Міністерство освіти і науки України
Національний університет «Полтавська політехніка імені Юрія Кондратюка»
Навчально-науковий інститу архітектури, будівництва та землеустрою
Кафедра архітектури будівель та дизайну

«ЗЕЛЕНА» АРХІТЕКТУРА БАГАТОФУНКЦІОНАЛЬНИХ КОМПЛЕКСІВ (НА ПРИКЛАДІ М. ДЮССЕЛЬДОРФ, НІМЕЧЧИНА)

Пояснювальна записка
до кваліфікаційної роботи
на здобуття ступеня вищої освіти «магістр»
за спеціальністю 191 «Архітектура та містобудування»
(освітня програма «Архітектура будівель і споруд»)

602-АБі 11550880 ПЗ

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Допустити до захисту

Завідувач кафедри архітектури будівель та дизайну
16 січня 2025 р. __________ Ніколаєнко В.А.
підпис

Ministry of Education and Science of Ukraine
National University "Yuri Kondratyuk Poltava Polytechnic"
Educational and Research Institute of Architecture,
Civil Engineering and Land Management
Department of Architecture of Buildings and Design

GREEN ARCHITECTURE OF MULTIFUNCTIONAL COMPLEXES (ON THE EXAMPLE OF DÜSSELDORF, GERMANY)

Explanatory note
to the qualification work
for obtaining a higher education degree "Master"
in specialty 191 "Architecture and Urban Planning"
(educational program "Architecture of Buildings and Structures")

602-ABi 11550880 EN

Developed by a student of group 602-ABi
15 of January 2025 ____________ El Moussaoui M.
signature

Supervisor of the qualification work
15 of January 2025 ____________ Dmytrenko A.Yu.
signature

Consultant on architectural structures
15 of January 2025 ____________ Semko O.V.
signature

Consultant on engineering
improvements and transport
15 of January 2025 ____________ Dmytrenko A.Yu.
signature

Consultant on landscape architecture
15 of January 2025 ____________ Dmytrenko A.Yu.
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Admit to the presentation

Head of the Department of Architecture of Buildings and Design
16 of January 2025 ____________ Nikolaienko V.A.
signature

CONTENT

	Surname, initials	Signature	Date	602-ABi 11550880 EN		
Developed by	El Moussaoui M.		15.01.24			
Supervisor	Dmytrenko A.Yu.		15.01.24	Explanatory note	Stage	Sheet	Sheets
Consultant	Semko O.V.		15.01.24		DW	3	73
Consultant	Dmytrenko A.Yu.		15.01.24		National University "Yuri Kondratyuk Poltava Polytechnic"		
Consultant	Dmytrenko A.Yu.		15.01.24				
Head of the Department	Nikolaienko V.A.		16.01.24				

Національний університет «Полтавська політехніка імені Юрія Кондратюка»
(повне найменування вищого навчального закладу)

Інститут, факультет, відділення *Навчально-науковий інститут архітектури, будівництва та землеустрою*
Кафедра *архітектури будівель та дизайну*
Рівень вищої освіти *магістр*
Спеціальність *191 «Архітектура та містобудування»*
(шифр і назва)
Освітня програма *«Архітектура будівель і споруд»*
(назва)

ЗАТВЕРДЖУЮ
Завідувач кафедри архітектури будівель та дизайну
____________ В.А. Ніколаєнко
(підпис) (ініціали, прізвище)

«28» жовтня 2024 року

З А В Д А Н Н Я
НА КВАЛІФІКАЦІЙНУ РОБОТУ СТУДЕНТУ

Ель Муссауі Мохамед
(прізвище, ім'я, по батькові)

1.Тема роботи «Зелена» архітектура багатофункціональних комплексів (на прикладі м. Дюссельдорф, Німеччина) / Green Architecture of Multifunctional Complexes (on the Example of Düsseldorf, Germany)
керівник роботи Дмитренко Андрій Юрійович, кандидат технічних наук, доцент,
(прізвище, ім'я, по батькові, науковий ступінь, вчене звання)
затверджені наказом закладу вищої освіти від «09» серпня 2024 року № 818-ф,а
2. Строк подання студентом роботи 17 січня 2025 р.
3. Вихідні дані до роботи генеральний план міста Дюссельдорф (ФРН)
4. Зміст розрахунково-пояснювальної записки (перелік питань, які потрібно розробити) 1)Науково-дослідницька частина (визначити прийоми проєктування об'єкту на основі аналізу теорії та практики); 2) Архітектурно-проєктна частина (описати містобудівні, функціонально-планувальні та архітектурно-композиційні рішення); 3) Архітектурні конструкції (описати інженерно-конструктивні рішення), 4) Інженерний благоустрій території та транспорт (описати інженерний благоустрій ділянки об'єкта та розрахунок парковок); 5) Ландшафтна архітектура (описати основні вирішення щодо озеленення та благоустрою ділянки).
5. Перелік графічного матеріалу (з точним зазначенням обов'язкових креслень)
Ілюстративний матеріал до науково-дослідницької частини роботи (до 25-30% від загального обсягу графічної експозиції), ситуаційна схема розташування об'єкта, опорний план ділянки проєктування (М 1:1000 – 1:500), генеральний план (М 1:1000 – 1:500), плани поверхів (М 1:100 – 1:200), розріз (и) (М 1:100 – 1:200), фасади (М 1:100 – 1:200), загальний вигляд будівлі (перспективне зображення), фрагмент озеленення та благоустрою території ділянки об'єкта.

6. Консультанти розділів проєкту (роботи)

Розділ	Прізвище, ініціали та посада консультанта	Підпис, дата	
		завдання видав	завдання прийняв
Архітектурні конструкції	Семко О.В., завідувач кафедри будівництва та цивільної інженерії	28.10	15.01
Інженерний благоустрій і транспорт	Дмитренко А.Ю., доцент кафедри архітектури будівель та дизайну	28.10	15.01
Ландшафтна архітектура	Дмитренко А.Ю., доцент кафедри архітектури будівель та дизайну	28.10	15.01

7. Дата видачі завдання 28 жовтня 2024 р.

КАЛЕНДАРНИЙ ПЛАН

№ з/п	Назва етапів кваліфікаційної роботи	Строк виконання етапів роботи	Примітка
1	Початок виконання кваліфікаційної роботи. Видача затверджених кафедрою бланків завдання на кваліфікаційну роботу.	28.10.2024	
2	Розроблення ескіз-ідей містобудівного, планувального і об'ємно-просторового вирішення об'єкту проєктування.	28.10.2024 – 01.11.2024	
3	Затвердження та захист ескіз-ідеї містобудівного, планувального і об'ємно-просторового вирішення об'єкту проєктування.	04.11.2024 – 08.11.2024	
4	Розроблення ескізу. Написання пояснювальної записки.	11.11.2024 – 29.11.2024	
5	Кафедральна перевірка: попереднє узгодження креслень ескізу по об'єкту проєктування комісією кафедри. Початок процесу перевірки на плагіат пояснювальної записки.	02.12.2024 – 06.12.2024	
6	Робота над ескізом. Консультація за розділами: архітектурні конструкції, інженерний благоустрій території і транспорт та ін. Доопрацювання ескізу за зауваженнями.	02.12.2024 – 20.12.2024	
7	Робота над ескізом, пояснювальною запискою. Виконання розрахунків. Перевірка на плагіат пояснювальної записки.	16.12.2024 – 20.12.2024	
8	Кафедральна перевірка: затвердження ескізу комісією кафедри. Допуск до подальшої роботи. Доопрацювання проєкту за зауваженнями комісії. Перевірка на плагіат пояснювальної записки.	23.12.2024 – 27.12.2024	
9	Робота над ескізом, пояснювальною запискою. Виконання розрахунків. Виконання та затвердження відповідних розділів проєкту консультантами. Перевірка на плагіат пояснювальної записки.	28.12.2025 – 05.01.2025	
10	Міжкафедральна перевірка: перегляд стану кваліфікаційної роботи комісією. Затвердження відповідних розділів роботи консультантами. Доопрацювання роботи за зауваженнями.	06.01.2025 – 10.01.2025	
11	Завершення перевірки пояснювальної записки на плагіат.	17.01.2025	
12	Рецензування. Отримання рецензії.	13.01.2025 – 17.01.2025	
13	Здавання роботи і пояснювальної записки на кафедру. Допуск до захисту. Попередній захист.	13.01.2025 – 17.01.2025	
14	Захист кваліфікаційної роботи в ЕК. Підсумки захисту атестаційних робіт в ЕК.	20.01.2025 – 24.01.2025	

Студент ____________ Ель Муссауі М.
(підпис) (прізвище та ініціали)

Керівник роботи ____________ Дмитренко А.Ю.
(підпис) (прізвище та ініціали)

SCHEME OF DIVISION OF GRAPHIC EXPOSURE ON SHEET

Sheet 1

LIST OF ILLUSTRATIONS AND DRAWINGS

Sheet	Name	Note
1	The Edge (Amsterdam, Netherlands)	
1	Salesforce Tower (San Francisco, USA)	
1	Capital Gate (Abu Dhabi, UAE)	
1	Torre Reforma (Mexico City, Mexico)	
1	One Angel Square (Manchester, UK)	
1	Sustainable building	
1	Green architecture (structural diagram)	
1	Sustainability of green architecture	
1	Transport accessibility scheme	
1	Map of Europe	
1	Situational scheme of Düsseldorf in Germany	
1	Map of Düsseldorf	
1	Transport scheme of Düsseldorf	
1	Düsseldorf 2030 Vision scheme	
1	Situational scheme	
1	Passive Solar Buildings	
1	Energy-Efficient Buildings	
1	Green Roof Buildings	

Sheet	Name	Note
1	Net-Zero Energy Buildings	
1	Biophilic Buildings	
1	Adaptive Reuse Buildings	
1	Smart Green Buildings	
1	General view of the multifunctional complex 1	
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1	Masterplan	
1	The ground floor plan	
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1	The 5th floor plan	
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1	The 11th floor plan	

GENERAL PROVISIONS

This qualification work is developed for obtaining the degree of higher education "Master" in specialty 191 "Architecture and Urban Planning" (educational program "Architecture of Buildings and Structures"). It follows the requirements of the academic and professional program "Architecture of Buildings and Structures" and the relevant methodological guidelines for the implementation and design of the master's qualification work in specialty 191 "Architecture and Urban Planning" for students studying in the educational program "Architecture of Buildings and Structures" of the second (master's) level of full-time higher education [1].

Relevance of the topic. The adoption of the United Nations Framework Convention on Climate Change in 1992 [2] demonstrated the seriousness of the problem of climate change and its awareness by all mankind. The development of “green” architecture, focused on reducing energy consumption, is today an integral part of achieving the UN’s sustainable development goals [3]. The energy efficiency problem is especially relevant for large buildings, most of which are multifunctional complexes today. These circumstances determine the relevance of the topic of the master’s qualification work “Green Architecture of Multifunctional Complexes (on the Example of Düsseldorf, Germany)”.

Research purpose. Determination of techniques aimed at implementing the principles of green architecture in the formation of multifunctional complexes in the conditions of the Federal Republic of Germany based on the design of office centers in modern conditions of Ukraine based on the analysis of world experience in this area.

Research main objectives: identification of historical prerequisites for the emergence of the concept of green architecture; analysis of world experience in the design and construction of green architecture objects; identification of features of multifunctional complexes that affect their energy efficiency; development of models of principles and methods for creating modern multifunctional complexes, the architecture of which contributes to achieving sustainable development goals.

Research object. The objects of research are world examples of multifunctional complexes that comply with the principles of green architecture.

Research subject. Principles and techniques for forming multifunctional complexes that meet the requirements of green architecture.

Research boundaries. The typological boundaries cover existing and design concepts of multifunctional buildings and complexes that meet the principles of green architecture, as well as the main techniques for their creation. The temporal boundaries cover the period from the middle of the 20th century to the present. The territorial boundaries cover both the territory of the Federal Republic of Germany and the countries of North America, Europe, and Asia (including Japan).

Research methods. The research methodology involves studying theoretical concepts of green architecture and already constructed objects using historical, structural, and comparative analysis methods.

Scientific novelty. For the first time, methods for forming multifunctional complexes based on modern principles of green architecture have been identified, which can be applied in the modern conditions of the Federal Republic of Germany.

Practical significance of the obtained results. The identified methods for forming multifunctional complexes based on modern principles of green architecture can be applied in design activities for new construction, reconstruction and operation of multifunctional complexes (both predominantly public and predominantly residential).

1. RESEARCH PART

1.1. Development of green architecture concept

Currently, “green architecture” is mainly perceived as a concept, the key components of which are the placement of a building taking into account its impact on the environment, the use of renewable energy sources, increasing the energy efficiency of buildings, the reuse of building materials and their environmental safety at all stages of production, use and disposal [4]. In parallel, the term "ecological architecture" (or “environmental-friendly”) is also used with a similar meaning [5].

In the middle of the 20th century. one of the arguments in favor of the development of neo-vernacular architecture was the attempt to create buildings that would not require much energy and resources for their construction, would be adapted to the natural and climatic conditions of a particular region and would use natural, environmentally friendly and relatively affordable building materials. Traditional folk architecture fully met these requirements, especially in regions with a warm and hot climate, where buildings did not require heating, and therefore – enhanced thermal insulation using modern effective insulation materials. The famous Egyptian architect Hassan Fathi (1900 – 1989) was one of the first who, back in the 1930s, turned to folk architecture in search of ecological design solutions, determined by the use of local natural building materials, traditional technologies and spatial planning solutions. The largest example of the implementation of these ideas was the development of the village of New Gurna (the relocated village of Sheikh Abd El Gurna) (1945–1948).

Italian architect Paolo Soleri (1919–2013) developed an urban planning concept called “arcology” in the late 1960s, which was a synthesis of architecture and ecology. This concept was embodied in the Arcosanti eco-village project near Phoenix, Arizona (beginning in 1970). Arcosanti was the architect’s minimum arcological unit of settlement, with an estimated population of 3,000.

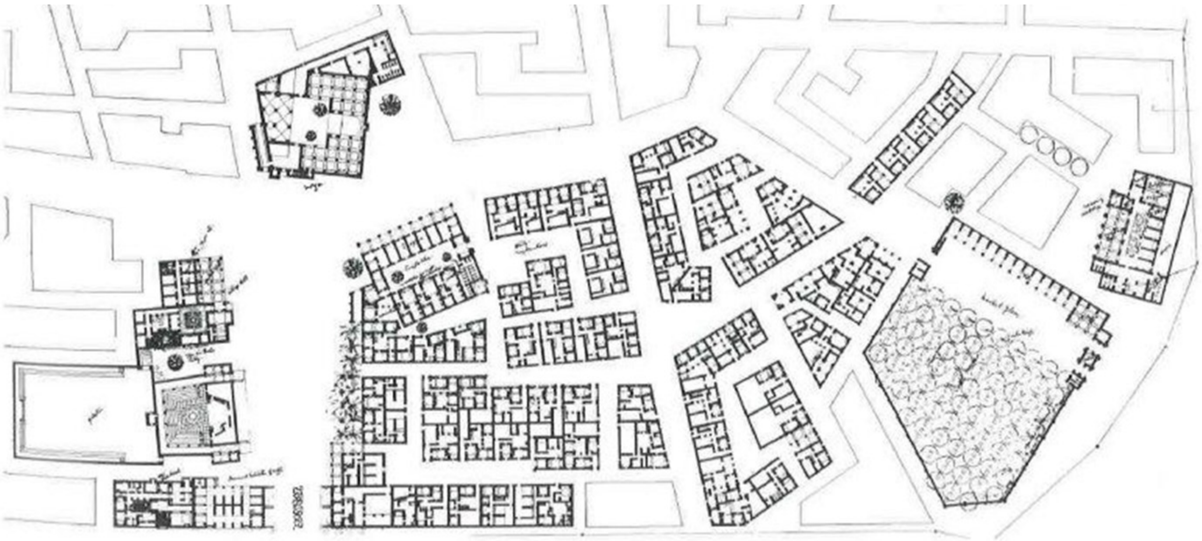

Fig.1.1. Project of New Gurna village (fragment of development). Architect H. Fathi, 1945 – 1948

Fig. 1.2. Arcosanti eco-village project near Phoenix, Arizona. Current state. Architect P. Soleri, end of the 1960s

The first idealistic projects of environmentalist architects in the 1960s and 1970s mostly limited the implementation of ecological architecture principles within a single building. The 1973 oil crisis stimulated the energy-saving technologies' development, including in architecture and construction. The search for new architecture based on the use of renewable (alternative) energy sources intensified.

The first example of "post-crisis" architecture was created in the UK in 1975. It was the Willis Faber and Dumas Headquarters, designed by Norman Foster (born 1935). The energy efficiency of the building was achieved through a wide body, a green inversion roof, the use of energy-efficient facade systems and engineering support systems (Figs. 1.3, 1.4).

