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Principles of integrating education and production in the architecture of training and production complexes

U.N. Ismagulov*, K.K. Arynov, A.M. Saurbayeva

L.N. Gumilyov Eurasian National University, Astana, Kazakhstan

E mail: ismagulov.un@gmail.com, arynov_kk@enu.kz, asaurbayeva_am_1@enu.kz

Abstract. This article examines approaches to the design of educational buildings and campuses that combine educational and industrial functions. Based on an analysis of international experience, principles for the architectural integration of education and industry have been identified. Case studies from France, Italy, the USA, and other countries are examined, where lecture theatres are located alongside workshops, laboratories, and production facilities. The key principles identified are: functional integration, spatial openness, adaptability of spaces, and partnership with industry. The authors justify the need to design flexible, multifunctional spaces that connect workshops, laboratories, classrooms, and industrial facilities through a common structural and spatial system. Projects and initiatives are used to demonstrate how architecture facilitates the convergence of theoretical education and real-world production practices, stimulating the 'academia-industry' innovation cycle. The results presented illustrate the importance of open learning spaces, visible interaction between students and industry, and infrastructural solutions for effective integration. The conclusions drawn can serve as a basis for developing design methods for educational and industrial complexes aimed at training highly qualified personnel.

Keywords: integration into architecture, educational complex, functional integrity, multifunctionality, collaborative spaces, flexible premises.

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* the correspondence author

Introduction

The modern economics of buildings, the requirements of the fourth industrial revolution and specialised training make it necessary to combine educational and production functions in architecture and place new demands on educational systems. Due to the shortage of qualified personnel, there is growing interest in integrating learning and production (industrial practice) processes [1, 2]. New types of educational buildings are emerging – "knowledge factories" – where students learn not in isolated classrooms, but in conditions close to real production. The concept of "integration of education and production" implies a combination of theoretical training and practical activities, where educational programmes are closely linked to the real production cycle. In scientific literature, the concept of a 'Learning Factory' is described as a learning environment that includes authentic production processes, multi-module lines, real product manufacturing, and a mixed approach to learning (formal and informal) [3]. According to Ifenthaler and Roll (2021), such spaces simulate real production chains, facilitating the practical acquisition of competencies [3].

International experience demonstrates various architectural strategies where university research is intertwined with industrial enterprises to solve this problem. For example, since the 1970s, the United States has been implementing Cooperative Research Centres and Engineering Research Centres, which combine the scientific potential of universities and enterprises. Architect Frederick Fisher created Iovine & Young Hall (2019), which is called the '21st-century learning factory'. There, classic lecture halls coexist with workshops and maker spaces connected by common 'collision' zones for cross-disciplinary interaction [4]. In the 1980s, science parks and technology parks began to emerge at universities in Europe (e.g., Heriot-Watt University in Edinburgh, Trinity College in Cambridge, Louvain-la-Neuve in Belgium) [1, 2, 5]. In Italy, the Learning Factory project (architect Walter Nicolino, 2020) converted a former factory into a university for applied arts, preserving its large industrial spaces and 'democracy of views' through transparent partitions [6]. In Belgium, the T2 Academy (architect Kempe Thill, 2020) combines theory and practice in a single building with concert workshops and exhibition areas [7]. These trends have led to modern campuses increasingly being designed as ecosystems that combine teaching, research and production.

In domestic academic practice, the integration of education, science and industry is regarded as a key factor in the innovative development of Kazakhstan's economy. It is noted that the integration of educational, research and industrial activities contributes to the formation of a complete cycle of specialist training—from the acquisition of knowledge to its application in actual industrial practice [8]. Researchers are also examining the architectural principles underlying the development of training and production centres. In particular, they highlight the need to integrate educational, industrial and public areas within a single spatial framework, as well as to establish a typological network of such facilities across different settlement levels [9].

Contemporary research also emphasises that, for the Republic of Kazakhstan, the integration of education, science, and industry should be regarded as the primary mechanism for modernising the economy and enhancing the competitiveness of national universities. In particular, emphasis is placed on the need to adapt international models of integration to local conditions and market needs [10].

