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INNOVATIVE STRUCTURES, MATERIALS AND ENGINEERING SYSTEMS

LECTURE NOTES

(for students of the second (master's) level of higher education all forms of education speciality 191 – Architecture and urban planning, of educational program "Architecture of buildings and structures")

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INTRODUCTION

The development of architecture and urban planning is inextricably linked to the introduction of innovative structures, modern materials and high-tech engineering systems. In the context of the rapid development of construction technologies and increased requirements for energy efficiency, environmental safety and sustainability of structures, professional training of architects involves thorough mastery of modern design methods and the use of advanced materials.

The discipline "Innovative Structures, Materials and Engineering Systems" is an important component of the educational training of applicants for the second (master's) level of higher education in the specialty 191 - Architecture and Urban Planning within the educational and educational-scientific program "Architecture of Buildings and Structures". It is aimed at forming in students an understanding of modern trends in the field of construction, principles of designing structures and systems that ensure comfort, energy efficiency and functionality of architectural objects.

The course covers:

- the latest design solutions in architecture and urban planning;
- modern building materials and their properties;
- integration of engineering systems into the design of buildings and structures;
- principles of sustainable construction and environmentally friendly technologies.

The lecture notes will help deepen the theoretical knowledge and practical skills necessary for the development of innovative architectural solutions that meet modern industry requirements.

TOPIC 1 EXPERIENCE IN IMPLEMENTING OF NEW MATERIALS, STRUCTURES AND ENGINEERING SYSTEMS IN BUILDINGS

1.1 The essence of innovations in the architectural and construction industry of Ukraine

The construction industry has traditionally been one of the most conservative sectors of the modern economy. The relatively low efficiency of the construction industry compared to most other sectors is largely explained by the fact that it is a complex industry, the various segments of which have great autonomy in relation to each other, while the overall level of systemic integration of these components, especially in the housing sector, is quite low (this, in particular, explains the fact that innovations in housing construction are usually introduced with a noticeable lag in time compared to the commercial segment).

In addition, this "innovative slowness" of the construction industry in general is also due to the fact that it is also quite rigidly embedded in an even broader value chain created by the real estate market, which does not stimulate radical technological innovations at all.

One of the most tangible manifestations of this technological conservatism is the extremely low level of investment in the construction industry compared to other industrial sectors (on average in leading industrialized countries, the average share of investment in construction varies in the range from 0,3 % to 0,5 % of total sales, while in most other industries this average figure is 3–4 %).

The real “cancer” of this industry is also the enormous amount of production waste in combination with very low energy efficiency and extremely high levels of total energy consumption. In particular, in the United States, at the beginning of the new millennium, construction waste accounted for 60% of the total volume of non-industrial solid waste, while the American construction industry as a whole consumed 70 % of the country's electricity production and was the source of 38 % of atmospheric carbon dioxide emissions. On average, in the total costs of construction work in the industry, according to a number of estimates, approximately

30 % is accounted for by various factors, such as production failures and errors, unspent materials, underutilization of labor, etc.

Similar critical comments were made in another study conducted in 2009 by order of the EU: “Currently, various buildings and structures account for about 40 % of total energy consumption in Europe and almost a third of total CO2 emissions in the region. At the same time, the European construction industry as a whole consumes millions of tons of non-renewable natural resources annually and produces 22 % of the total volume of industrial waste. The need for radical reform of the construction industry today is dictated by many different factors. The dominance of production methods and processes established over the years in the industry and the inertia of its legislative regulation impose serious restrictions on the introduction of more effective technologies and solutions. In addition, due to the inherent separation of the design and construction stage inherent in the construction process, as well as the lack of overall system integration in the industry, a significant part of the new effective technological solutions offered in it usually remain at the stage of prototypes and mock-ups” [3].