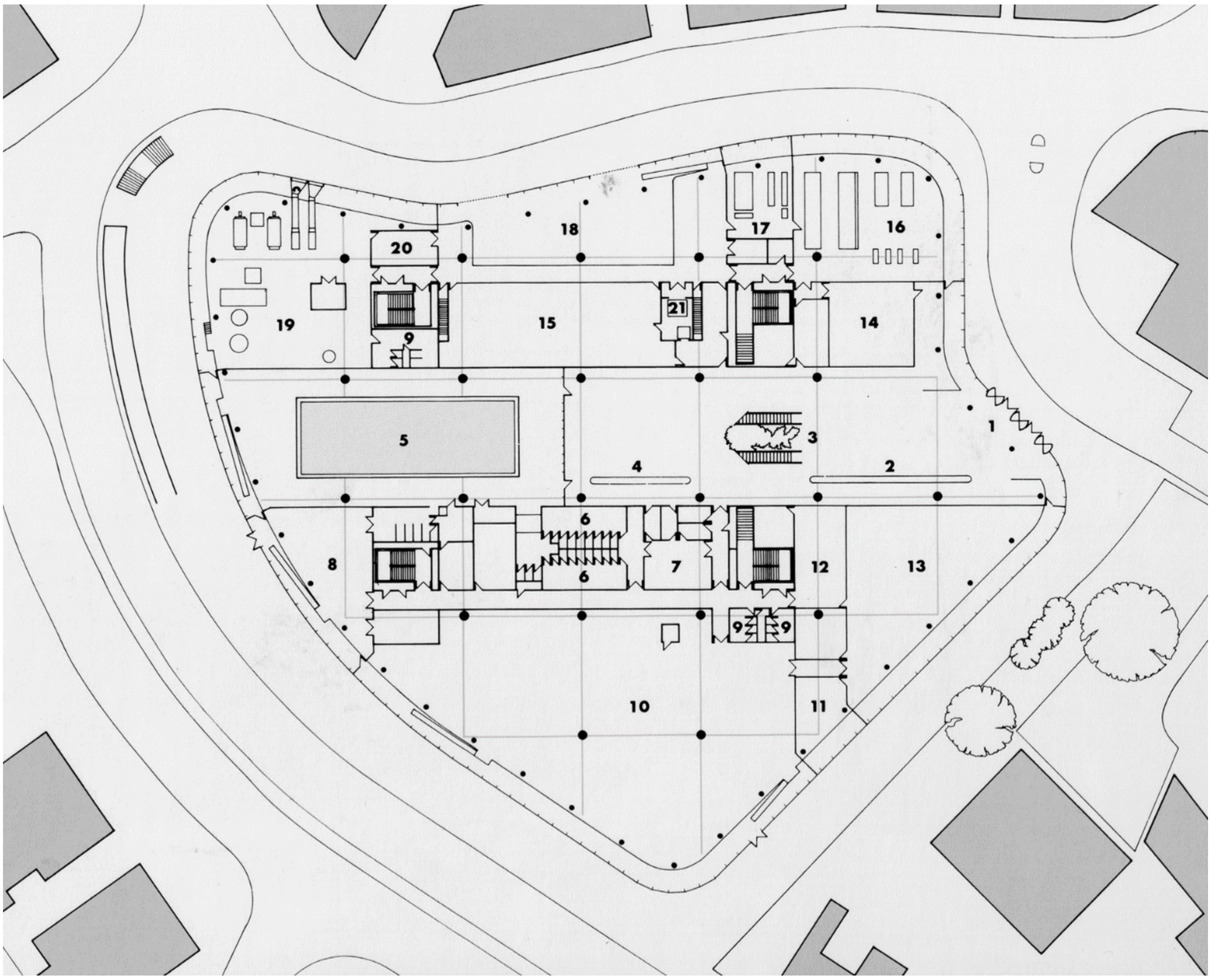

Fig. 1.3. The Willis Faber and Dumas Headquarters, Ipswich, UK, 1970 – 1975. Designed by Norman Foster and Michael Hopkins. The ground floor plan [6]

The growth of the scale of anthropogenic impact on the environment, the rapid development of scientific and technological progress have led to an objective increase in the negative impact of humanity on nature and at the same time to a subjective awareness (and – perhaps – some exaggeration) of the scale of this impact.

Fig. 1.4. The Willis Faber and Dumas Headquarters, Ipswich, UK., 1970 – 1975. Designed by Norman Foster and Michael Hopkins. Aerial view

The International Conference on Environmental Protection, held in 1992 in Rio de Janeiro, formulated the concept of sustainable development as a means of solving international economic and environmental problems. The concept of sustainable development [7] is based on the need to establish a balance between meeting the current needs of humanity and protecting the interests of future generations, including their need for a safe and healthy environment.

The principles of sustainable development are fully implemented in the field of architecture and urban planning, combining environmental, economic and socio-cultural aspects.

The main areas of sustainable development in architecture are:

– in the environmental aspect – protection of natural resources and preservation of ecosystems;

– in the economic aspect – minimization of costs for ensuring the life cycle of architectural objects, improving economic indicators;

– in the socio-cultural aspect – creation of a safe, healthy and comfortable environment, achievement of high functionality of objects [8].

An ecological building today is designed to provide healthy and safe conditions for people inside it, while minimizing the harmful impact on the natural environment outside. The characteristic features of ecological architecture are the use of innovative technologies for aesthetic expressiveness and for the rational use of natural resources.

The main principles of ecological construction today are:

minimization of energy consumption and CO_2 emissions throughout the entire life cycle of the building (which includes: the production of building materials, structures, and parts; construction process; operation of the building during the estimated period; dismantling and disposal of building structures after the completion of its life cycle);

– ecological cleanliness (i.e. safety for humans and the natural environment) of building materials during their production and operation;

– taking into account the natural and climatic features of the construction region;

– use of alternative energy sources;

– bioclimaticity – creating favourable conditions for human life inside the building, as close as possible to the natural conditions of the relevant region;

– proper waste disposal and use of closed recirculation systems;

– minimizing the negative impact of the facility on the natural environment.

Green architecture is not a separate style. It is the architecture of the future, and its principles are gradually becoming mandatory for all new buildings. Accordingly, in any of the current architectural styles and trends, objects are being created that can be attributed to ecological architecture.

That is why the leaders of the ecological trend have not been determined: all famous masters of architecture, in whatever styles they work, consistently implement the principles of ecological architecture in their latest works.

1.2. Classification of green architecture buildings

In the world practice of designing ecological and energy-efficient buildings, methods have been developed for assessing their quality and comparing them with each other. For this purpose, several standards and certification systems are used in different countries of the world, among which the main ones are:

– BREEAM (Building Research Establishment Environmental Assessment Method);

– LEED (Leadership in Energy and Environmental Design);

– DGNB (German: Deutsche Gesellschaft für Nachhaltiges Bauen).

BREEAM is a method for assessing the environmental performance of buildings, developed in 1990 by the British company BRE Global. BREEAM defines standards for sustainable design and construction and also makes it possible to compare different buildings according to the degree of their impact on the environment. The ratings that are given are graded Pass, Good, Very Good, Excellent, and Outstanding [9].

LEED – "Leadership in Energy and Environmental Design" is a rating system for certifying green buildings, developed in 1993 by the United States Green Building Council (USGBC) [10]. The scores are given in points as follows: Certified – 40 – 49 points, Silver – 50 – 59 points, Gold – 60 – 79 points, Platinum – 80 points and more.

DGNB – "Deutsche Gesellschaft für Nachhaltiges Bauen" ("German Society for Sustainable Building") – a German system of environmental certification of buildings, developed in 2009 with a thorough assessment of more than 50 factors covering environmental and economic indicators, socio-cultural aspects, technological and functional processes [11]. The quality level is determined by the ratings Gold (Gold), Silber (Silver) and Bronze (Bronze).

All of the above environmental certification systems have developed specialized assessment criteria for buildings of different typological groups, as well as methods for calculating environmental indicators of both existing buildings and buildings under design. The basis of "green standards" is the LCA (Life Cycle Assessment) method – an assessment of environmental, economic, and social impacts on the environment at all stages of the product life cycle, including its production, operation, and disposal.

Not only individual buildings, structures and their complexes, but also building materials, products, and structures are subject to environmental certification.

One of the methods of such certification is environmental labeling, introduced in Ukraine since 2003 in accordance with the DSTU ISO 14024 standard [12]. The main goal of environmental labeling is to create conditions for expanding demand for products and services by providing reliable information about the environmental characteristics of products and services and to promote the introduction of products and services in the architectural and construction industry that have the least environmental impact.

Ecolabels are divided into three groups:

– signs to indicate improved environmental characteristics of goods in general at all stages of their life cycle or their individual properties (for example, “Green Crane”, Ukraine; “Ecolabel” or “Flower”, EU; “Blue Angel”, Germany, etc.);

– signs indicating certain environmental characteristics (for example, “Content of recycled material”, “Suitable for recycling”, “Suitable for composting”, “Demountable structure”, “Green dot”, Germany);

– signs indicating danger to people and the environment (for example, “Dangerous for the environment”).

These signs are used for various groups of goods, including building materials and products, equipment, machinery, and furniture. Providing such information is of great importance for the possibility of conscious choice of ecological materials and services in the design, construction, and operation of buildings.

In world practice, some definitions have been formed regarding the characteristics of energy-efficient buildings depending on the amount of energy used.

The main ones are:

– “Low-energy buildings” – annual energy consumption in which is up to 70 kWh/m²;

– “Zero energy buildings” – Zero net energy (ZNE) building, Nearly zero energy building (NZEB), Net zero building (NZB)) – these are buildings with a zero energy balance during the year, which can be achieved by seasonal accumulation and redistribution of energy using various architectural and engineering methods. The zero annual balance during the year is determined by calculating the amount of energy received and consumed, CO_2 emissions, cost, etc.;

– “Plus energy buildings” – those in which more energy is received than is consumed during the year. For this purpose, a complex of engineering equipment can be used, in particular, solar collectors, heat pumps, wind generators, etc.

A special type of energy-efficient house is the “Passive House”, for which clear quantitative indicators of energy consumption are established to achieve a favorable microclimate in the house and ensure energy needs for its functioning. One of the main criteria for defining a passive house is the use of no more than 15 kWh/(m^2 per year) for heating. Modern categories of passive houses, which take into account primary energy consumption and energy generation from alternative sources, are:

– “Passive House Classic” – consumes 60 kWh/(m² per year);

– “Passive House Plus” – consumes 45 kWh/(m² per year) and generates 60 kWh/(m² per year);

– “Passive House Premium” – consumes 30 kWh/(m² per year) and generates 120 kWh/(m² per year).

Based on the passive house concept, the Saint-Gobain corporation proposed a type of "Multicomfort House", which, in addition to meeting energy standards, provides for achieving a high level of comfort.

Along with energy efficiency, the name of a building type can indicate its environmental friendliness, such as: "zero-emission building", which has minimal impact on the environment; "active house", which uses alternative energy sources; "green building", designed according to "Green Building" standards; "ecological building", which complies with the principles of sustainable architecture.

1.3. Analysis of practical experience in implementing green architecture ideas

Proclaimed in 1992, the concept of sustainable development quickly found ardent supporters among architects, such as the French Françoise-Hélène Jourda (1955–2015). Among her most famous projects is the Botanical Garden Museum in Bordeaux (2006) (Fig. 1.5).

Fig. 1.5. Botanical Garden Museum in Bordeaux, France (2006). Architect Françoise-Hélène Jourda

The Rio de Janeiro conference was a testament to the world community's concern about the environmental situation and at the same time influenced the agenda of many events, in particular, the International Exhibition EXPO-92 in Seville (Spain). Therefore, during the creation of the exhibition building complex, the problem of a regulated environment became one of the main ones.

The main task was to neutralize the Spanish summer heat by consuming less energy. Among the many climate control strategies demonstrated at the exhibition, the water wall of the British Pavilion, designed by the British architect Nicholas Grimshaw (born 1939), stood out. From the upper part of the glass screen on the eastern facade, water flowed down in a thin film, then broke off from the lower edge of the screen, turning into "rain" in front of the glass panels of the first floor, and fell into a pool, from where it was again pumped to the upper part of the screen. The western side of the pavilion was protected from overheating by an awning stretched over steel structures [13].

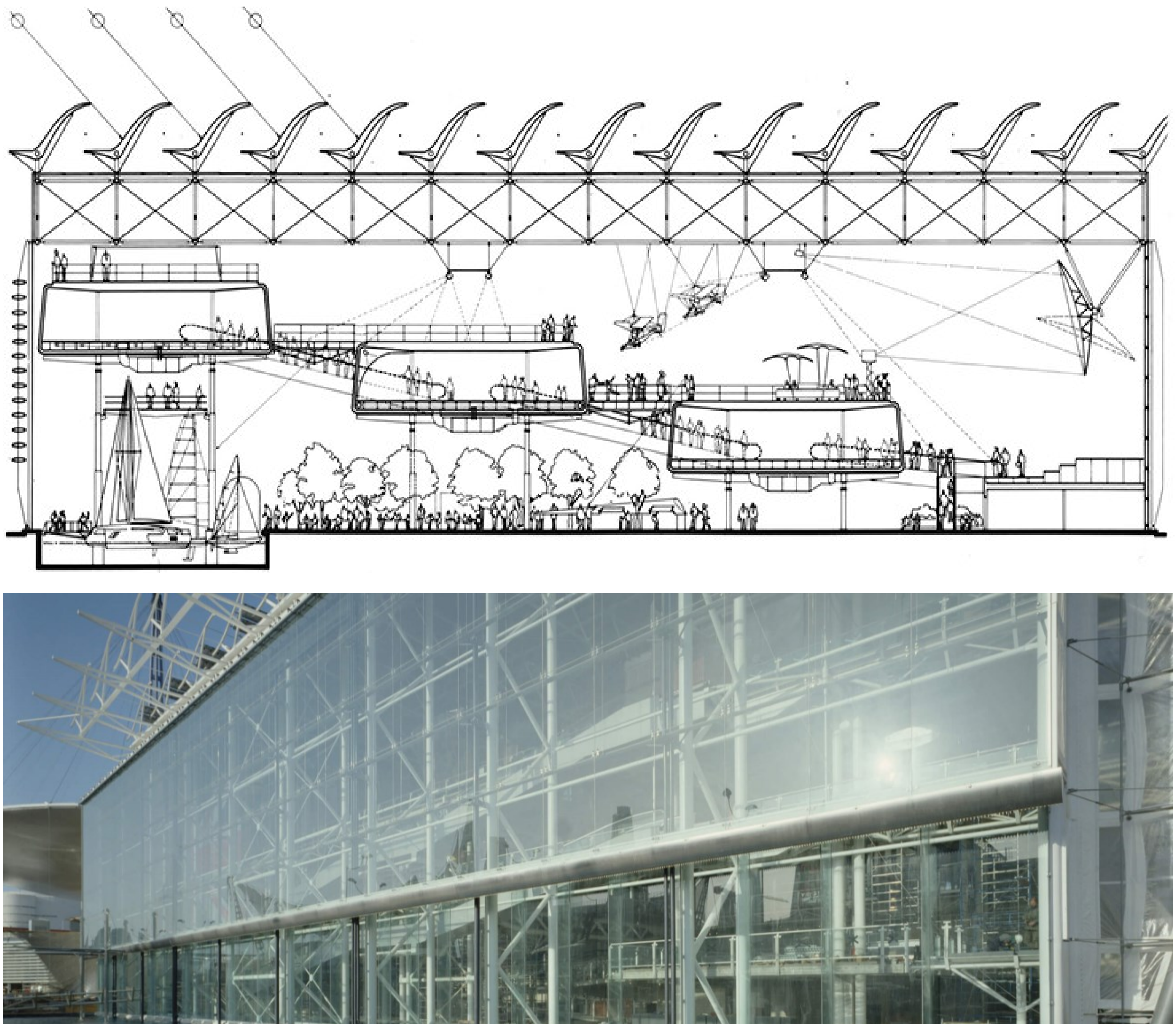

Fig. 1.6. British Pavilion Expo 1992 Seville, Spain. Architect N. Grimshaw. The longitudinal section, the "water wall" on the southern façade [13]

Fig. 1.7. British Pavilion Expo 1992 Seville, Spain. Architect N. Grimshaw. The view from the west [13]

The Eden Project in Cornwall, UK (1996–2001), designed by N. Grimshaw, not only demonstrates the ideas of global biodiversity and human dependence on the plant world, but is also part of a larger project to rehabilitate a former clay quarry, located 2 km from the town of St. Blaise and 5 km from the larger town of St. Austell. The complex is dominated by two huge covered spaces consisting of adjacent geodesic domes (Fig. 1.8). The tubular steel frame of the domes supports a double shell of thousands of five- and six-sided ethylene tetrafluoroethylene (ETFE) cells filled with an inert gas. This shell design is lightweight, provides sufficient thermal insulation and does not interfere with the penetration of sunlight. The larger of the two volumes recreates a tropical rainforest ecosystem (and is the largest indoor tropical forest in the world), while the second recreates a Mediterranean natural environment. The main parameters of the internal environment are monitored and automatically regulated by a computer system.