In an architectural context, integration means creating spaces that simultaneously perform the functions of teaching and production. The aim of this research is to identify the principles of such integration based on foreign practices and examples. The article analyses examples of educational institutions and scientific and production complexes, and highlights approaches to the design of educational and production spaces. The article is based on a review of literature and design publications, as well as case studies of well-known architectural projects in the field of 'university-factory,' 'learning factory,' and technology parks [11, 12]. Based on publications and descriptions of real projects, recommendations are formulated for the planning, design, and functional solutions of such complexes.

The methodology

The study was conducted using a combined approach, which included a systematic review of foreign literature and an analysis of architectural case studies on the topic of combining education and production. First, an analysis was conducted of scientific publications, reports, and monographs on the topic of combining educational and production systems (research on learning through practice and dual education models). Secondly, foreign architectural examples of campuses and educational institutions were examined, where classrooms, laboratories and production workshops are combined in a single complex. The selected case studies include projects in different countries and on different scales, demonstrating various aspects of integration: from digital production laboratories to large-scale campuses with industrial production areas. By comparing the characteristics of these examples, general principles for the design of 'educational and production' spaces in architecture have been formulated.

Findings/Discussion

An example of a hybrid campus and education-production centre.

The WBF Lab project (Teaching and Research Winery and August A. Busch III Brewing and Food Science Laboratory) at the University of California, Davis, exemplifies an architectural realisation of a model in which educational, research and production functions are integrated into a single spatial and technological system. The complex was originally conceived as an environment that 'integrates laboratory research with applied process technologies', enabling students and researchers to directly test theoretical hypotheses under conditions approximating industrial ones. The key idea behind the project is to bridge the gap between academic knowledge and industrial practice, which is achieved through the spatial and functional integration of the various stages of the production cycle [13].

One of the fundamental principles is the integration of so-called bench-top science (laboratory science) with applied process technologies. In architectural terms, this means that laboratories, teaching spaces and production lines are not isolated, but form a single chain in which:

– theoretical research transitions into experimentation;
– experimentation transitions into prototyping;
– prototyping transitions into pilot production.

This approach creates a continuous 'research – development – production' cycle, within which the educational process is integrated into real-world technological operations. As a result, students are given the opportunity to 'directly test theories and validate new production processes [13].

The building's layout (Figure 1) is governed not by formal composition, but by the logic of technological flows. The production areas (winery, brewery, food laboratories) are complemented by:

– analytical laboratories (quality control, diagnostics);
– teaching rooms;
– support areas (storage, refrigeration, raw material processing).

All these elements are integrated into a single system, in which each functional unit fulfils both an educational and a production role. At the same time, each production line is given a specialised spatial layout, whilst retaining shared infrastructure elements: laboratories, offices and storage areas [13].

Figure 1. Functional zoning of the WBF Lab project

Crucially, the layout ensures direct accessibility of production processes for teaching, visual and functional links between stages, and the ability to conduct research and production simultaneously.

The WBF Lab functions not only as a university facility but also as a platform for interaction with industry. The building is positioned as a ‘link between academic research and industrial application’ [14].

This manifests itself in several ways:

– the involvement of industry representatives in the development and testing of technologies;

–the use of the facility as a pilot site for testing production processes;

Access for external specialists to the laboratory and production infrastructure.

From an architectural perspective, this requires:

–flexibility in planning solutions,

–versatility of technological spaces,

–the ability to scale processes.

The result is a hybrid institutional model in which the educational environment becomes part of the production ecosystem.

Learning factory.

Contemporary architecture of educational spaces is characterised by a shift from traditional functional separation towards the integration of learning and practical activities. One of the key approaches is the Learning Factory concept, which involves creating an environment in which the educational process is directly linked to industrial practices. Such spaces provide the conditions for learning by doing and enable the simulation of real-world professional scenarios. In the academic literature, the Learning Factory is defined as an environment that combines learning, research and production processes into a single system for training specialists [15]. The theoretical basis for this approach is the concept of experiential learning, developed by David Kolb, according to which learning is a process based on experience and its reflection. Within this model, the direct interaction of the learner with a real or simulated professional environment plays a key role [16].

