance urban resilience in hot, humid climates. For facilities engaged in crop production, vertical greening represents a sustainable solution for urban agriculture, offering improvements in spatial efficiency and resource utilisation. By optimising the use of vertical space, facilities could achieve the dual objective of maximising crop yields while minimising land usage, which is particularly relevant in densely populated areas.

A. Maciejewska *et al*. (2024) examined the role of greenery in enhancing the quality of life of urban residents. Similarly, the incorporation of green architectural solutions within crop production facilities serves not only to enhance agricultural productivity but also to confer societal benefits, namely the promotion of green spaces that improve air quality and biodiversity in urban environments. In a similar vein, Y.-H. Jung & Y.-S. Park (2023) investigated the potential of eco-corridors in urban settings, which is consistent with the findings on the design of crop production facilities that integrate natural ventilation and sunlight. The findings of their study lend support to the concept of utilising eco-corridors or open-air designs in crop production facilities. This approach could enhance natural airflow and light, thereby reducing reliance on mechanical systems for climate control.

The study by J. Bosch Abarca (2024) on single-row planning models in German cities provides insights into optimising spatial distribution for sustainability. In a similar context, the research proposes the implementation of modular and scalable architectural designs for crop production facilities, which can adapt to various environmental conditions and urban layouts. Such flexible planning can support both large and small-scale operations, thereby aligning with the sustainable urban development goals. In contrast to conventional designs that may fail to consider environmental sustainability, the study proposes a more integrated architectural approach. In alignment with the findings of A. Maciejewska *et al*. (2024), it is imperative to emphasise that architectural designs must be adapted to align with local climatic and urban conditions to facilitate sustainable crop production. To illustrate, the closed-loop water system described in Vertical Farm Beijing represents a model for the implementation of water recycling solutions within crop production facilities, particularly in regions with limited water resources (Xu, 2024).

Additionally, the findings underscore the impact of intrinsic factors, including crop varieties, production objectives, and cultivation techniques, on the architectural necessities associated with these plants. The environmental conditions required by different plant species are distinct, and these can be met through the implementation of specific architectural adaptations (Mero *et al*., 2023). For instance, crops that are of considerable height may necessitate vertically spacious structures, whereas those that are low-growing or cultivated hydroponically may benefit from modular designs that are horizontally efficient. In addition, local anthropogenic factors, including urbanisation and pollution, have an impact on the architectural and operational aspects of crop production facilities. Specialised filtration and ventilation systems must be employed to maintain optimal air quality within these structures, particularly in urban settings where pollution levels are elevated (Hezentsvei & Bannikov, 2020). In a similar manner to the environmental performance framework presented by A. Gamal *et al*. (2023), the research proposes the implementation of adaptable and resilient architectural solutions to mitigate the impacts of urban and climatic changes on crop production.

This study serves to reinforce the idea that any architectural solutions for crop production facilities must give priority to sustainability, adaptability and efficiency to meet the challenges posed by climate change and urban expansion. The incorporation of intelligent technologies, energy-efficient systems and environmentally conscious design features can facilitate the attainment of sustainable agricultural output within urban environments, thereby ensuring the dual objectives of food security and environmental resilience.

CONCLUSIONS

This study highlights the significance of adaptive architectural solutions in optimising the efficiency, resilience and sustainability of crop production facilities in response to the evolving climatic and anthropogenic challenges. The findings demonstrate that external environmental factors, including temperature fluctuations, precipitation patterns, humidity levels, and sunlight exposure, as well as internal variables such as plant type, care methods, and production goals, have a significant impact on the architectural design and operational functionality of these structures.

The study demonstrates that regional temperature conditions are a key factor in determining the selection of insulation materials and the integration of heating and cooling systems, with the objective of creating optimal growth environments. Similarly, the architectural design must take into account local precipitation and humidity levels, which affect water supply needs, irrigation system integration, and overall moisture control within the facility. The utilisation of transparent materials and structures orientated in a strategic manner serves to enhance the availability of sunlight, thereby supporting essential photosynthetic processes. Furthermore, wind conditions are taken into account in the structural design of buildings in order to maintain stability and safety, which is becoming increasingly important in regions that are prone to extreme weather events.