Fig. 1.8. The Eden Project in Cornwall, UK (1996–2001), Architect N. Grimshaw. The aerial view

It is worth noting that the criterion for classifying a certain object as ecological architecture can be not only its functional and structural features but also its ideological content. The Eden project is an example of such an object.

Itsuko Hasegawa (born 1941) created a similar, but smaller project in Japan - the Fruit Museum in Yamanashi-shi (1993 – 1995) [14]. Three buildings, covered with transparent shells of complex curvature, symbolize the "fruits" of spiritual sensuality, intelligence and passion. In a general sense, buildings are trees that create the fruits of the creativity of visitors, who themselves will spread sensitivity to our fragile environment, and, as the authors of the project hope, will themselves create "green" buildings.

Fig. 1.9. Fruit Museum in Yamanashi-shi (1993 – 1995) by Itsuko Hasegawa [14]

Founded in 1970 in New York by James Wines(born 1932) and his partners, the SITE architecture and environmental art studio focused its activities on the creation of ecological objects in the 1990s. In 1994, the studio developed a project for the shutdown and dismantling of the Tresvent nuclear power station in North Wales. It proposed the elimination of radioactive waste using robots and a comprehensive greening of the territory, combined with the construction of the Energy Resources Research Center on the hilltop.

The technique of integration into the landscape was also used by SITE architects in the Aquatorium project – "Museum of Water" in Chattanooga, Tennessee (1993). The circular structure is "cut" by a series of walls of wavy outlines into separate strips of structure fragments and open watered and landscaped areas. The exposition is not closed within the interior and merges with the surrounding natural landscape (Fig. 1.10).

Fig. 1.10. The Aquatorium project – "Museum of Water" in Chattanooga, Tennessee (1993). Designed by SITE

Argentine architect and designer Emilio Ambasz (born 1943) perceives the designed object as part of the natural landscape. In his projects, he consistently embodies the concept of development with the help of high technologies of the “second”, man-made nature, which will gradually displace the “first” nature, while simultaneously taking over its functions. The project of the International Center in Fukuoka (1994), developed by E. Ambasz, is a clear embodiment of the idea of “man-made nature” (Fig. 1.11). In the very center of the urbanized area, a massive stepped structure rises, the greened “steps” of which resemble a mountain slope overgrown with forest. From a functional point of view, the greening of the building is almost the only means of approaching ecological balance [15].

Fig. 1.11. The International Center in Fukuoka, Japan (1994) by E. Ambasz [15]

The Mikal Cultural Center in Shin-Sanda, Japan (1994) is one of E. Ambasz's important projects that made him world-famous. The facility was built in the epicenter of the earthquake that destroyed Koba (Fig. 1.12).

Fig.1.12. The Mikal Cultural Center in Shin-Sanda, Japan (1994) by E. Ambasz. General view

The structure, partially sunk into the ground, is formed by two L-shaped volumes, between which is located an equally L-shaped fragment of the natural landscape (Fig. 1.13). The cultural center clearly illustrates the architect’s desire to create architecture that, in his words, is “simultaneously present and absent.”

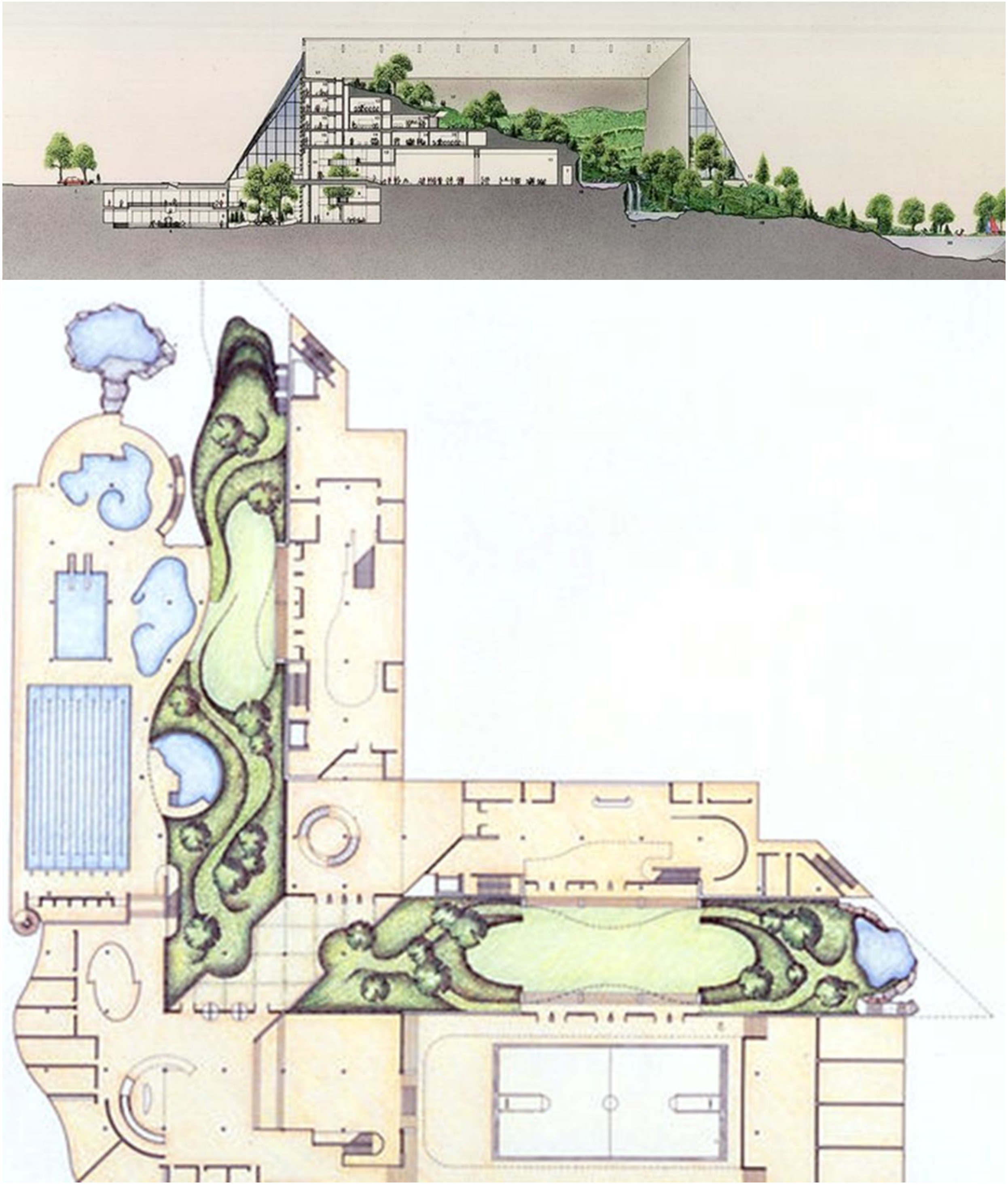

Fig. 1.13. The Mikal Cultural Center in Shin-Sanda, Japan (1994) by E. Ambasz. Section, the ground floor plan

The so-called House of Spiritual Rest, created by E. Ambasz near Sierra Morena (2005), is more reminiscent of a theatrical set – two perpendicular walls on the outside of the corner resemble a real house, but on the inside – a theatrical set on the reverse side, where two staircases converge in the corner opposite the opening that leads to a kind of "bay window" on the "outer" side of the object (Fig.1.14).

Fig. 1.14. The House of Spiritual Rest, near Sierra Morena (2005), Spain. Architect E. Ambasz. Outside (top) and inside (bottom)

In 1994, E. Ambasz designed the Nuova Concordia residential complex in Castellaneta al Maro, Italy (Fig. 1.14). Critics refer to it as a form of landform architecture, as residential buildings, a shopping complex, and sports and wellness centers located around man-made lakes are integrated into the landscape, forming man-made hills.

Fig. 1.15. Nuova Concordia residential complex in Castellaneta al Maro, Italy. Architect E. Ambasz. General view (top) and fragment (bottom)

The environmentally friendly, self-contained single-family house Grafton Hall in Cheshire (UK) was the subject of the 21st Century House competition (2002). The winning design, designed by the Japanese-Scottish architectural firm Ushida Findlay Architects, was another milestone in their creative process. Improving energy efficiency was one of the main objectives of the project, so the starfish-shaped building is partially buried in the ground to use the heat of the soil (Fig. 1,16). The autonomy of the house is ensured by passive heat storage systems and a rainwater collection and purification system. Even though the design won the competition, it was never implemented [16].

Fig. 1.16. Grafton Hall in Cheshire (UK), 2002, by Ushida Findlay Architects [16]

Often, ecological architecture objects are designed taking into account not only natural conditions but also the cultural traditions of a particular region, as in the case of the Jean-Marie Tjibau Cultural Center in Nouméa, New Caledonia, designed by Renzo Piano (born 1937). The architect used not only specific natural conditions, but also traditions of local culture: types of settlement organization, types of buildings, and natural materials. R. Piano sought to demonstrate the real possibility of creating ecological architecture, energy-efficient and culturally and aesthetically valuable.

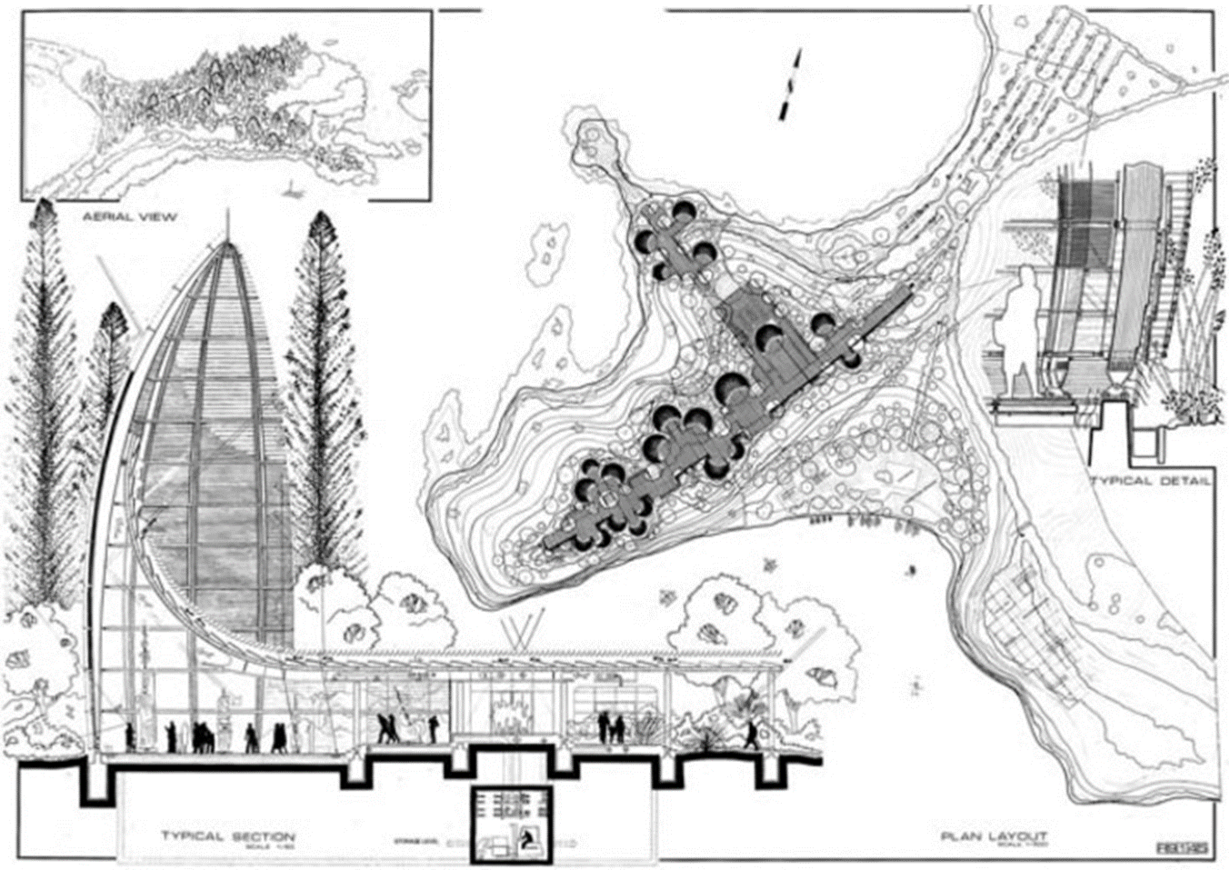

Fig. 1.17. Jean-Marie Tjibau Cultural Center in Nouméa, New Caledonia, 1998. Architect R. Piano

The California Academy of Sciences Museum in San Francisco, California (2001–2009), designed by R. Piano, is a part of the park raised above the ground, beneath which, within a rectangular volume, are located the Planetarium, Aquarium, and Museum of Natural History (Fig. 1.18).

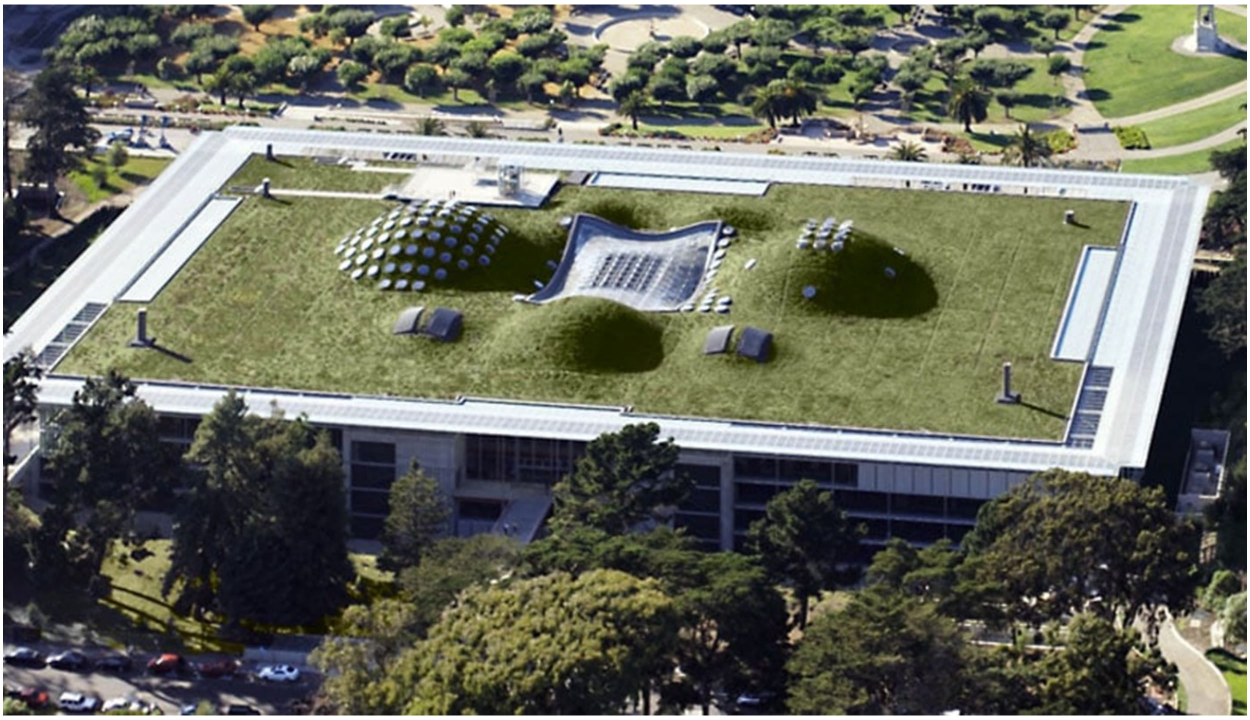

Fig. 1.18. The California Academy of Sciences Museum in San Francisco, California (2001–2009). Architect R. Piano

In the 1990s, other high-tech architects turned to environmental issues, such as the British architect Michael Hopkins (born 1935), who built the Nottingham Tax Centre between 1992 and 1994. Six office buildings, L-shaped and square with a courtyard, with rounded corners and cylindrical towers, are grouped around a spectacular public services building (Fig. 1.19).