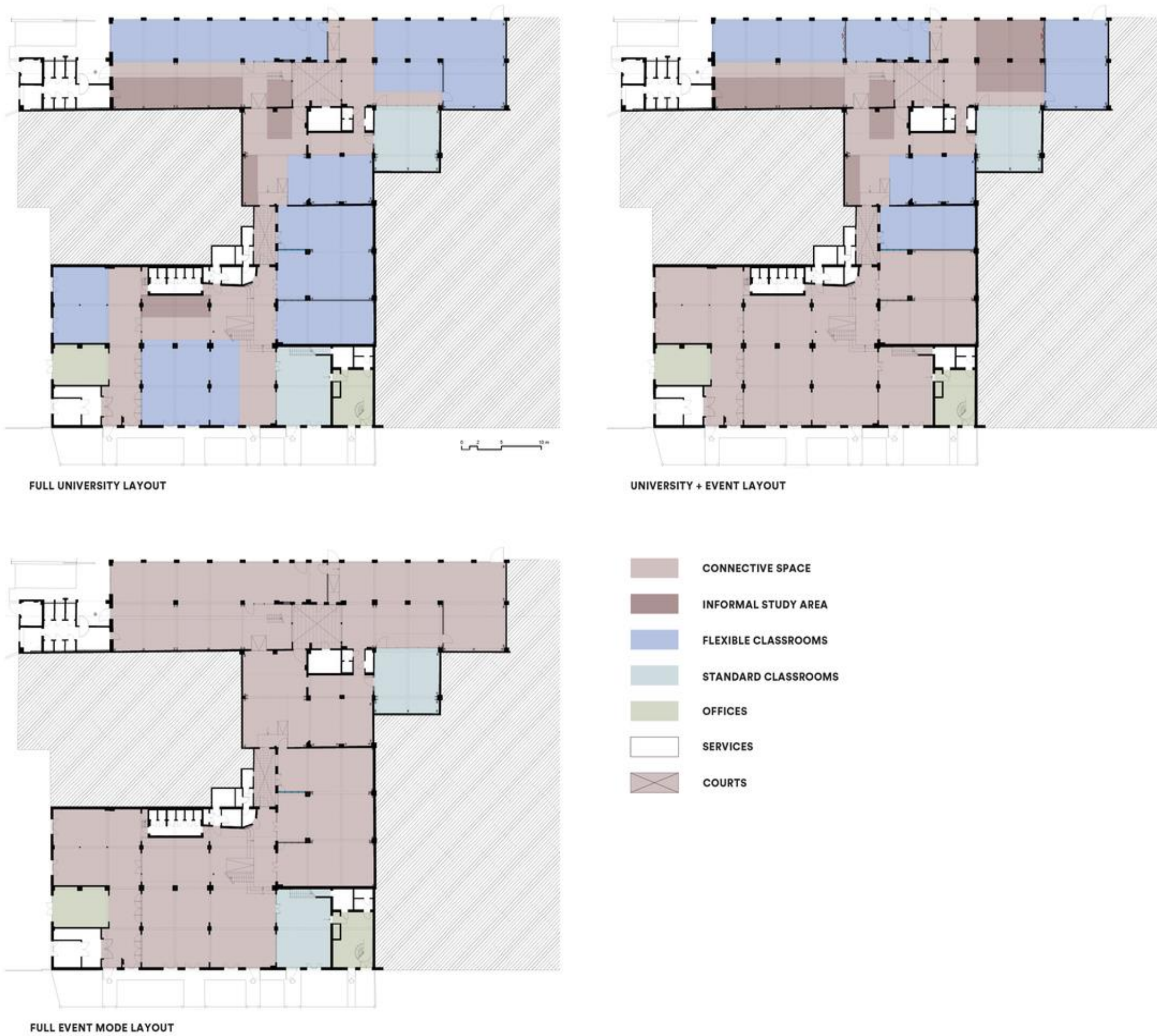

Figure 2. The zoning scheme of the Learning Factory* (WNA Walter Nicolino Architects, Italy)