The findings underscore the significance of sophisticated architectural techniques, such as vertical farming and hydroponic systems, in enhancing spatial efficiency and resource utilisation. The implementation of closed-loop water recycling systems, energy-efficient lighting, and climate control technologies has the dual benefit of reducing water and energy consumption while also facilitating sustainable crop production within urban and resource-limited settings. Notable examples such as the Urban Vertical Farm of Brightfood in Shanghai and the Vertical Farm Beijing demonstrate the viability of integrating food production within urban areas, promoting biodiversity, and achieving substantial resource savings through innovative architectural design.

In conclusion, the study demonstrates that the application of sustainable design principles to crop production facilities enhances food security, minimises environmental impact and ensures long-term agricultural productivity. It is recommended that future research explores emerging technologies, such as artificial intelligence for climate monitoring and renewable energy solutions, in order to further improve the adaptability of crop production facilities to meet the demands of diverse and challenging environments.

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CONFLICT OF INTEREST

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REFERENCES

[1] Amirbekova, A., Abdykarimova, Sh., & Oliynyk, O. (2023). Renovation of residential buildings of the first mass series from a sustainable development point of view. *Civil Engineering and Architecture*, 11(4), 1814-1823. doi: 10.13189/cea.2023.110412.

[2] Askarova, A., Girfanova, I., & Nigmatullina, G. (2020). Agricultural production planning taking into account the factor of "location" of producers. *IOP Conference Series: Earth and Environmental Science*, 421(2), article number 022026. doi: 10.1088/1755-1315/421/2/022026.

[3] Bacon, C.M., Getz, C., Kraus, S., Montenegro, M., & Holland, K. (2012). The social dimensions of sustainability and change in diversified farming systems. *Ecology and Society*, 17(4), article number 41. doi: 10.5751/ES-05226-170441.

[4] Bosch Abarca, J. (2024). The modern German city single row planning model. *Architecture, City and Environment*, 18(54), article number 11870. doi: 10.5821/ace.18.54.11870.

[5] Czyżewski, B., Czyżewski, A., & Kryszak, Ł. (2019). The market treadmill against sustainable income of European farmers: How the CAP has struggled with Cochrane's curse. *Sustainability*, 11(3), article number 791. doi: 10.3390/su11030791.

[6] Dovgal, O., Potryvaieva, N., Bilichenko, O., Kuzoma, V., & Borko, T. (2024). Agricultural sector circular economy development: Agroecological approach. *Ekonomika APK*, 31(4), 10-22. doi: 10.32317/ekon.apk/4.2024.10.

[7] Gamal, A., Eleinen, O.A., Eltarabily, S., & Elgheznawy, D. (2023). Enhancing urban resilience in hot humid climates: A conceptual framework for exploring the environmental performance of vertical greening systems (VGS). *Frontiers of Architectural Research*, 12(6), 1260-1284. doi: 10.1016/j.foar.2023.09.003.

[8] Guth, M., Smędzik-Ambroży, K., Czyżewski, B., & Stępień, S. (2020). The economic sustainability of farms under common agricultural policy in the European Union countries. *Agriculture*, 10(2), article number 34. doi: 10.3390/agriculture10020034.

[9] Haghighi, Z., Angali Dehnavi, M., Konstantinou, T., van den Dobbelsteen, A., & Klein, T. (2021). Architectural photovoltaic applications: Lessons learnt and perceptions from architects. *Buildings*, 11(2), article number 62. doi: 10.3390/buildings11020062.

[10] Hassan, M., & Silleli, H.H. (2024). Evaluation of air conditioning parameters in semi-closed greenhouses under Turkey's climatic conditions. In E. Cavallo, F. Auat Cheein, F. Marinello, K. Saçılık, K. Muthukumarappan & P.C. Abhilash (Eds.), *15th international congress on agricultural mechanization and energy in agriculture* (pp. 199-216). Cham: Springer. doi: 10.1007/978-3-031-51579-8_20.