Christoph Ingenhoven (born 1960) is considered one of Germany's leading eco-architects. When Ingenhoven, along with Frei Otto, took part in the competition for the reconstruction of Stuttgart's railway junction – Stuttgart 21 – in 1997, he could hardly have foreseen the challenges that awaited this large-scale project. Construction only began in 2007, sparked massive public protests in 2010–2011, and only in 2023 was the last cup-shaped column completed, which supports the green cover above the railway tracks and passenger platforms. After the project is completed, a real park will appear above the railway station, interspersed with skylights, through which the interior of the railway station will receive natural light and aeration. (Fig. 1.20)

Fig. 1.19. Nottingham Tax Centre, UK, (1992 – 1994) by M. Hopkins

Fig. 1.20. Reconstruction of Stuttgart's railway junction – Stuttgart 21 (began 2007) by Christoph Ingenhoven

The work of architects who advocate direct reproduction, such as C. Terry (born 1937) and R. Adam (born 1948), also does not stand aside from today's environmental problems. According to these architects, a building built from natural materials traditional for a given area, using traditional construction technologies and traditional spatial planning solutions, is much more environmentally friendly than a modern building, because it does not require many modern energy-intensive technologies (in particular, air conditioning), and is also more durable. Traditional planning and building materials, however, are often combined with the use of the latest energy-saving technologies, as in the Solar House in Sussex Down (UK), designed by Robert Adam (Fig. 1.21). To maximize natural sunlight, 60% of the surface of the southern facade is glazed. The shape of the portico is specifically changed to allow more sunlight into the atrium located behind it. The atrium is additionally illuminated and heated through an overhead skylight, and the adjacent rooms are heated thanks to a special air exchange system. The ventilation shafts have been transformed into tall towers that crown the silhouette of the roof.

Fig. 1.21. The Solar House in Sussex Down (UK), 1992 – 2001, by Robert Adam

The ecological approach has even penetrated the design of skyscrapers, the most environmentally harmful structures due to the high level of energy consumption (both in the production of building materials for them and in their operation). Malaysian architect Ken Yeang (born 1948), recognizing the unecological nature of high-rise buildings, nevertheless believed in the possibility of making them less harmful to the environment and even introduced the term "ecological skyscraper". Since K. Yeang worked on buildings for tropical climates, the main problem of energy conservation was to reduce the need for air conditioning. For the first time, he comprehensively applied the principles he developed in a relatively low, 15-story building (which can by no means be attributed to skyscrapers). This is the office of the Menara Mesiniaga company in Panang (1990 – 1992), the volumetric-spatial structure of which protected from excessive insolation and stimulated natural ventilation. The cylindrical volume of the building is penetrated by spiraling terraces and green spaces that provide natural ventilation, and curved screens on the outside protect the office premises from overheating by sunlight [17].

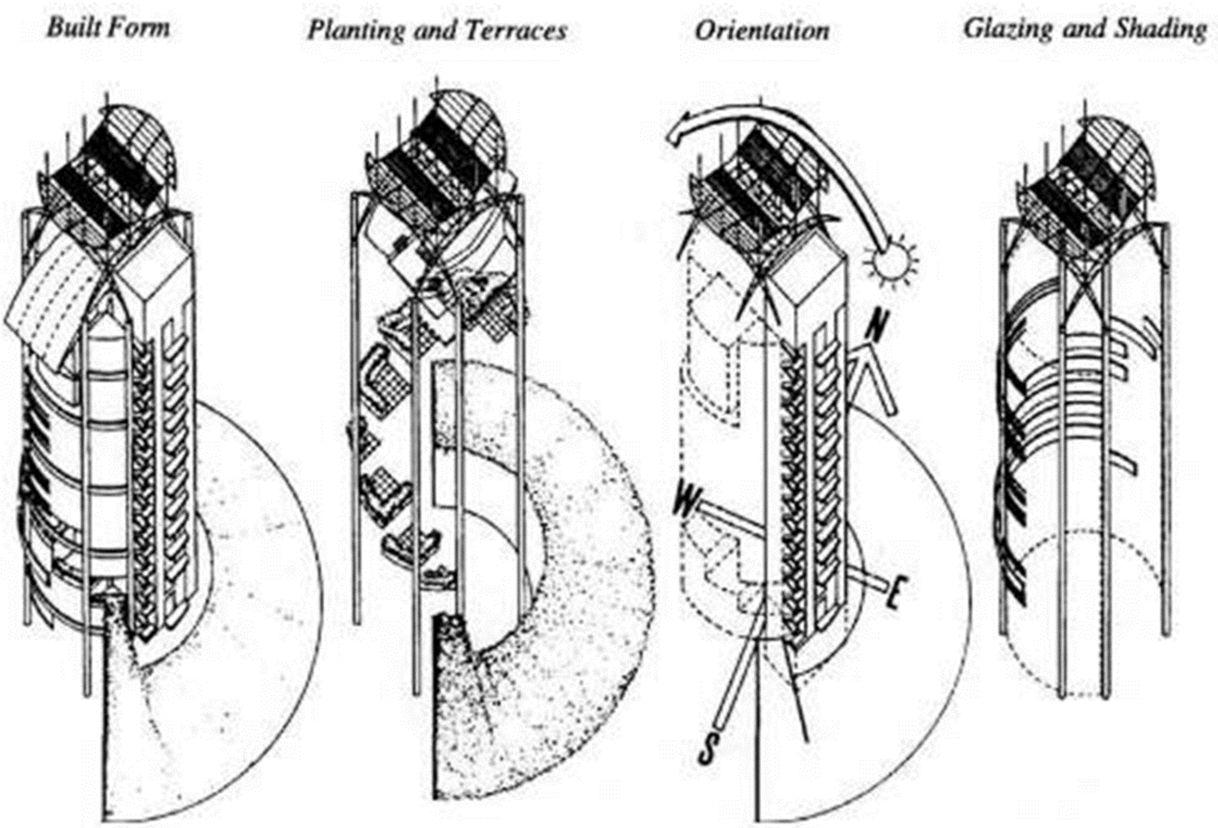

Fig. 1.22. Mesiniaga Tower, Petaling Jaya, Malaysia (1992). Architects: T. R. Hamzah & Yeang Sdn. Bhd. [17]

The role of form in improving the energy efficiency of a building is demonstrated in London City Hall, which houses the city's municipal services (N. Foster, 1999 – 2000). The form of the building, developed using computer modeling methods, is obtained from a geometrically modified sphere. This form provides optimal energy efficiency by minimizing the surface area exposed to direct sunlight. Some active and passive shading devices are used: on the south, the upper floors overhang the lower ones, thereby shading them, and the building's cooling systems use groundwater pumped through boreholes. from groundwater. For most of the year, the building does not require additional heating and air conditioning, consuming only a quarter of the energy consumed by a typical air-conditioned office building.

Fig. 1.23. London City Hall, London, UK (N. Foster, 1999 – 2000)

The London office of Swiss Re (1996–2002), designed by N. Foster, was nicknamed the "gherkin" for its unusual shape (Fig. 1.24). It was calculated using a specially developed computer program, ensuring optimal air circulation around and inside the building. The floor slabs resemble six-pointed "snowflakes" in plan (Fig. 1.25). The triangular atriums thus formed encircle the building in spiral trajectories, providing natural ventilation in summer and distributing solar heat obtained through passive heating throughout the building in winter. The atriums also allow sunlight to pass through the building, making the working environment more pleasant and reducing lighting costs. The building became the first skyscraper with windows that open and close automatically depending on air temperature and wind speed. The use of volumetric and spatial and engineering solutions allowed to reduce energy consumption by half compared to similar skyscrapers.

Fig. 1.24. The London office of Swiss Re (1996–2002), designed by N. Foster

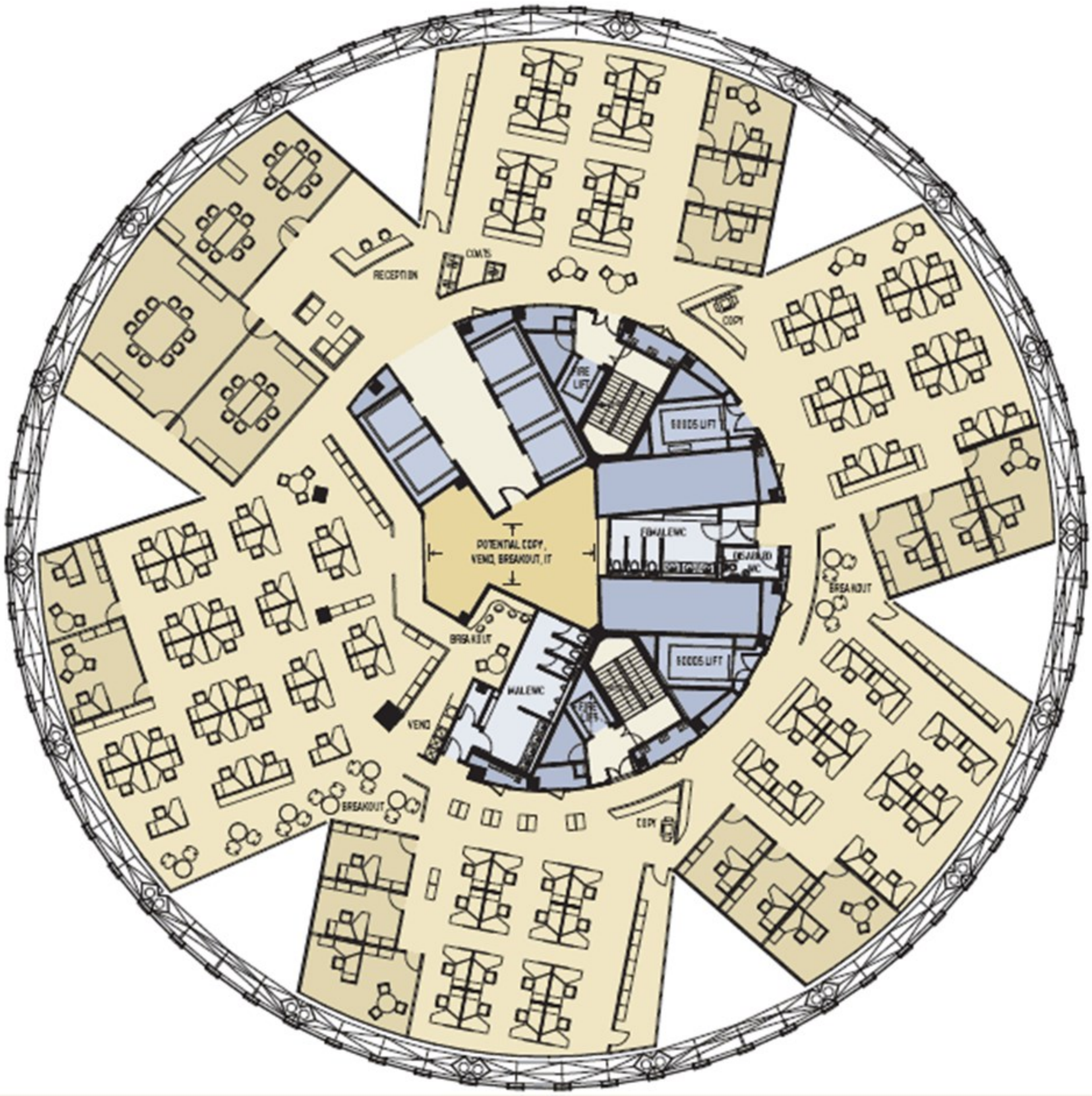

Fig. 1.25. The London office of Swiss Re (1996–2002), designed by N. Foster. The typical floor plan

An example of the influence of form on the energy efficiency of a building is the headquarters of the Hearst Media Corporation in New York (2003–2006), also designed by N. Foster. Hearst Tower is the first skyscraper without vertical steel frame elements; instead, a lattice shell made of triangular cells made of steel beams was used, which made it possible to save about 20% of steel, a material that is extremely energy-intensive to manufacture. The energy consumption of this building is 22% lower than that of similar projects, and the need for technical water is completely met by using atmospheric precipitation.

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Fig. 1.26. The Hearst Tower, New York, USA (2003 – 2006) by N. Foster

The British architectural firm Atkins & Partners has implemented its most significant projects in the “oil monarchies” of the Persian Gulf. Among them is the World Trade Center in Manama (2008, architect Shauna Killa). The energy independence of the building is ensured by three giant wind turbines with a total capacity of 1,100 MW/h, ingeniously incorporated into the structure of the building. The shape of the skyscraper is designed to create high-speed air flows, directing them to the giant turbine blades.

Fig. 1.27. World Trade Center in Manama (2008, architect Shauna Killa)

One of the leading eco-architects in the United States is Chad Oppenheim (born 1971). His company designed a 25-story mixed-use building in Miami (completed in 2008). The building's layout is standard, but its originality is given by a perforated "case" with round openings (which provide sun protection and ventilation in the space between the outer perforated and inner glass shells) and built-in wind turbines located at the top of the building. The building was once called the first "green" high-rise building in Miami.

Fig. 1.28. 25-story mixed-use building in Miami (completed in 2008) by Chad Oppenheim. General view (left), the typical floor plan (right)

1.4. Recommendations for designing modern green buildings

In modern architectural practice, a number of architectural and planning techniques have been developed and successfully implemented that ensure increased energy efficiency of the building as a whole. These include: architectural and planning and spatial solutions aimed at obtaining solar energy and its accumulation in the cold season; protecting the building from overheating, using sun protection in the hot season; reducing heat loss by the building due to the compactness of the structure as a whole and its elements; thermal zoning of functional and planning groups in the building; differentiation of facade solutions depending on the orientation to the cardinal points (number of openings, color, texture); selection of appropriate engineering and structural and technological solutions.

A significant part of heat loss occurs from the surface of the building, so it is desirable to reduce the ratio of the surface area of the building's enclosing structures to its heated (cooled) volume. This ratio is expressed by the compactness index of the building. The compactness index of the building improves when using simple plan forms and compact volumetric and spatial forms, as well as when increasing the physical dimensions of the building. To improve the compactness index, it is advisable to use the methods of embedding and adding individual public institutions to other buildings, for example, residential ones. Most often, the stylobate part of modern residential complexes is formed from public facilities.

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For separately located multifunctional complexes, it is desirable to use a compact volumetric-spatial solution. First of all, this means the priority use of a centralized scheme, when the course of all functional processes takes place in one volume of the building. It is also advisable to use a block scheme, which allows combining individual blocks of the building into a single complex [18].

The overall energy efficiency of the building is improved by preventing heat loss due to the reduction of wind load on the building. In this case, the use of aerodynamic forms of the building is effective – “streamlined” forms of the plan and overall volume. This is especially true for high-rise buildings that perceive significant wind loads.

Such aerodynamic forms are characteristic of high-rise buildings designed in different climatic conditions – the Swiss RE office building (architect Norman Foster, London, Great Britain), Commerzbank (architect Norman Foster, Frankfurt am Main, Germany), the Petronas Towers (architect Cesar Pelli, Kuala Lumpur, Malaysia), etc.

When elongated houses and buildings of considerable height are placed next to each other, undesirable aerodynamic effects may appear in the area around them. The aerodynamic qualities of the shape of the house and the building as a whole are checked on models – prototypes (models) by testing them in a wind tunnel or by computer modeling of the movement of air flows.

From the point of view of increasing the energy efficiency of multifunctional complexes, it is important to: analyze the requirements for the orientation of the premises; introduce additional protection of the building; use passive solar heating systems. On the north side of the building in the plan, it is desirable to place vertical communication nodes, auxiliary rooms or rooms that themselves are a source of heat (computer classes, technological kitchen rooms, etc.). On the northern facades, it is recommended to arrange a minimum number of openings, to provide enhanced thermal insulation. Increasing the area of window openings on the southern facade may be quite justified in the case when they are part of the passive solar heating system.

Passive solar heating systems contribute to the irradiation of massive structures inside the building and the subsequent accumulation of thermal energy in them. Such structures inside the building play the role of a thermal massif. Passive solar heating systems are divided into types of direct and indirect irradiation, which affects the nature of the planning and spatial solution. These techniques are implemented in the form of single- and double-light spaces, "greenhouse rooms", "winter gardens" and atriums. In this case, the atrium performs not only the functions of a communicative, recreational, buffer space, but also contributes to the creation of a comfortable microclimate inside the house, protection of the facades of the house from the effects of negative natural phenomena, stabilization of the temperature regime, and improvement of the compactness index.

In winter, the use of glazing of the southern facade, an atrium with overhead lighting leads to energy savings on heating, but in summer it can cause overheating. Therefore, when designing energy-efficient public buildings, it is necessary to provide for sun protection – stationary as part of the building or dynamic with a variable position of the elements. Stationary sun protection elements are located mainly horizontally on the southern facade and vertically on the western facade. Elements of horizontal stationary sun protection can be balconies, canopies, visors, specialized sun protection devices – slats; vertical stationary sun protection – protruding vertical elements of the facade of the building. Mobile means of sun protection are awnings, awnings, canopies with a variable position, screens, rotary slats, etc. An innovation for modern public buildings is the installation of adaptive facades that dynamically respond to changing conditions of solar radiation or wind load.

At the engineering, structural, and technological levels, a significant effect can be achieved by the use of system-integrated solutions related to the general structure of the building. The enclosing structures of the shell of public buildings must meet the requirements for thermal performance. Modern engineering equipment allows you to significantly increase the energy efficiency of buildings in heating, ventilation and cooling of the building, lighting, through the use of control devices, recuperation units, heat pumps, solar collectors (thermal and photovoltaic), wind generators, etc. It should be noted that, for example, a forced ventilation system with the use of recuperation is an integral part of a "passive house". An important part of ensuring the life of multifunctional complexes is computer monitoring of engineering systems, energy supply, and microclimate indicators using Smart Building, Intelligent building systems, etc.