In the project The Learning Factory* (WNA Walter Nicolino Architects, Italy), the integration of educational and production functions is achieved through spatial continuity and functional overlap. The architectural design comprises a single volume within which there is no rigid division between classrooms and production workshops. The layout (Figure 2) is organised in such a way that the user's movement through the building becomes part of the educational process, ensuring constant contact with the production environment. The visual openness and accessibility of processes contribute to the formation of an intuitive understanding of technological operations and enhance student engagement [6].

Architectural integration in this project is achieved through continuous circulation routes, including ramps and transitional spaces that connect various functional zones. This aligns with contemporary approaches to designing educational environments, where openness, flexibility and the visual connectivity of spaces play a key role. Such characteristics foster the formation of interdisciplinary connections and enhance the effectiveness of learning [17].

In the Training Centre + Workshops for Apprentices project (Atelier Téqui, France), the integration of educational and production functions is achieved through vertical zoning (Figure 3). The production workshops are located on the ground floor, whilst the training facilities are situated on the upper floors. Despite this functional separation, the architectural design ensures a close connection between the levels through visual openings and compact circulation routes. This structure allows for the maintenance of specialised conditions for different types of activities, whilst simultaneously uniting them into a single educational system [18].

Figure 3. The zoning scheme of the Training Centre + Workshops for Apprentices project (Atelier Téqui, France)
Note: orange – production workshops, yellow – training facilities, blue – common spaces, purple – living areas

This model is consistent with contemporary research in the field of vocational education, which emphasises the need for a balance between functional specialisation and the integration of processes. An effective educational environment must simultaneously ensure safety, technological efficiency and accessibility for learning, which is achieved through thoughtful spatial organisation and visual connections between functions [19]. An analysis of the two projects reveals two main approaches to integrating educational and industrial functions: a horizontal approach, based on spatial integration, and a vertical approach, involving their distribution across different levels. Despite their differences, both approaches aim to create an environment in which learning becomes inseparable from practical activity. In this context, architecture acts as an active tool in the educational process, determining the nature of the user's interaction with the industrial environment.

Architectural and spatial integration strategies

Circulation axis ('education-production axis'). Many projects integrating educational and production functions feature a single central axis or 'spinal' route along which user movement is organised. For example, at the İzmir Agriculture Development Centre (Sasalı Biolab), the key element is a bioswale – a forest-forming biochannel along which the educational and production areas are linearly arranged [12]. Movement from the entrance along this axis leads visitors first through the educational premises (classrooms, laboratories), then to the 'eco-market' (a combination of educational and agricultural areas), and further to the agricultural fields and greenhouses (Figure 4).