[11] Hezentsvei, Yu., & Bannikov, D. (2020). Effectiveness evaluation of steel strength improvement for pyramidal-prismatic bunkers. *EUREKA, Physics and Engineering*, 2, 30-38. doi: 10.21303/2461-4262.2020.001146.

[12] Jung, Y.-H., & Park, Y.-S. (2023). The urban eco-corridor construction strategy as an urban void-focused on the high-speed railway station area development of Stuttgart. *Journal of the Architectural Institute of Korea*, 39(6), 67-76. doi: 10.5659/JAIK.2023.39.6.67.

[13] Kaletnik, G., Honcharuk, I., & Okhota, Yu. (2020). The waste-free production development for the energy autonomy formation of Ukrainian agricultural enterprises. *Journal of Environmental Management and Tourism*, 11(3(43)), 513-522. doi: 10.14505/jemt.v11.3(43).02.

[14] Karamanis, D., *et al*. (2024). Transitioning to building integration of photovoltaics and greenery (BIPVGREEN): Case studies up-scaling from cities informal settlements. *Environmental Research: Infrastructure and Sustainability*, 4(4), article number 042001. doi: 10.1088/2634-4505/ad8374.

[15] Maciejewska, A., Sobieraj, J., & Kuzak, Ł. (2024). Analysis of greenery coverage of the area of the city of Warsaw on the quality of life of residents on the basis of spatial and statistical data. *Archives of Civil Engineering*, 70(1), 237-258. doi: 10.24425/ace.2024.148909.

[16] McClements, D.J., & Grossmann, L. (2021). A brief review of the science behind the design of healthy and sustainable plant-based foods. *Science of Food*, 5(1), article number 17. doi: 10.1038/s41538-021-00099-y.

[17] Mero, G., Skenderasi, B., Shahini, E., Shahini, S., & Shahini, E. (2023). Main directions of plants integrated protection in the conditions of organic agriculture. *Scientific Horizons*, 26(3), 101-111. doi: 10.48077/SCIHOR3.2023.101.

[18] Muzdybayeva, T., Alipbeki, O., Chikanayev, A., & Abdykarimova, Sh. (2022). Road pavement using geosynthetics on the territory of rural settlements. *International Journal of GEOMATE*, 23(96), 61-68. doi: 10.21660/2022.96.3294.

[19] Mysak, Yo., Galyanchuk, I., & Kuznetsova, M. (2016). Development of mathematical models and the calculations of elements of convective heat transfer systems. *Eastern-European Journal of Enterprise Technologies*, 4(8(82)), 33-41. doi: 10.15587/1729-4061.2016.74826.

[20] Ozpinar, A. (2023). A hyper-integrated mobility as a service (MaaS) to gamification and carbon market enterprise architecture framework for sustainable environment. *Energies*, 16(5), article number 2480. doi: 10.3390/en16052480.

[21] Radchenko, O., Tkach, L., & Dendebera, O. (2023). Financing innovations in the agricultural industry as a component of the digital development of Ukraine's economy. *Scientific Bulletin of Mukachevo State University. Series "Economics"*, 10(4), 54-65. doi: 10.52566/msu-econ4.2023.54.

[22] Shao, Y., Li, J., Zhou, Z., Hu, Z., Zhang, F., Cui, Y., & Chen, H. (2021). The effects of vertical farming on indoor carbon dioxide concentration and fresh air energy consumption in office buildings. *Building and Environment*, 195, article number 107766. doi: 10.1016/j.buildenv.2021.107766.

[23] Singleton, B.E. (2023). Viewpoint: Two more lamps. Augmenting urban planning for biodiversity. *Cities*, 141, article number 104501. doi: 10.1016/j.cities.2023.104501.

[24] Stouhi, D. (2021). Stefano Boeri Architetti combines architecture, agriculture, and aesthetics in newly unveiled project. *ArchDaily*.

[25] Tovar, E. (2024). Future-focused food production: Integrating high-tech agriculture into cities. *ArchDaily*.

[26] Um-e-Habiba, Ahmed, I., Asif, M., Alhelou, H.H., & Khalid, M. (2024). A review on enhancing energy efficiency and adaptability through system integration for smart buildings. *Journal of Building Engineering*, 89, article number 109354. doi: 10.1016/j.jobe.2024.109354.