In general, environmental friendliness and energy efficiency of public buildings is achieved by the comprehensive implementation of appropriate urban planning, architectural planning, spatial and engineering design solutions.

2. ARCHITECTURAL AND PROJECT PART

2.1. Urban panning solution

The designed object is located in Düsseldorf, a city in the western part of the Federal Republic of Germany in the Rhine-Ruhr region, the administrative centre of the federal state of North Rhine-Westphalia (Fig. 2.1). Düsseldorf has a long and eventful history: its first written mention dates back to 1135, and it received city status in 1288. Nowadays Düsseldorf is one of the five most significant economic, transport, and cultural centres of Germany (along with Berlin, Frankfurt am Main, Munich, and Hamburg) and the sixth most populous city in the country (611,258 people as of 2022) [19]. The city is home to the headquarters of many large corporations, many higher education institutions, an international airport, and two river harbours.

Fig. 2.1. Location of Düsseldorf in the Federal Republic of Germany

Düsseldorf is located on the Lower Rhine Plain opened to the North Sea, which causes a predominantly oceanic climate (Cfb according to the Köppen classification) (Fig. 2.2). Due to the predominantly westerly winds carrying moist air masses, winters are mild, mostly snowless, and summers are humid and moderately warm. Düsseldorf's climate is primarily oceanic, which is due to the relief open to the North Sea (Lower Rhine Plain). The dominant westerly winds bring moist air masses with them. As a result, the city is characterized by mild, snowless winters and moderately warm and humid summers (average annual temperature 10.6 ° C). The weather is changeable, the number of sunny days is one of the lowest in Germany, but an average of 800 mm of precipitation falls per year.

Climate data for Düsseldorf (1991–2020 normals, extremes 1981–present) [hide]													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	16.4 (61.5)	21.0 (69.8)	23.8 (74.8)	28.8 (83.8)	33.8 (92.8)	36.8 (98.2)	40.7 (105.3)	38.5 (101.3)	34.0 (93.2)	27.7 (81.9)	20.4 (68.7)	16.3 (61.3)	40.7 (105.3)
Mean daily maximum °C (°F)	6.0 (42.8)	7.2 (45.0)	11.1 (52.0)	15.6 (60.1)	19.4 (66.9)	22.5 (72.5)	24.7 (76.5)	24.2 (75.6)	20.1 (68.2)	15.2 (59.4)	10.0 (50.0)	6.6 (43.9)	15.2 (59.4)
Daily mean °C (°F)	3.4 (38.1)	4.0 (39.2)	6.9 (44.4)	10.5 (50.9)	14.3 (57.7)	17.3 (63.1)	19.4 (66.9)	18.9 (66.0)	15.3 (59.5)	11.2 (52.2)	7.1 (44.8)	4.2 (39.6)	11.0 (51.8)
Mean daily minimum °C (°F)	0.5 (32.9)	0.7 (33.3)	2.6 (36.7)	5.0 (41.0)	8.7 (47.7)	11.7 (53.1)	14.0 (57.2)	13.7 (56.7)	10.7 (51.3)	7.5 (45.5)	3.9 (39.0)	1.5 (34.7)	6.7 (44.1)
Record low °C (°F)	−20.8 (−5.4)	−15.4 (4.3)	−16.1 (3.0)	−6.3 (20.7)	−1.2 (29.8)	2.4 (36.3)	4.8 (40.6)	5.0 (41.0)	0.7 (33.3)	−6.2 (20.8)	−9.4 (15.1)	−15.3 (4.5)	−20.8 (−5.4)
Average precipitation mm (inches)	61.5 (2.42)	56.5 (2.22)	54.1 (2.13)	46.4 (1.83)	61.1 (2.41)	65.7 (2.59)	73.2 (2.88)	77.0 (3.03)	60.3 (2.37)	61.2 (2.41)	63.8 (2.51)	70.0 (2.76)	750.7 (29.56)
Average precipitation days (≥ 0.1 mm)	17.5	15.9	16.1	12.5	13.9	14.1	14.6	14.7	14.2	15.5	17.2	18.8	185.1
Average snowy days (≥ 1.0 cm)	3.4	2.3	0.7	0	0	0	0	0	0	0	0.3	1.8	8.5
Average relative humidity (%)	81.6	78.6	73.5	68.2	68.5	69.3	68.8	70.8	76.5	80.5	83.6	84.3	75.4
Mean monthly sunshine hours	56.9	73.1	125.0	172.6	202.0	199.3	208.2	193.9	149.5	109.8	62.5	47.1	1,610.6

Fig. 2.2. Climat data for Düsseldorf

The design site is located in administrative Borough 3 (Stadtbezirk 3), in the quarter (Stadtteile) Bilk [21] (Fig. 2.3).

The design site is located in the western part of the city, inside the loop formed by the Rhine River, near the intersection of two highways – local No. 8 and the Südring motorway connecting highways No. 57 and No. 46 (Fig. 2.4).

A light rail line runs from the west. Thus, the future complex will be located on a site with good transport connections.

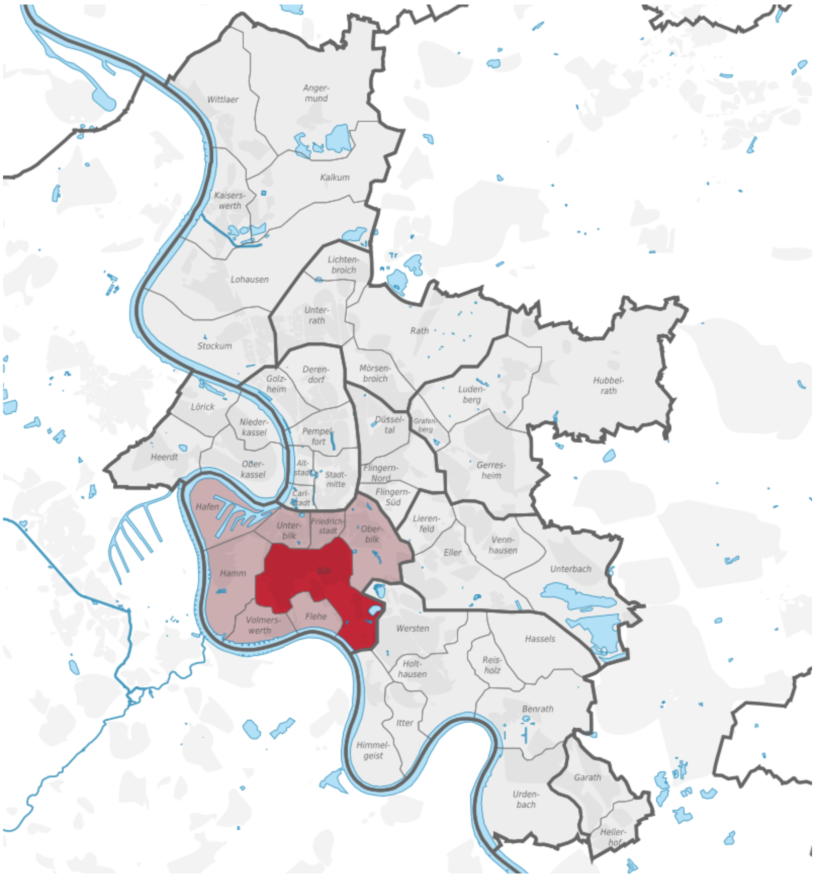


Fig. 2.3. Map of administrative division of Düsseldorf

Fig. 2.4. Map of Düsseldorf with surrounding areas

As part of the Raumwerk D initiative, the municipality of Düsseldorf was asked to develop different options for city development strategies for the period up to 20230 (2030 Vision). Figure 2.5 shows the option developed by Reicher Haase Assoziierte (RHA) in collaboration with MIC-HUB and LAND. According to this proposal, the design area falls into one of the city's priority development zones.

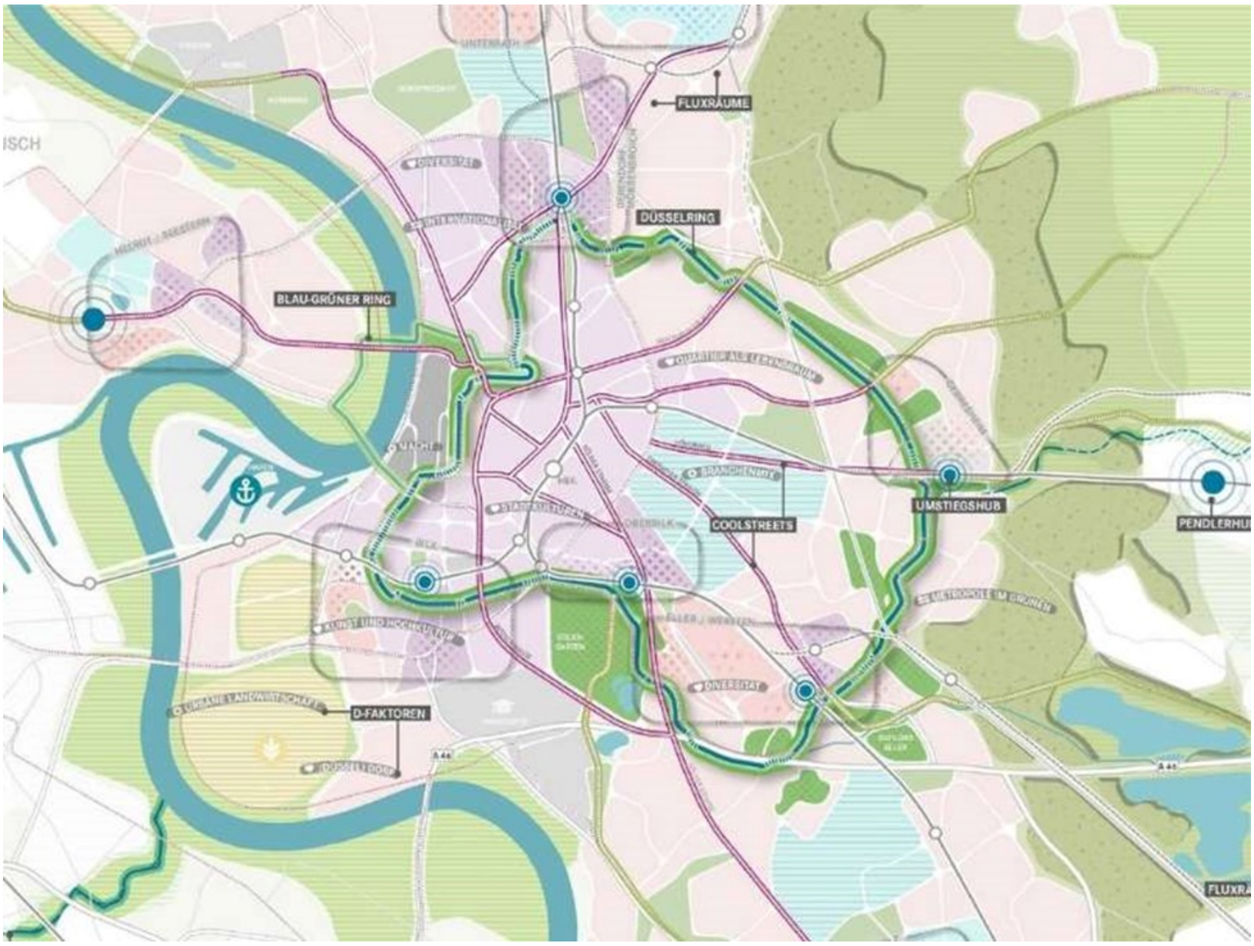


Fig.2.5. The Düsseldorf City Vision 2030 by RHA in collaboration with MIC-HUB and LAND

The design area is bounded to the north by the Südring motorway at the junction with Volklingen Straße on the north side (Fig. 2.6). The visual axis of Volklingen Straße abuts the design area. This indicates the possibility of erecting a high-rise building here, which will close the perspective of Volklingen Straße and create a compositional accent, marking this important urban planning node (Fig. 2.7).

The site is bordered by local roads to the west, east and south. A park adjoins the site to the south, and a tram line and the Südfriedhof tram stop and D-Südfriedhof city bus stops to the west. Two small businesses, LIV-Steinmetz and Oliver Moser Grabmale Esper, are located to the east of the design site. The design area is currently occupied by an open-air car park. The western part of the car park is proposed to be retained and used for parking for employees and visitors of the multifunctional complex.

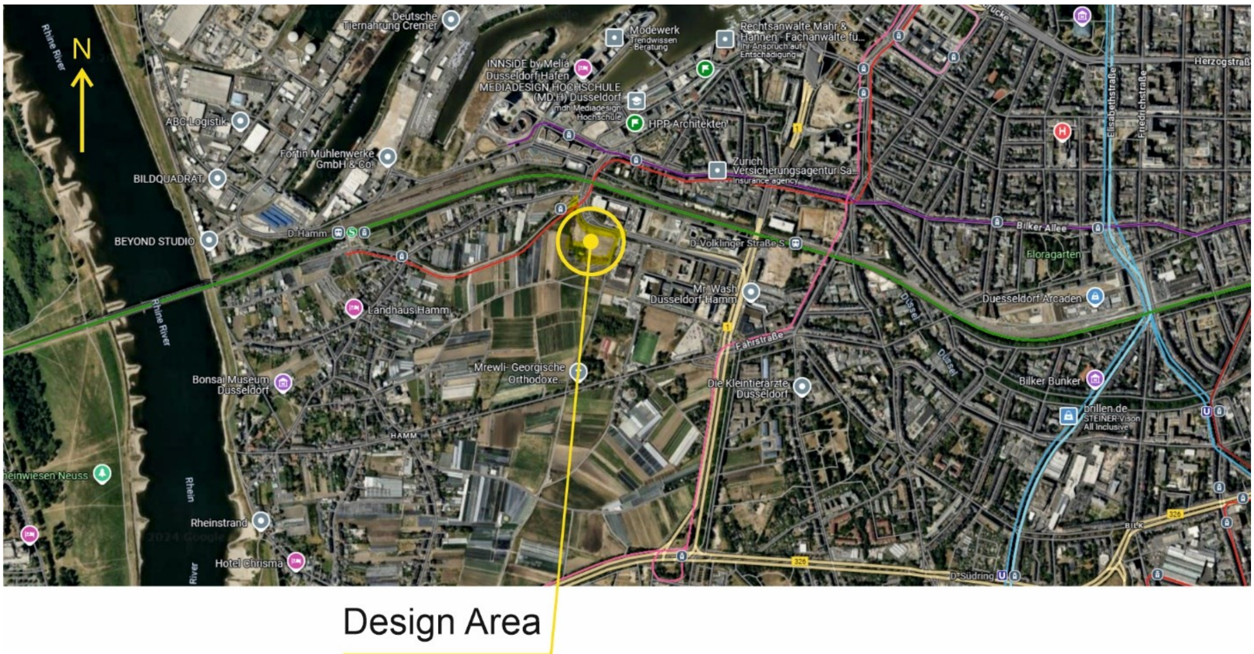


Fig. 2.6. Situational scheme of the design site

Fig. 2.7. Project view of the multifunctional complex from the park main avenue

2.2. Solution of site's master plan

The multifunctional complex site is rectangular in shape, close to a square. It is bounded to the north by the red line of the Südring motorway, and to the west, south, and east by local roads.

In the center of the site, there is a multifunctional complex, which consists of a low-rise part in the form of the upper part of a sphere with four lateral cylindrical cutouts, where the shopping mall is located, and a centrally located, circular in plan, high-rise part, in which the office center is located (Fig. 2.8).

Accordingly, in the plan, the multifunctional complex resembles the letter X or an oblique cross. The cutouts in the stylobate part of the complex are used to organize areas in front of three entrances – from the parking lot from the west, from the Südring from the north, and from the park from the south.

The loading of the shopping mall is carried out from the local road located from the east. Parking spaces are provided on the west side, where part of the former parking lot, located outside the object area, continues to be used for its previous purpose.

Fig. 2.8. Site of the multifunctional complex. Aerial view

The following functional zones are distinguished on the site: building location zone, entrance zone, parking zone, landscaping zone, utility zone.

Although parking lots are not part of the territory of the multifunctional complex, when determining the number of parking spaces, they were determined based on the retail area of the shopping mall (based on 3 – 4 parking spaces for every 100 m^2), as well as the number of employees and visitors to the office center (based on 5 – 10 parking spaces for every 100 visitors and employees of the office centre).

There are no separate driveways with asphalt concrete pavement on the site. All hard surfaces are made of concrete paving slabs, which allow precipitation to seep into the soil without increasing the load on the city's storm sewer system. The paved surface is used both by pedestrians and for the access and unloading of trucks and fire engines in the event of a fire.

Thanks to the four cutouts in the stylobate, fire trucks can approach the high-rise part of the complex from all four sides at a distance of 8 – 11 m from the walls of the high-rise part.