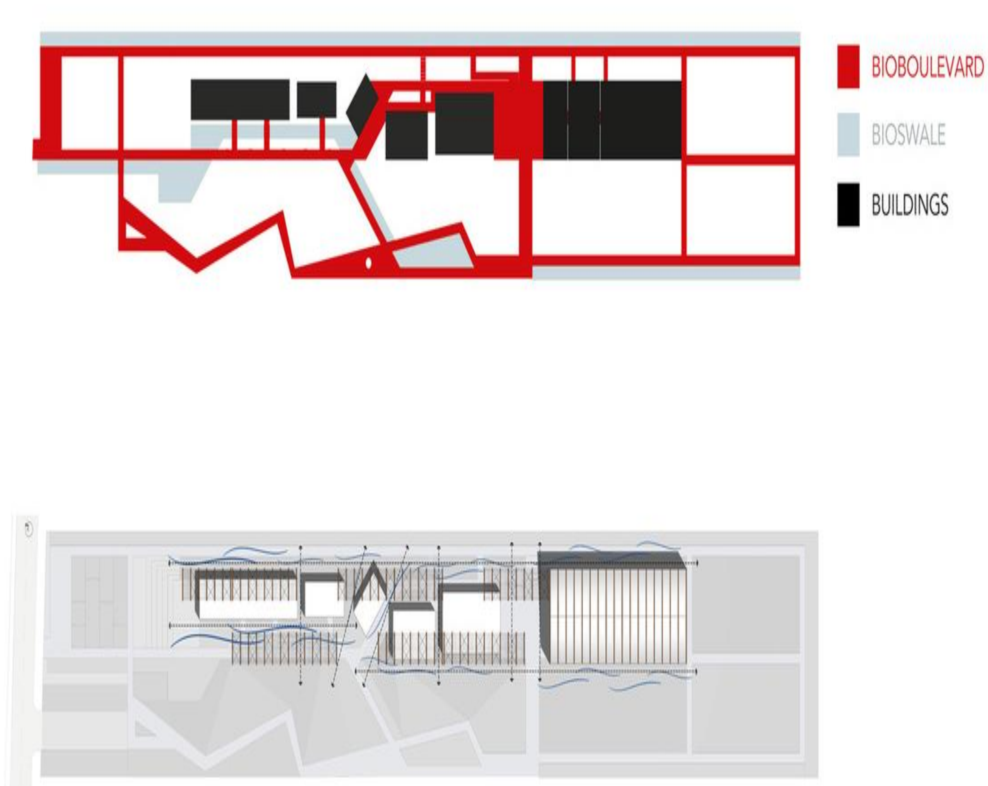

Figure 4. Diagram of connections and user routes at the İzmir Agriculture Development Centre

This approach ensures a transparent link between theory and practice: students physically pass through production areas, observe and participate in farming training processes. Similarly, at the Technical Campus Blue Gate (Belgium), training workshops and classrooms are located around a central core with a freight lift (Figure 5) [5]. The vertical 'vertex' of the building serves as an axis of movement – cargo and students are lifted to the upper floors to the workshops. This system allows students to constantly see the production process and facilitates the delivery of materials between levels (freight lifts, conveyors, fenced-off 'sectional' staircases) [5, 12].

Interference between educational and industrial functions**.** The architecture of integrated campuses often seeks to mix functions so that teaching spaces and production areas border or partially overlap visually.

Figure 5. Location of training workshops and classrooms around the core of the building
Note: blue – training workshops and classrooms, green – central core

At the Bologna Learning Factory (Italy), traditional closed classrooms are adjacent to flexible workshops separated from each other by transparent partitions (Figure 6) [6].

Figure 6. Cross-section of the Bologna Learning Factory

Glass walls between classrooms and other spaces ensure ‘democracy of views’ – students and teachers can see what is happening on both sides of the screen. This creates additional motivation and promotes the exchange of ideas: school lessons flow into practical work at workstations. Similarly, in the CMU (Carnegie Mellon) workshop laboratories, the openness and visibility of students' model-making work helps teachers and industry partners observe the progress of projects. This strengthens the connection between theory and practice, as learning ‘in plain sight’ reveals meaningful connections.

Vertical integration (‘vertical factory’). Limited space may result in workshops and production facilities being located above teaching spaces. This is how the ‘vertical factory’ design came about in the Blue Gate project [5]. The designers realised that the responsibilities for ensuring technical regulations (ventilation, strength, safety) became more complicated on the upper floors, so the building was conceived as a “multi-storey factory” [5]. This creates a strong reinforced frame designed to withstand the weight of heavy equipment and possible redevelopment [5]. In architectural terms, this is reflected in a mixture of ‘heavy’ industrial elements (freight shafts, reinforced floors) and educational blocks: horizontal glazing for classrooms and tall windows for workshops (to maximise light and visual communication) [5]. This approach requires consideration of the engineering standards of an industrial building (damage resistance, fire safety, noise insulation, etc.), but allows functions to be synthesised in a limited area.