[27] Weingaertner, C., & Moberg, Å. (2014). Exploring social sustainability: Learning from perspectives on urban development and companies and products. *Sustainable Development*, 22(2), 122-133. doi: 10.1002/sd.536.

[28] Wu, Z., Zhou, Y., & Ren, Y. (2024). Green space-building integration for Urban Heat Island mitigation: Insights from Beijing's fifth ring road district. *Sustainable Cities and Society*, 116, article number 105917. doi: 10.1016/j.scs.2024.105917.

[29] Xu, J., Gu, B., & Tian, G. (2022). Review of agricultural IoT technology. *Artificial Intelligence in Agriculture*, 6, 10-22. doi: 10.1016/j.aiia.2022.01.001.

[30] Xu, X. (2024). Greenery building: A path to sustainable urban living. In P. Du, K. Al-Kodmany & M.M. Ali (Eds.), *The Routledge handbook on greening high-density cities: Climate, society and health* (pp. 530-546). New York: Routledge. doi: 10.4324/9781003318385-34.

[31] Xue, Z., Wu, J., Liu, X., Shen, J., & Zhang, W. (2024). Preservation and adaptive reuse of historical buildings: A case study of the Lin Hall at the former site of Dongwu University. In S.M. Ghadiri & Y. Zhuge (Eds.), *Urban construction and management engineering IV* (pp. 208-217). London: CRC Press. doi: 10.1201/9781032626444-29.

[32] Yang, W., He, Y., Xie, Z., & He, T. (2024). Design and implementation of virtual simulation experimental system for deformation monitoring of tall buildings based on internet of things and GNSS. In J. Dong, L. Zhang & D. Cheng (Eds.), *Proceedings of the 2nd international conference on internet of things, communication and intelligent technology* (pp. 152-167). Singapore: Springer. doi: 10.1007/978-981-97-2757-5_17.

[33] Zhangabay, N., *et al*. (2023). Analysis of the influence of thermal insulation material on the thermal resistance of new facade structures with horizontal air channels. *Case Studies in Construction Materials*, 18, article number e02026. doi: 10.1016/j.cscm.2023.e02026.

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Сучасні принципи формування об'єктів для виробництва рослинної продукції

Анотація. Актуальність цього дослідження проявляється у необхідності адаптації архітектурних рішень до змінних кліматичних умов та антропогенних факторів. Метою дослідження було вивчення сучасних принципів формування структур для виробництва рослинної продукції та виявлення критичних аспектів, що мають вирішальне значення для оптимізації цього процесу. Для досягнення цієї мети були використані методи аналізу, синтезу, дедукції та індукції. Результати дослідження показують, що архітектурні рішення мають бути адаптовані до різних кліматичних умов, щоб оптимізувати ріст рослин. Це потребує коригування систем контролю температури, освітлення та управління водними ресурсами. Конкретні архітектурні приклади, зокрема Міська Вертикальна Ферма компанії Brightfood у Шанхаї та Вертикальна Ферма в Пекіні, представлені в якості тематичних досліджень для демонстрації цих принципів. Міська Вертикальна Ферма компанії Brightfood включає тераси з їстівними рослинами, сучасні гідропонічні системи та прозорі матеріали, що максимально використовують сонячне світло. Подібним чином, Вертикальна Ферма в Пекіні інтегрує систему водного замкненого циклу та ефективне світлодіодне освітлення для мінімізації енергоспоживання та витрати води, сприяючи тим самим продовольчій безпеці міста. Ці приклади ілюструють важливість адаптації архітектурних проектів до екологічних та міських обмежень. Дослідження дало можливість зрозуміти значення архітектурних та інженерних рішень у виробництві рослинної продукції, що може привести до створення більш ефективних та стійких систем вирощування рослин, що, у свою чергу, може підвищити продуктивність та якість сільськогосподарської продукції

Ключові слова: оптимізація врожайності; природно-кліматичні фактори; інноваційні агротехнології; структури; системи культивації