There is also the possibility of a circular bypass of the building of the multifunctional complex on a hard-surfaced surface, with the width of the passage not less than 3.5 m, the distance to the stylobate within 5 – 7 m, and the radius of curvatures on all turns is not less than 6 m.

The stylobate part is designed as a green hill, into which four entrances are cut. At the four ends of the oblique cross, the roof surface of the stylobate smoothly transitions into the ground surface.

Since the surface of this green hill can be freely accessed from the ground, a solid fence with a height of at least 1.2 m has been installed above the entrances along the perimeter of the cylindrical cutouts to prevent people from falling from height differences.

These four round peninsulas are greened with grass and bushes, and the trees are placed further away so that they are not located between the circular fire escape and the building of the multifunctional complex.

The distances to neighbouring buildings (the closest of which are located to the east of the multifunctional complex building on the other side of the local road) significantly exceed the requirements of fire safety standards.

Thus, the layout of the multifunctional complex site prevents the spread of fire between neighbouring buildings and creates favourable conditions for extinguishing the fire.

Accessibility of the site for people with reduced mobility is ensured by a set of measures. All hard surfaces on the site of the multifunctional complex are located at the same level. Paved surfaces have joints no wider than 15 mm.

All intersections of pedestrian paths with driveways have ramps with a slope of no more than 8%, which ensure accessibility for people with reduced mobility.

The width of all pedestrian-accessible passages, which provide side-by-side passages in opposite or same directions for people in wheelchairs, is not less than 1.8 m.

In front of all entrances and ramps, warning tactile strips made of special concrete flagstones measuring 0.4x0.4 m with a surface made of truncated cones have been installed. The same warning tactile strips are placed in front of pedestrian crossings across local thoroughfares.

All three entrances to the multifunctional complex building are equipped with tactile information signs for people with visual impairments.

Parking spaces for cars belonging to people with reduced mobility are marked with special markings on the road surface and signs on vertical posts.

The paving around the perimeter of the multifunctional complex building is made of concrete paving slabs with hidden waterproofing. The area paved with paving flagstones around the perimeter is framed by curbstones.

For landscaping, shrubs and trees of local species were used. Trees are used only outside the perimeter of the circular fire escape around the building of the multifunctional complex, only shrubs and lawns are used around the building.

As for small architectural forms and portable products, these include benches, urns, and low-height lamps.

2.3. Architectural and planning solution of multifunctional complex

The main functional blocks of the multifunctional complex are a shopping mall located in the low-rise part and an office center located in the high-rise part. Офісний центр відноситься до класу А (за класифікацією Building Owners and Managers Association International [22]).

Given the limited space and the complex configuration of the shopping mall plan, there are no traditional mall anchors (retail or service enterprises that attract large flows of visitors), such as supermarkets. Largely focused on office center employees and park visitors, the shopping center consists of relatively small stores that do not require daily delivery of goods and catering establishments.

The shopping center is designed in the configuration of a closed mall and does not belong to any of the types defined by the ICSC (International Council of Shopping Centers) classification [23]. Toilets are also provided (including those accessible to people with reduced mobility).

The ground floor also houses the entrance to the office center with controlled access and a security room. The loading of the catering company and the centralized loading of the shopping mall are carried out from one side, from the east side.

The ground floor also houses the entrance to the office center with controlled access and a security room. The loading of the catering company and the centralized loading of the shopping mall are carried out from one side, from the east side.

The floors of the office part, located above the first floor, have generally the same layout. The differences in the floor plans are explained by the inclination of the high-rise part of the multifunctional complex to the ground surface, at an angle other than 90°.

This inclination is formed due to the variable length of the cantilever extension of the slabs from the vertically arranged load-bearing columns. Located in the center of the high-rise part, the elevators with the elevator hall, stairwells, toilets and other auxiliary rooms form a vertical core.

There is free space along the perimeter, which can be organized both according to the open plan office principle and divided into separate offices.

One of the staircases of type N4 (according to classification [24]) leads to the roof of the high-rise part of the multifunctional complex, thus providing access to the roof for maintenance and repair, as well as for firefighters to extinguish the fire.

The spatial planning and architectural compositional solution of the multifunctional complex was largely dictated by its location at the closure of the visual axis of Volklingen Straße and the proximity of the park and the natural environment (Fig. 2.9).

The composition in the form of a glass tower on a green hill creates a dynamic accent with a bright individuality near an important transport interchange and at the end of the perspective of the main avenue of a large park and at the same time fits well into the natural environment. The decoration of the building of the multifunctional complex uses mirror glass, which reflects the sky and greenery, as well as the green lawn of the roof of the low-rise part – the shopping mall.

Fig. 2.9. General view of the multifunctional complex

2.4. Security and inclusion of multifunctional complex

The safety of using a multifunctional complex building can be divided into the following components: fire safety, safety of movement and use inside the building, protection against unauthorized entry, and control of the situation in the internal space.

Fire safety of a building is ensured by: using non-combustible and fire-resistant materials of the main load-bearing and enclosing structures, using fire warning systems and automated fire extinguishing, limiting the spread of fire both between buildings and inside the building, installing a system for simple and effective evacuation of people and rescue of material values in the event of a fire or other danger, ensuring conditions for fire extinguishing both on the site of the facility and inside the building.

The building has a monolithic reinforced concrete frame with beamless floors and curtain walls with aluminum frames and an infill of heat-efficient double-glazed windows. Non-combustible materials were used in the decoration of the interior spaces and evacuation routes. This reduces the likelihood of a fire and limits the spread of fire within the building.

The building is equipped with a fire alarm system and automated fire extinguishing with sprinklers.

Limiting the spread of fire between buildings is ensured by the significant distance of the multifunctional complex from other buildings. Also, the distance from the building to the adjacent parking lot exceeds 25 m.

Evacuation of people and material assets from the first floor (shopping mall) is ensured by sufficient width of evacuation exits and evacuation corridors (not less than 1.8 m), and the presence of at least two evacuation exits from each point of the floor.

To evacuate people from floors above the first floor, two staircases of type N4 (according to classification [24]) located in the middle of the building are used, with artificial emergency lighting and air support in case of fire, which is maintained in fire sluices at the entrance to the staircase from each floor. One of the elevators is made in a separate shaft and meets the requirements for fire-fighting elevators. Its load capacity is 1000 kg, and the internal dimensions of the cabin are not less than 1.1x2.1 m, which allows it to be used for rescuing people on stretchers. The elevator lobby has air support in case of fire, separated from the main space of the floor by fire doors with a fire resistance class of EI 60 and can be used as a fire-safe zone for people with reduced mobility, where they can wait for rescue by the fire brigade. Vestibules at the entrance to stairwells can also be used as such fire-safe zones.

Ensuring conditions for fire extinguishing outside the building of a multifunctional complex is achieved by arranging a circular driveway for fire engines around the building with a width of at least 3.5 m at a distance of 5 – 7 m from the low-rise part of the complex and at a distance of 8 – 11 m from the high-rise part.

Ensuring conditions for extinguishing a fire inside the building is ensured by the presence of a fire elevator, the presence of an exit to the roof of the high-rise part of the multifunctional complex from one of the N4 type stairwells, the presence of a fence on the roof of the high-rise part with a height of at least 0.6 m, the presence of a fence on the roof of the shopping mall with a height of no more than 1.2 m.

Prevention of people falling from a height is ensured by the presence of stairwell railings with a height of at least 0.9 m, railings in rooms with glass curtain walls and on the operated green roof of the shopping mall with a height of at least 1.2 m.

Uncontrolled penetration into the building is prevented by using external doors and windows on the ground floor that are resistant to burglary.

Control over the penetration and movement of people inside the building is carried out using security alarm systems and video surveillance systems.

Ensuring the accessibility of the facility area for people with reduced mobility is ensured by solving all surfaces with hard surfaces at the same level, the presence of smooth slopes at all intersections of pedestrian crossings with local roads, the presence of tactile and visual means of accessibility for people with reduced mobility

– tactile warning strips in front of the entrances to the building and in front of pedestrian crossings, as well as highlighting thresholds, curbstones, and other obstacles in contrasting colors. At all entrances to the building, there are tactile information signs with an inscription in relief regular letters and Braille, which indicate data on the name of the facility, institutions and companies present in it, and operating hours.

Parking lots shall provide at least 4 spaces for disabled vehicles for every 100 parking spaces. These parking spaces shall be located no more than 50 m from the main entrances to the building.

Accessibility of the building for persons with reduced mobility is ensured by the presence of sufficient width of entrance and interior doors (not less than 0.9 m in clear view, in double-leaf doors the width of at least one leaf must be not less than 0.9 m), sufficient dimensions of entrance vestibules (width not less than 2.2 m, depth not less than 1.8 m), sufficient width of corridors (not less than 1.8 m) and staircases (not less than 1.35 m), the presence of toilets on each floor accessible to persons with reduced mobility (universal toilet cubicle with a plan size of not less than 1.65x1.8 m, equipped with a toilet, special handrails, and a washbasin), the presence of elements of tactile and visual accessibility, and duplication of fire notification with a light signal for persons with hearing impairment.

For vertical movement between floors, there are elevators accessible to people with disabilities, with internal cabin dimensions of at least 1.1 x 1.4 m, door width of at least 0.9 m, special horizontal handrails, and controls adapted, including for people with visual impairments.

All rooms where a person with reduced mobility may be alone, in case of emergency, are equipped with an audio and video communication system (for people who can communicate only in sign language) to communicate with the staff on duty. These devices must be available even when the person is lying on the floor (if the person has fallen and cannot get up).

For people with visual impairments, an audio information system has been installed in the lobby of the office center and at the entrance to the shopping mall.

.5. Engineering equipment of multifunctional complex

The project involves equipping the multifunctional complex with a set of modern engineering systems to ensure its safe and comfortable functioning.

The heat supply to the facility is autonomous, using a heat pump and electricity. Heating is mainly carried out through a ventilation system, with heating of the supply air in winter.

Air conditioning in summer is also carried out from a centralized system, single for the entire building, using a heat pump.

Ventilation is mainly mechanically driven (fans), recuperators are installed in the premises to utilize the heat of the air removed from the premises.

Electricity supply from the city network, combined with autonomous – photovoltaic panels installed on the roof of the high-rise part. The electricity generated by the photovoltaic panels is transmitted to the centralized network through a specially equipped metering unit to reduce electricity supply costs.

Water supply and drainage are provided centrally, from city networks. Given the significant annual amount of precipitation, it is planned to collect atmospheric precipitation in special tanks, the water from which is additionally purified and used as technical water in sanitary appliances. Electric boilers are used to heat water in toilets for people with limited mobility, the cafe kitchen, etc.

The main and emergency lighting in the building and an outdoor lighting system are provided. The luminaires are equipped with LED lamps. The premises for occasional visits are equipped with motion sensors for automatic switching on and off of lighting. Some of the outdoor luminaires are equipped with solar panels and batteries, that is, they are partially autonomous.

The building is equipped with automatic fire extinguishing systems, fire alarm systems, security alarms and a video surveillance system.

The building is also equipped with a fiber optic network for Internet connection, telephony and an intercom system.

3. ARCHITECTURAL STRUCTURES

3.1. General description of the building

The building consists of a one-story cruciform stylobate inscribed in a circle, in the center of which is the high-rise part of the complex. Structurally, the building consists of five structurally independent blocks, separated by expansion joints. Four of these blocks are single-story, one is multi-story.

In general, the building is a frame structure, the frame is monolithic reinforced concrete. The facades are glass curtain walls.

3.2. Main structural elements of the building

3.2.1. Foundation

Taking into account the hydrogeological conditions of the site and the large weight of the high-rise part of the multifunctional complex, as well as the comparative analysis of different types of foundations, considered in works such as [26, 27, 28], it was decided to design pile foundations for all five structural blocks of the building.

Along the outer perimeter of the lower part of the building, which houses the shopping mall, the project provides for the installation of four segment-shaped pile caps, on which the first floor covering rests, which is rounded and smoothly transitions into the walls.

Given the absence of a basement and the high groundwater level, it was decided not to arrange a continuous pile cap for all piles of the structural block, but to design separate four piles for each column, as shown in Figure 3.1.

The project involves the installation of reinforced concrete bored piles reinforced and concrete-poured in-situ.

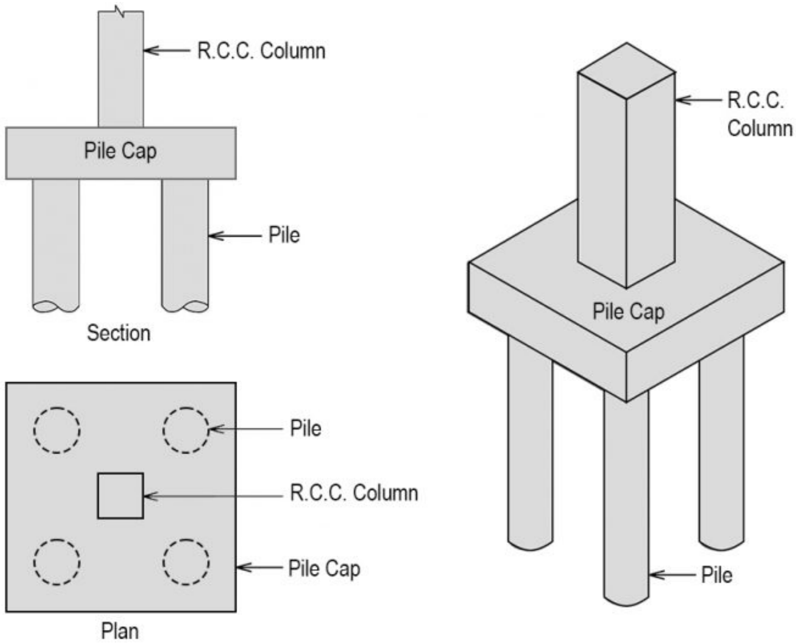


Fig. 3.1. Elements of a pile foundation for a separate column

3.2.2. Frame

The project provides for the installation of a monolithic reinforced concrete frame with columns with a cross section of 400x400 mm arranged in concentric circles with a distance between columns from 6 to 7.5 m. The floors above the stylobate are curved, convex, on monolithic beams. The thickness of the monolithic floor slab is 250 mm.

The floor of the high part is a flat plate, 300 mm thick due to the presence of consoles with a sufficiently large console extension – up to 2.5 m from the axis of the extreme column (Fig. 3.2).

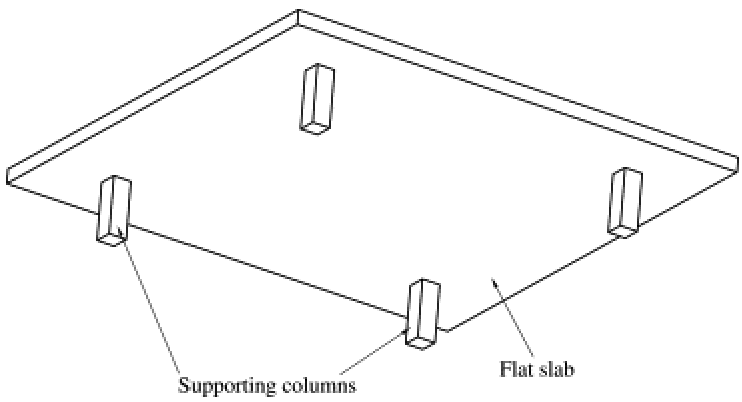


Fig. 3.2. Reinforced concrete flat slab [29]

A rigidity core provides the frame's spatial rigidity. It consists of interlocking stairwells and elevator shafts surrounded by 300 mm thick reinforced concrete monolithic walls. Monolithic flights and landings provide additional rigidity to the stairwells.

3.2.3. Internal walls and partitions

The interior walls and partitions are autoclaved aerated concrete (AAC) blocks. Unlike conventional concrete, the only filler in aerated concrete is quartz sand [30]. Cement is mixed with aluminum powder, triggering a chemical reaction, the product of which is hydrogen. Hydrogen bubbles aerate the mixture, creating about 80% of the voids inside. The resulting wet mixture is autoclaved for up to 12 hours. The resulting material is strong, fire-resistant and thermally insulating. The accuracy of block manufacturing and compliance with certain dimensions and geometric shape is much better than that of ceramic bricks. Accordingly, the seams between the blocks are very thin, up to 3 mm, and the laying is carried out not on a solution, but on a special polymer-cement adhesive, similar to tile adhesive. This allows you to create a flat surface of the walls, which is easy to decorate. To cover doorways, you can use a special U-shaped block, which becomes a mold for a monolithic reinforced concrete lintel.