Figure 7. Transformable space Bologna Learning Factory

Flexibility and transformability of space. Projects integrating education and production require adaptability. Spaces must be easily reallocated for various educational and production tasks. At the Bologna Learning Factory, great attention is paid to the mobility of the interior:

partitions, hanging curtains and portable furniture allow the area to be quickly reconfigured from a lecture hall to an exhibition or laboratory (Figure 7) [6].

This allows for joint project sessions with industry partners and prototype exhibitions [6]. This approach facilitates the integration of learning with practice, as a group of students can switch to a real production task at any time.

Table 1. Analysis of the applied principles of integration of production and business in foreign projects

Project	Principles	Notes
Greenspoint Studios and Learning Commons (Houston, USA)	1. The ‘bench-to-production’ principle: continuity between educational and production processes	The spatial layout is organised around technological flows, integrating production, laboratory and teaching areas into a single system
	2. Spatial integration through technological logic	Teaching, research and production are integrated through spatial interconnectivity and operate as part of a unified process
	3. Integration with industry as a spatial and organisational principle	The building functions as a platform for interaction between the university and industry for joint research and technology implementation
Training Center + Workshops for Apprentices (Atelier Téqui, France)	4. The principle of spatial connectivity	Vertical zoning that maintains a visual and functional connection between the workshops on the ground floor and the teaching spaces on the upper floors, facilitating a smooth transition from theory to practice
İzmir Agriculture Development Center (Izmir, Turkey)	5. A single circulation system (vertical/ horizontal) connecting educational and production facilities	This system allows the student audience to constantly see the work of production and facilitates the supply of materials between levels (freight elevators, conveyors, enclosed "sectional" stairs)
Blue Gate (Antwerp, Belgium)		
Bologna Learning Factory (Bologna, Italy)	6. Creation of modular, flexible spaces (multi-transformable classrooms/laboratories)	The ability to quickly switch between training and research/production. This approach facilitates the integration of learning with practice, so that at any moment, a group of students can switch to the real task of production.
	7 The principle of ‘learning by doing’	The creation of a single open-plan space in which teaching and production areas are integrated, and students are directly involved in real-world production processes
CMU (Pittsburgh, USA)	8. Visual and functional transparency between classes and production	Providing direct visibility of processes and products (for example, through glazing, viewing galleries, demonstration areas). This strengthens the relationship between theory and practice, as learning "in plain sight" reveals semantic connections.

Social and institutional integration**.** The architecture of the educational space should support not only technical but also social connections with production partners. The Blue Gate project deliberately mixes student contingents of different levels (work/learn school and adult courses) and neighbours with businesses in the business park [5].

This creates a favourable environment for internships and employment. For example, the 'public space' at Greenspoint Studios connects the educational programme with the local community, while the Learning Factory's demonstration areas encourage companies to visit the projects [13]. This convergence is architecturally realised through the presence of open galleries, conference rooms and laboratories with the participation of industry mentors.

Results of the analysis of the principles of integration in foreign projects.

Based on the analysis of foreign projects, unique principles of integration of production and education (Table 1) were identified in various aspects, ranging from the hybridisation and conversion of abandoned factories to the implementation of architectural strategies in new projects. Thus, the architectural design of educational and industrial complexes boils down to combining the 'building' and the 'factory' into a single organism. This is achieved through strategic zoning, engineering systems, interior design solutions, and the overall configuration of the building. Successful integration makes training more practical and quicker to adapt to industry demands, while enterprises gain useful scientific and human resources potential [1, 13].