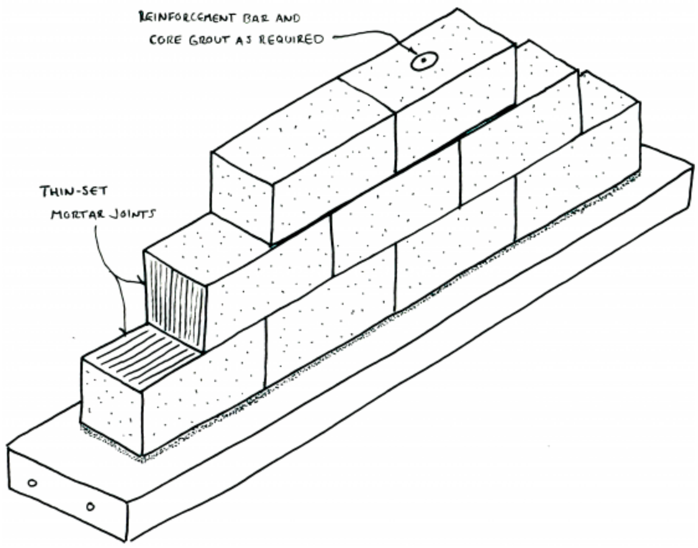


Fig. 3.3. The wall of AAC blocks [31]

3.2.4. Curtain walls

The use of curtain walls as external building enclosures is a common solution for modern high-tech office buildings. Such a facade is aesthetically attractive, weatherproof and durable. However, it also has certain disadvantages, including overheating (especially of the western facades of buildings) in the warm season, significantly lower thermal inertia and heat-conducting qualities than those that can be achieved with proper thermal insulation of traditional blind walls.

In general, the thermal insulation properties of a curtain wall are inferior to those of a conventional wall [32, 33]. However, there are several techniques to increase the energy efficiency of this structure while reducing its environmental impact, which were applied in this project. These include triple glazing, the use of fritted glass, low-iron glass, integrated photovoltaic systems, and metal panels [34].

The main elements of a curtain wall, the load-bearing elements of which are attached directly to the floors, are shown in Fig. 3.4. However, the key element on which the thermal insulation qualities of the wall depend remains the glazing, the design of which is shown in detail in Fig. 3.5.

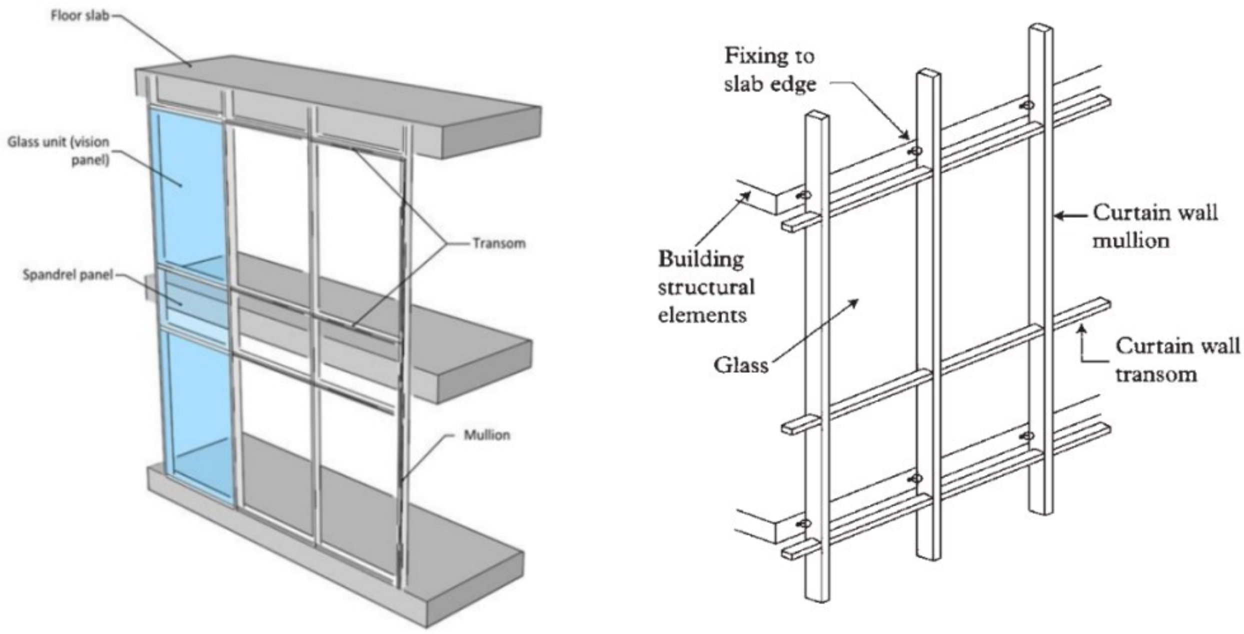


Fig. 3.4. Main elements of curtain wall [35]

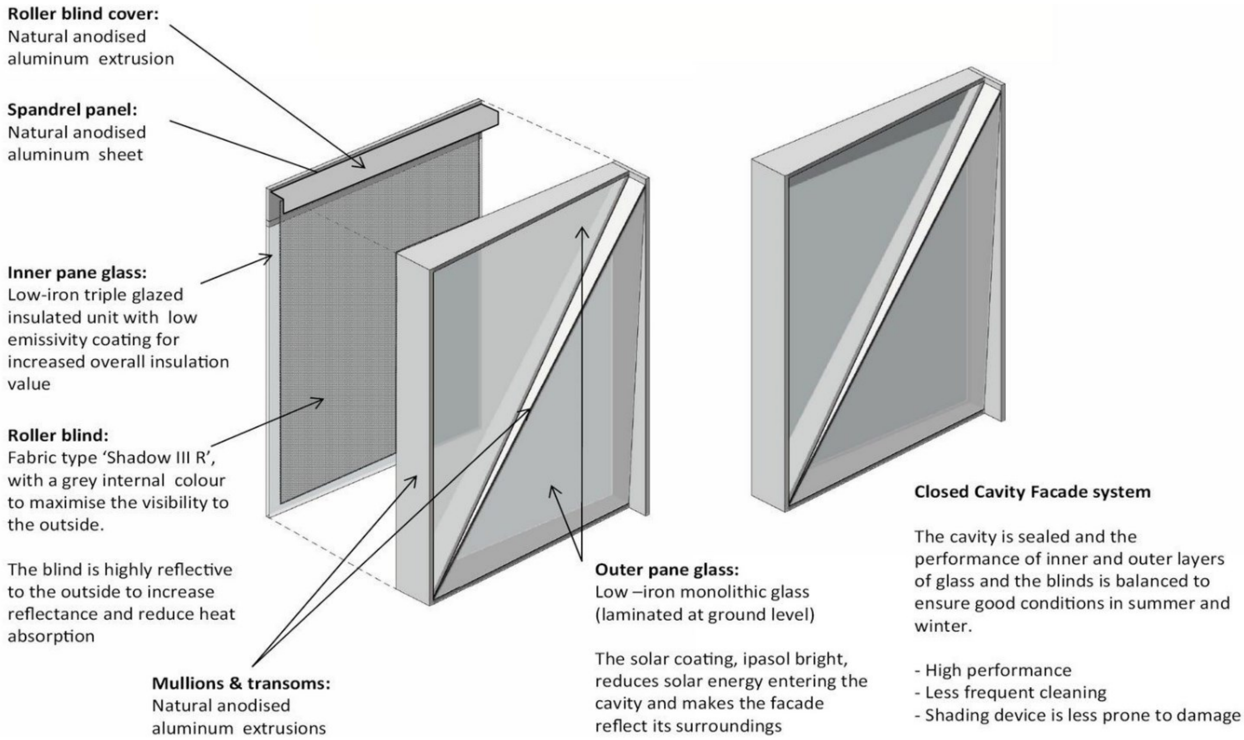


Fig. 3.5. Closed cavity façade system: typical glazed panel [34]

3.2.5. Roof

An inverted green roof is arranged on the flat roof of the high-rise part of the multifunctional complex, which is not intended for permanent human occupancy.

The design of such a roof is as follows. The following layers are laid on top of the ceiling: vapour barrier film with double-sided adhesive, a protective layer of lightweight concrete with double-sided geotextile, a PWC waterproofing membrane, a non-woven air-permeable geotextile separation layer, thermal insulation boards made of extruded polystyrene, a geomembrane with spikes, a non-woven geotextile with thermal bonding.

For a green roof, the ballast will be the soil on which planting material will be planted, such as: lawn grass, shrubs without a large root system, and some steppe plants (cereals) that are not damaged by the wind and do not require excessive care.

Along the parapet around the perimeter of the building in a strip 500 mm wide, the top layer of the roof is ballast – a backfill of light-coloured gravel (Fig. 3.6). This design solution was used to simplify the junction of the parapet to the roof and facilitate plant care.

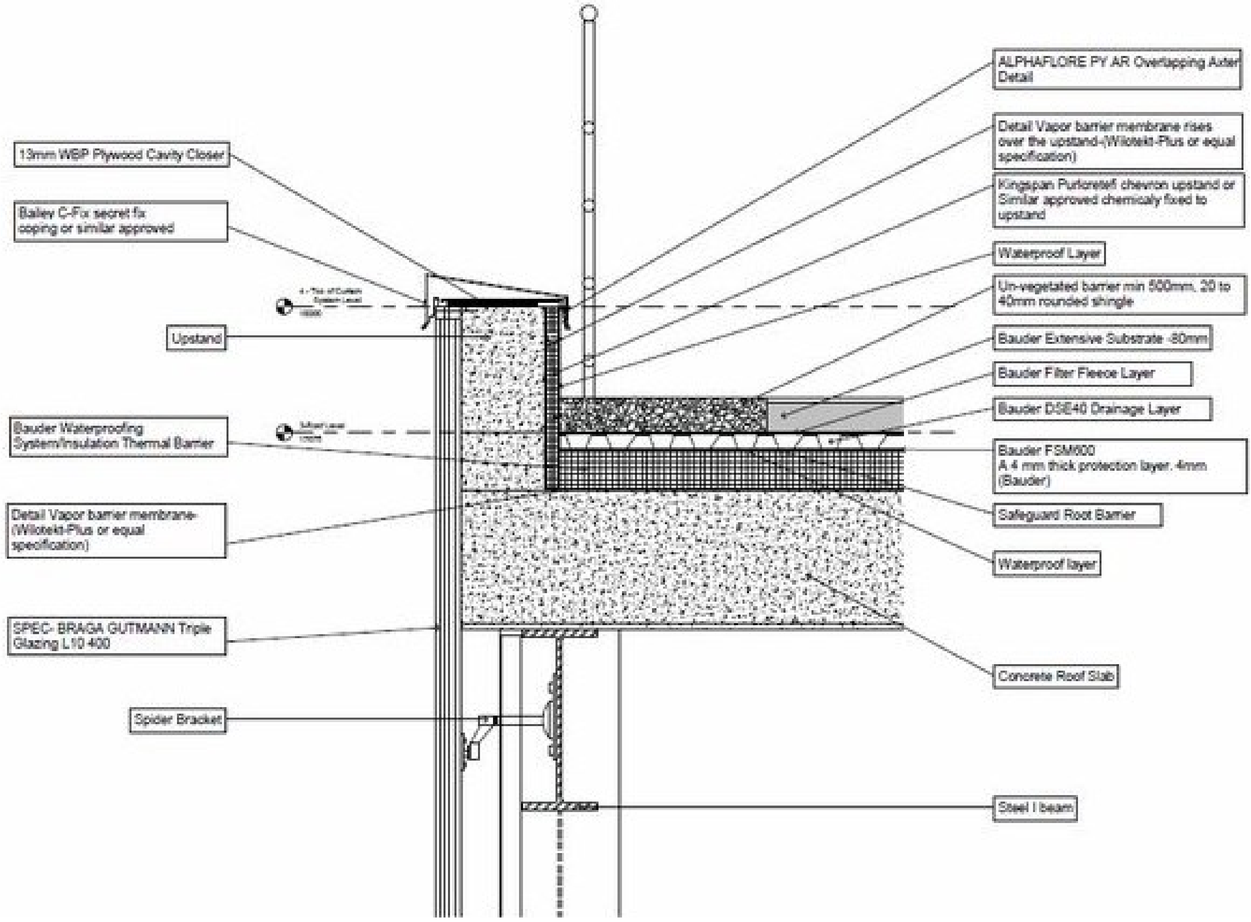


Fig. 3.6. Detail of the parapet joining the inverted roof, showing the layers of the green roof

3.2.6. Floors

The floor of the ground floor in the shopping mall is made on the ground. It consists of plain concrete layer, a waterproofing layer, a reinforced concrete slab 100 mm thick, rigid insulation boards made of extruded polystyrene foam 100 mm thick, a reinforced screed 50 mm thick, waterproofing made of a cement-polymer mixture, an adhesive layer and porcelain gres tiles.

The floors on the floors of the high-rise part are self-leveling polyurethane on a cement-sand mortar screed, as shown in Fig. 3.7.

The floors in toilets on first and higher placed floors are made of porcelain gres tiles on a waterproofing layer and a cement-sand screed (Fig. 3.8). The floors in auxiliary rooms, lift lobbies, and vertical communications on first and higher placed floors are made of porcelain gres tiles (Fig. 3.9).

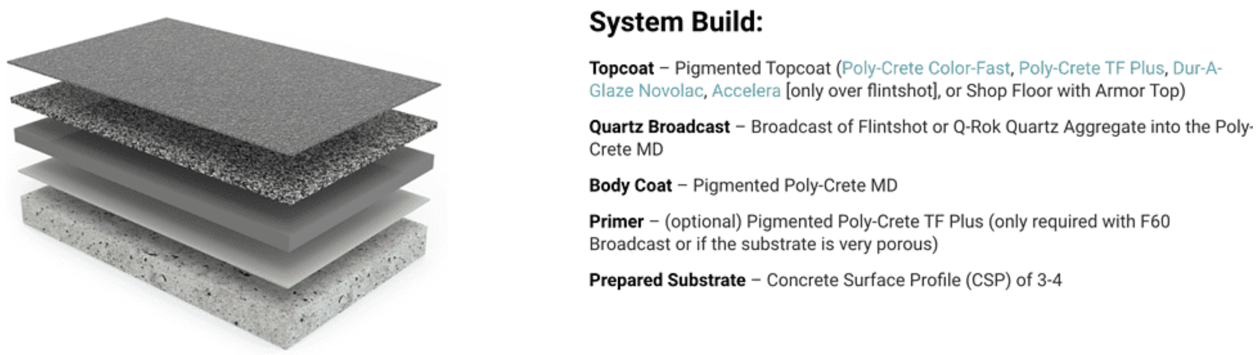


Fig. 3.7. Design of polyurethane floor layers

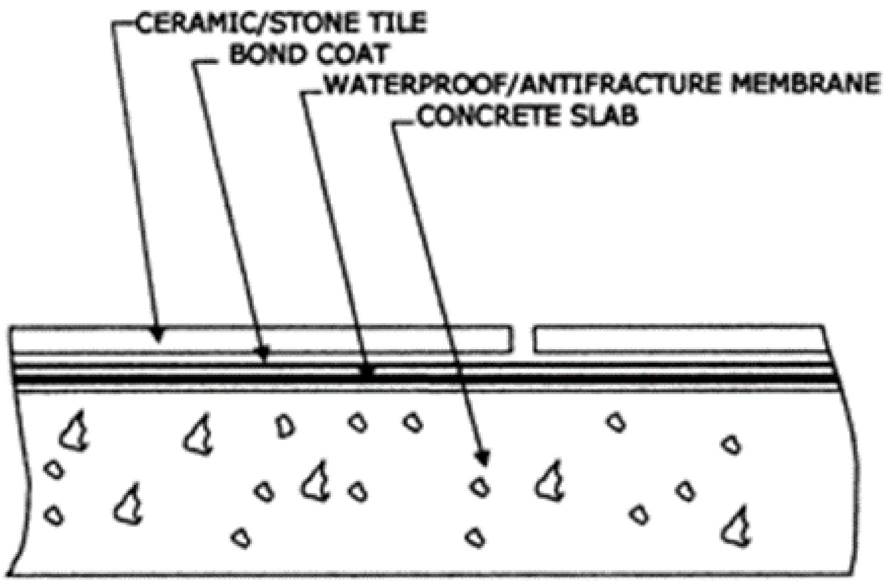


Fig. 3.8. Design of porcelain gres tiles floor with waterproof layer

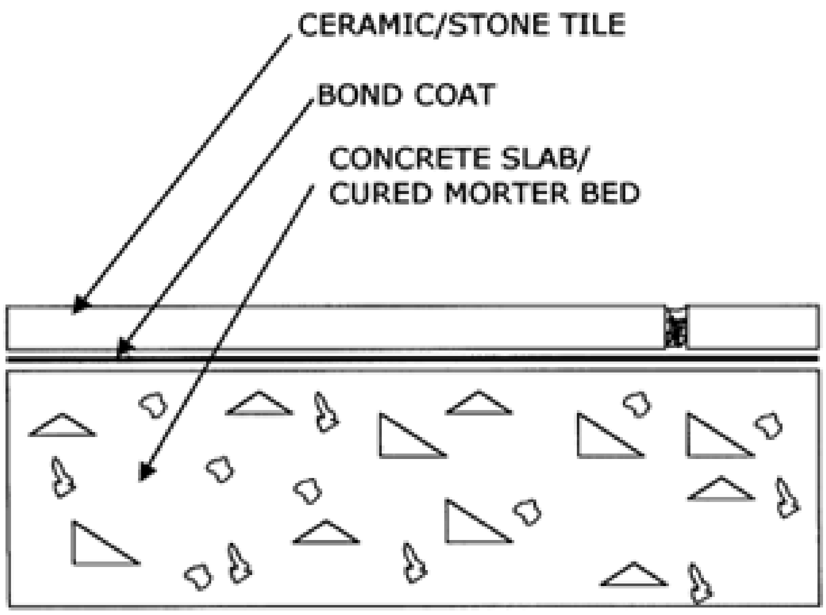


Fig. 3.8. Design of porcelain gres tiles floor without waterproof layer

4. ENGINEERING IMPROVEMENTS AND TRANSPORT

The site of the designed multifunctional complex is located in the western part of the city of Düsseldorf in a well-developed and landscaped area. The task of vertical planning, drainage in general has already been solved before the start of the design. The territory is currently occupied by a parking lot, and therefore does not require additional engineering protection measures, the construction of retaining walls, drainage trays. That is, after the completion of the construction of the facility, the site will require minor measures of vertical planning in order to organize drainage from its territory.