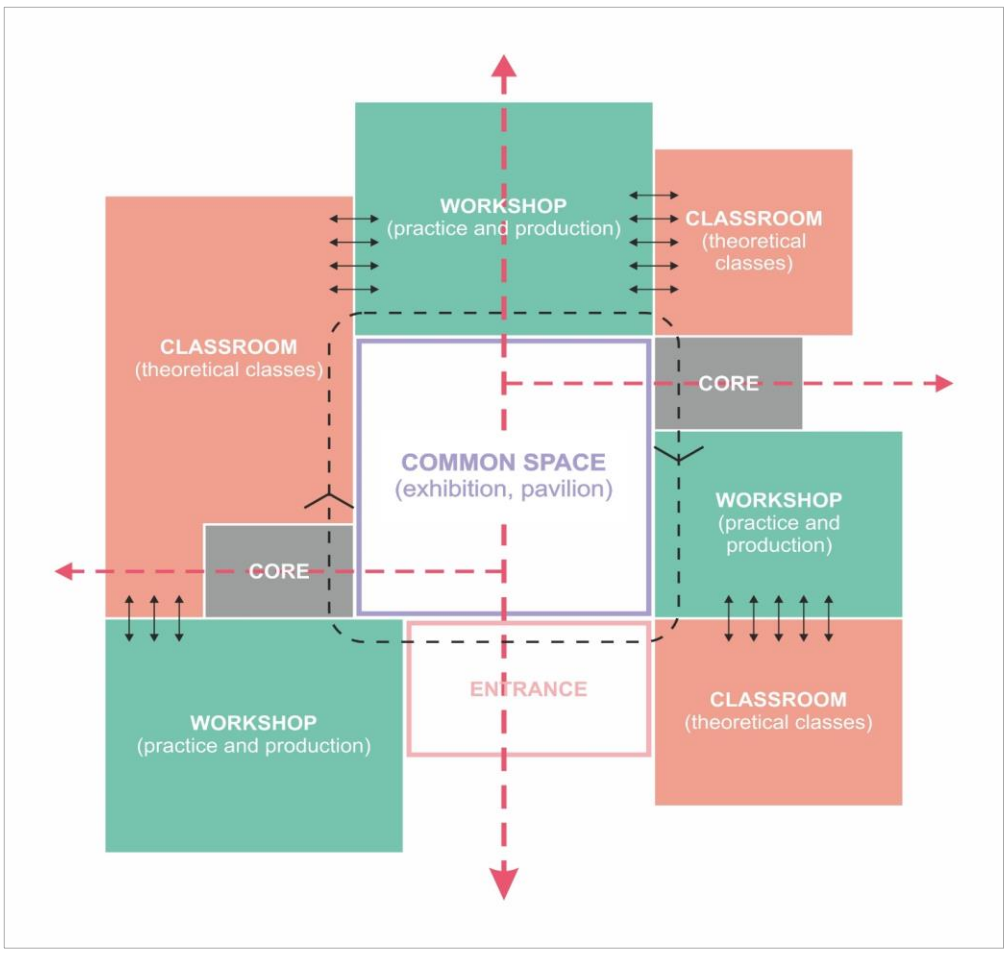

Figure 8. Conceptual model of integration of educational and production functions

Conceptual model of an educational and production complex.

Based on the analysis of foreign examples and the identified principles, a general conceptual model of the integration of educational and production functions can be formed through the implementation of accompanying principles, which is reflected in Figure 8.

This conceptual model can serve as a basis for the further design of new educational and production centres or the refurbishment/reconstruction of abandoned factories. The model is based on the following principles:

• Structural integrity**.** Creating a unified architectural structure in which educational and

production facilities are organised as parts of a common ‘cluster’ or campus (e.g., through a common route or building core archdaily.com archdaily.com). This facilitates movement and exchange between classrooms, laboratories, and production areas.

• Physical coupling of functions. Designing buildings so that teaching spaces are directly adjacent to workshops, laboratories, and equipment areas. The boundaries between them can be transparent or movable so that teaching is closely linked to practice.

• Shared spaces. Designing common areas where students, teachers, and industry representatives can meet and work together. These ‘interzonal’ spaces (open labs, coworking spaces, exhibition galleries) connect educational and production units and stimulate interdisciplinary interaction.