The vertical planning of the site is carried out according to the so-called urban principle, when atmospheric precipitation is drained from the surface of lawns and solid paving from paving slabs to the driveways located below them in level, and from the driveways – into the city storm sewer system.

It should be taken into account that the paving slab coating (with the exception of a 1.8 m wide strip of paving around the perimeter of the building with hidden waterproofing) allows most of the precipitation to pass into the drainage layer underneath, and then the water gradually seeps into the soil. Shrubs and trees with a developed root system extract this water from the underlying soil layers and evaporate it, preventing excessive moisture in the underlying soil.

The entire hard surface of the site is made with a top layer of 8 cm thick concrete paving slabs, which allows not only pedestrians but also trucks and fire engines to move along it, thus making its multipurpose use possible (Fig. 4.1).

A 1.8 m wide strip of paving with hidden waterproofing was installed along the perimeter of the multifunctional complex building to prevent the soil under the foundation from getting wet and to divert precipitation away from the building (Fig. 4.2).

In front of all entrances and ramps, warning tactile strips made of special concrete flagstones measuring 0.4x0.4 m with a surface made of truncated cones have been installed (Fig. 4.3). The same warning tactile strips are placed in front of pedestrian crossings across local thoroughfares.

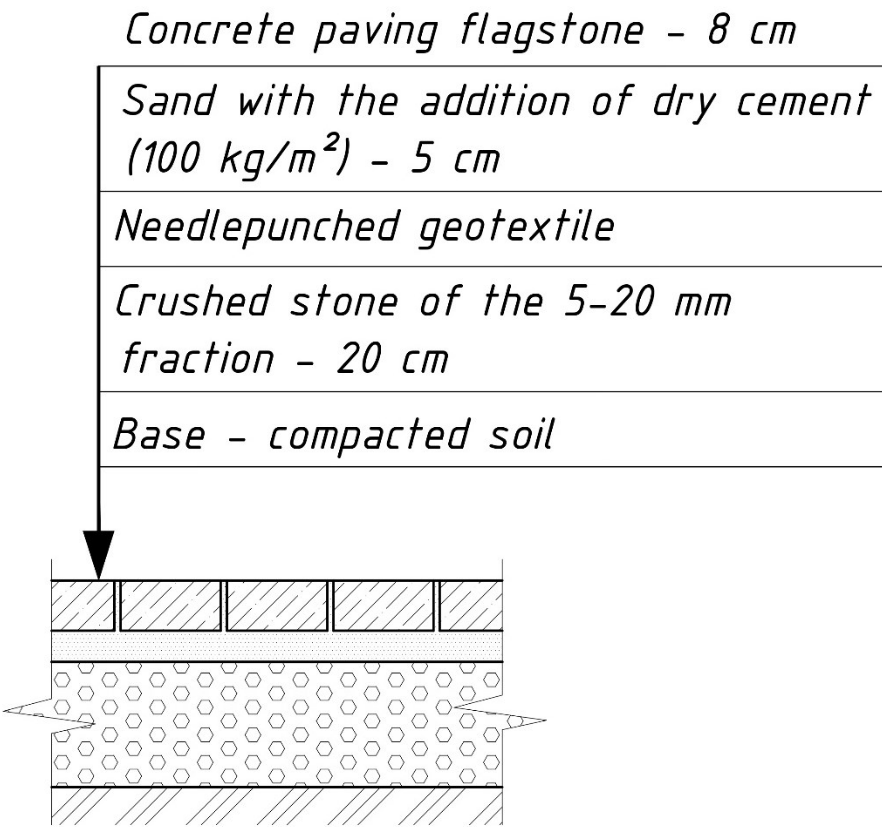
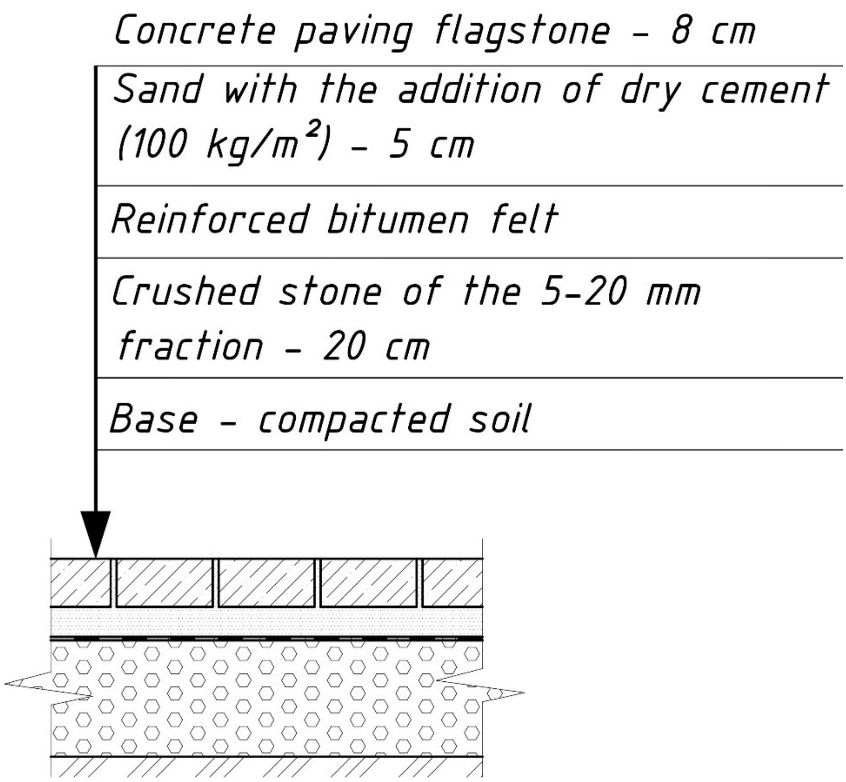


Fig. 4.1. Paving construction made of paving flagstones, suitable for the passage of trucks and fire trucks



Fig, 4.2. Design of a warning tactile strip in front of the entrance to the building of a multifunctional complex

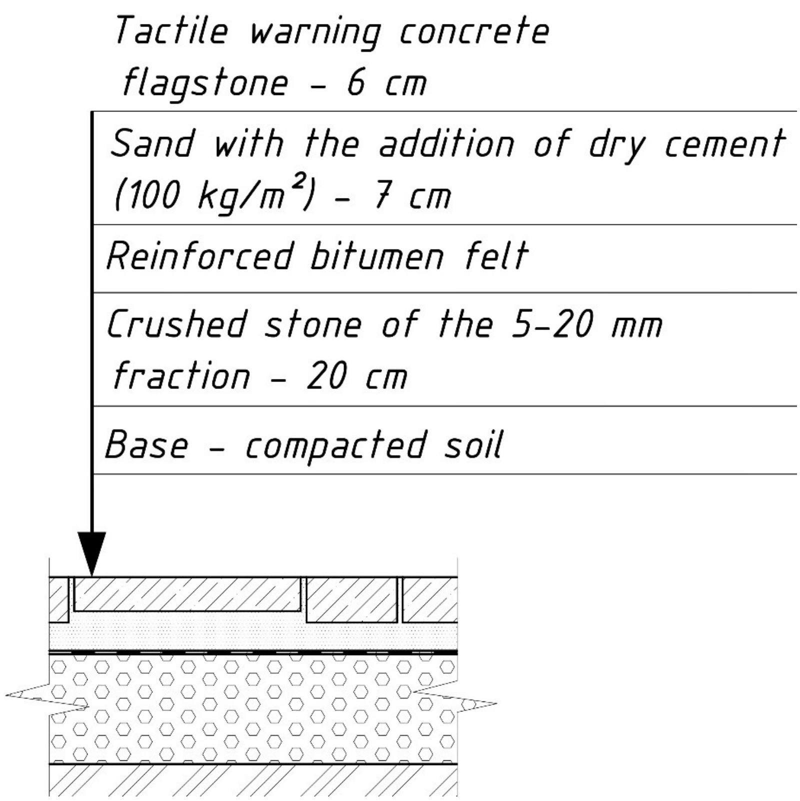


Fig. 4.3. Design of a warning tactile strip in front of the entrance to the building

The loading of the shopping mall is carried out from the local road located from the east. Parking spaces are provided on the west side, where part of the former parking lot, located outside the object area, continues to be used for its previous purpose. Although parking lots are not part of the territory of the multifunctional complex, when determining the number of parking spaces, they were determined based on the retail area of the shopping mall (based on 3 – 4 parking spaces for every 100 m^2), as well as the number of employees and visitors to the office centre (based on 5 – 10 parking spaces for every 100 visitors and employees of the office centre).

Parking lots shall provide at least 4 spaces for disabled vehicles for every 100 parking spaces. These parking spaces shall be located no more than 50 m from the main entrances to the building.

Ensuring conditions for fire extinguishing outside the building of a multifunctional complex is achieved by arranging a circular driveway for fire engines around the building with a width of at least 3.5 m at a distance of 5 – 7 m from the low-rise part of the complex and at a distance of 8 – 11 m from the high-rise part.

5. LANDSCAPE ARCHITECTURE

In general, the landscaping of the multifunctional center area is not much different in nature from the nearby city park. This was done specifically to create the impression of the multifunctional complex building "dissolving" in the natural environment. Local types of grasses, shrubs and trees were used for landscaping, which require minimal experience, are well adapted to local natural and climatic conditions, and are resistant to adverse factors inherent in the urban environment, such as car exhaust gases, etc.

A completely different, much more difficult task is the landscaping of the surface of the green roof of the shopping mall located on the ground floor, which, according to the architectural design, should resemble a green hill. Vegetation on such a green roof is subject to a particularly strong influence of drought, frost and wind. A separate problem is the formation of the upper layer of soil, strengthened by plant roots, which can only hold on surfaces with a significant slope (Figs. 5.1, 5.2). In addition, such a coating must be resistant to visitors walking on it.

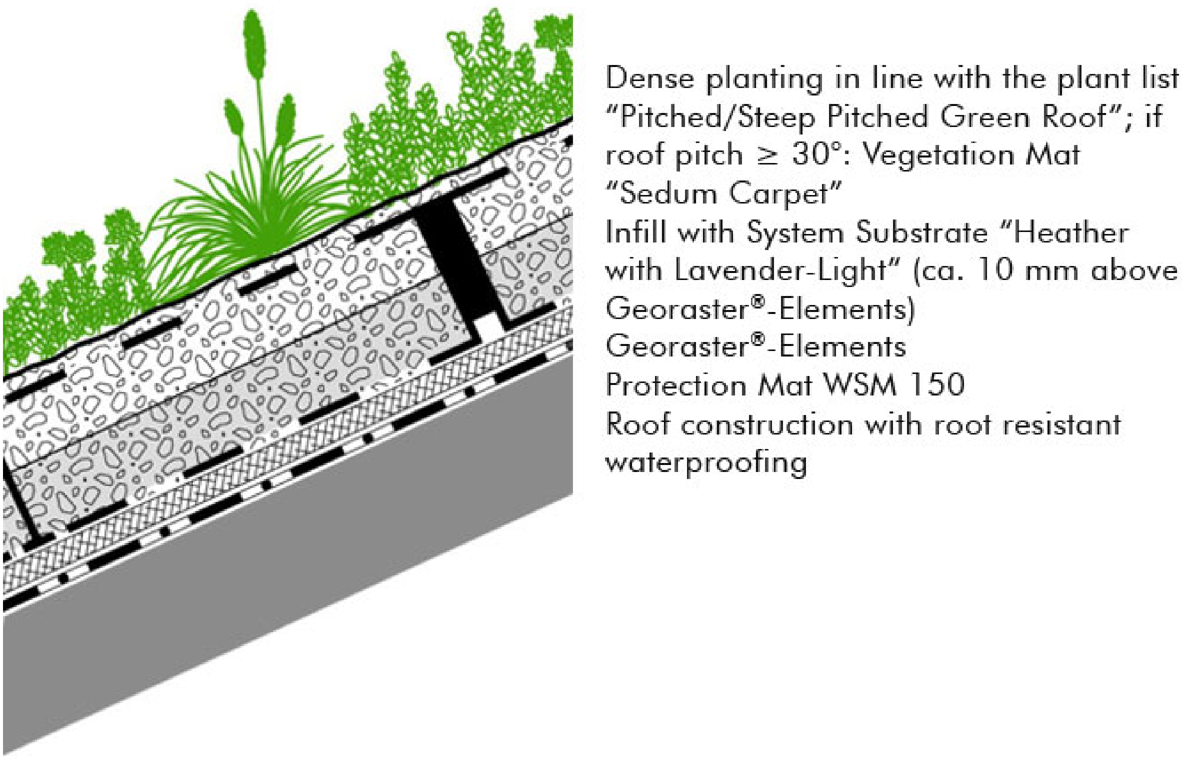


Fig. 5.1. Steep-pitched green roof up to 35°. System build-up [38]

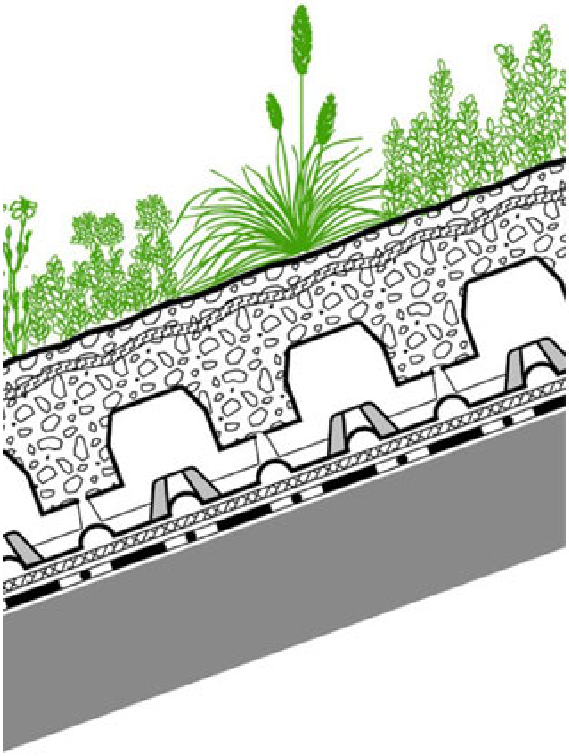


Fig. 5.2. Steep-pitched green roof up to 25°. System build-up [39]

The green roof of the shopping mall is an extensive green roof that does not require special care. To form the correct plant layer, sedum mats were used, which were specially developed for cultivating plants on green roofs with a slope of up to 45°. The special feature of these sedum mats is that the sedum was planted on a special mat made of coconut fiber and/or on a specially developed growing medium. Plastic reinforcements above and below the coconut fiber provide additional stability and a particularly secure grip on steeply sloping roofs [40]. 7 plant species were selected for use in the sedum carpet: 3 from the stonecrop family (Crassulaceae) including yellow stonecrop (Fig. 5.3) and 4 from the houseleeks family – S. tectorum (common houseleek), S. montanum (mountain houseleek), S. arachnoideum (cobwebbed houseleek), and the limestone houseleek (S. calcareum) (Fig. 5.4).

These plant species not only provide a particularly beautiful appearance to the roof, giving it a resemblance to a natural hill covered with grass but also provide environmental benefits. The selected plant species are resistant to drought, frost and wind, can accumulate moisture in the upper soil layer and are unpretentious in caring for them.

Fig. 5.3. Stonecrops. Left to right: Yellow Stonecrop (Sedum nuttallii), Wormleaf Stonecrop (Sedum stenopetalum), "Cristatum" (Sedum Reflexum)

Fig. 5.4. Houseleeks. Top row left to right: Sempervivum tectorum (common houseleek), Sempervivum calcareum (limestone houseleek); bottom row left to right: Sempervivum arachnoideum (cobwebbed houseleek), Sempervivum montanum (mountain houseleek)

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