• Spatial openness and visual connection**.** Effective interaction between educational and production areas is achieved through transparent divisions and large openings. This ‘democracy of views’ creates an open learning environment. Open atriums, courtyards and gaps between floors become places for collective communication, enhancing the exchange of ideas between students and production workers.

• Flexibility of use**.** The use of transformable and multifunctional spatial systems (movable partitions, modular furniture, universal laboratories) allows rooms to be adapted to various educational and industrial tasks.

• Infrastructure provision. Taking into account special engineering requirements: reinforced structures, ventilation, power supply, transport communications (e.g., freight lifts for delivering materials to training workshops). The architecture must provide for the possibility of placing heavy equipment and safe operation within the building.

• Information and technical integration**.** Inclusion of digital platforms and ‘digital twins’ in the project to simulate production processes. As the practice of Werk150 and other laboratories shows, the use of virtual production systems (3D printing, robots) is often closely linked to the architecture of the premises where these technologies are located.

Conclusion

The study shows that the integration of educational and industrial functions within architectural design is not merely a spatial or functional challenge, but also a strategic tool for modernising the higher education system. A key finding is that the effectiveness of such integration is determined by the creation of an architectural environment of the ‘educational-industrial ecosystem’ type, in which teaching, research and real-world industrial processes are combined into a single spatially and functionally interconnected structure.

From a practical perspective, the paper formulates a set of architectural and planning principles applicable to the design of modern university campuses in Kazakhstan. These include: the organisation of continuous spatial connections between educational and production zones, the introduction of flexible and transformable spaces, and the creation of open production areas integrated into the educational environment. Implementing these solutions can significantly bridge the gap between theoretical training and practical skills, which is one of the key challenges facing higher education in the country.

At the national development level, the implementation of these principles could serve as a key tool for diversifying Kazakhstan's economy and reducing its dependence on the raw materials sector. Integrating production into the university system helps to train specialists who are attuned to the real needs of industry, whilst also stimulating the development of engineering, technological and applied disciplines. Furthermore, such spaces lay the foundation for building sustainable links between universities, industrial enterprises and the private sector, which is particularly relevant in the context of implementing industrial and innovation development programmes.

For universities in Kazakhstan, the research findings point to the need to move away from the traditional campus model with its rigid functional divisions towards hybrid educational environments based on the principle of 'learning by doing'. In this context, architecture takes on the role of an active pedagogical tool, creating the conditions for practical learning, interdisciplinary interaction and student participation in real-world production processes. The implementation of such approaches will improve the quality of graduate training and their competitiveness in both the national and international labour markets.

Prospects for further research relate to the development of methodologies for assessing the effectiveness of education-industry collaboration spaces in the Kazakh context, including their impact on the quality of specialist training, the level of engagement with industry, and their contribution to regional innovation. Another important area is the adaptation of these principles to the country's various sectoral contexts — from industrial manufacturing and construction to the agricultural sector and the creative industries.

Contribution of the authors.

Ismagulov U.N. – collected literature and case-study projects for further study, created a conceptual model for the integration of production and business based on the analysis and identified principles. Translated the article.

Arynov K.K. – participated in the critical revision of the content of the article and in the approval of the final version for publication.

Saurbayeva A.M. – conducted an analysis of the collected literature and world projects. Identified the unique principles of integration and systematized the results in a table.

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Information about the authors:

Ismagulov U.N. – corresponding author, Master of Architecture, Faculty of Architecture and Civil Engineering, L.N. Gumilyov Eurasian National University, 01000, Republic of Kazakhstan, Astana, st. Kazhymukan, 13

Arynov K.K. – doctor of Architecture, Professor of the Department of Architecture, Faculty of Architecture and Civil Engineering, L.N. Gumilyov Eurasian National University, 01000, Republic of Kazakhstan, Astana, st. Kazhymukan

Saurbayeva A.M. – PhD, Senior lecturer at the Department of Architecture, Faculty of Architecture and Civil Engineering, L.N. Gumilyov Eurasian National University, 01000, Republic of Kazakhstan, Astana, st. Kazhymukan, 13