However, despite all the very serious problem areas mentioned above, at this time, people continue to talk enthusiastically about a global boom in the construction industry. At least, the fairly widespread opinion that the construction industry has practically not changed over the past century and continues to use largely outdated technologies and materials is unlikely to be true. Moreover, even if we take as an example its formally most conservative component, residential construction, despite the fact that the majority of new residential buildings are still built “the old-fashioned way” directly on site (on a construction site), and not on a prefabricated-modular (offsite) principle, almost all key components of the construction process (both the basic building materials used and production practices) have undergone quite significant transformation over the past decades.

In particular, it is enough to briefly mention the use of various insulation materials, lattice trusses, wall panels, factory-assembled load-bearing structures, and, finally, the most energy-efficient window frames and doors compared to previous ones (of course, the list of construction innovations can be continued).

1.2 Innovative approach in the world's architectural and construction industry

According to the authoritative British magazine "Builder", the average rate of implementation of technological innovations in the construction industry (at least in the leading industrialized countries of the world) has increased significantly over the past decade, largely due to increased external economic pressure and increased public attention to various factors related to environmental protection (primarily, strict requirements for environmental friendliness and energy efficiency).

A special report by the leading American research and consulting firm in the field of engineering and construction, FMI Corp., notes that the post-crisis year of 2009 may have become the notorious "inflection point" in the construction industry. The economic shocks of recent years must inevitably lead to rapid dramatic changes in the AEC sector, which will be caused by the cumulative effect of several major external and internal factors (processes of world globalization, the rapid growth of the influence of various social and environmental requirements and standards, increasing pressure from various government agencies and, finally, the natural desire of the main players in the industry to improve overall economic results in the construction industry). And, as soon as this shift begins to manifest itself in full, construction site owners, as well as general contractors and subcontractors, will simply be forced to pay close attention to the technological component, which will become the most important catalyst for the growth of "team-wide interaction" and the effectiveness of their joint projects.

Another very significant factor that should have a decisive impact on the pace of technological recovery of the industry in the next few decades may be the progressive depletion of reserves of a number of non-renewable natural materials that are actively used in the global construction industry. For example, according to recent estimates provided by specialists from the United States Geological Survey (United

States Geological Survey study), if the current average annual growth rates of world production are maintained (about 2 % annually), the earth's reserves of many of the most important metals and minerals will be practically exhausted within the next two or three generations: a sharp shortage of lead and tin may occur within the next 15 years, copper – due to 20 years, iron ore and bauxite – because 60–65 years. In light of these alarming forecasts, in particular, a completely obvious conclusion suggests itself for the construction industry in particular, which boils down to the need to implement a full-scale reorganization of the main production processes in it within a fairly limited time frame (in particular, finding mechanisms for rapidly reducing the specific consumption of basic raw materials) and sharply intensify efforts to develop alternative technological solutions and create new materials.

In other words, the notorious "houses of the future" for completely objective reasons will have to become not only much more energy and resource efficient, but also, in many cases, the very "material content" of a number of their most important elements will have to change completely.

And, as many experts in the industry note, the raw material shortage, which clearly manifested itself at the beginning of the XXI century, is already one of the most significant problems that the entire AEC segment (architects-designers, civil engineers, and builders themselves) will face in its entire centuries-old history.

However, according to the most optimistic experts in the construction industry, already in the first decade of the new century there was a powerful surge in the development and implementation of new materials and technologies, and many of these innovative materials and products have quite interesting and promising physical and chemical characteristics for future use in the industry. In addition, an additional incentive for technological transformation in the building materials sector in recent years has been various factors related to the rational use of nature (primarily the increasing rigidity of requirements from state regulatory bodies for environmental safety and energy efficiency for buildings and infrastructure facilities under construction. As a result, at this time, there is even a certain surplus of promising technological opportunities in the industry as a whole.

Finally, another important trend, which, according to many experts, has had a particularly noticeable impact on the technological development of the construction industry in the last decade, is the accelerated implementation and integration of complex computer modeling at all stages of construction (development, planning, and the actual construction process).And if at the very early stage, the use of these models by designers looked more like a spectacular advertising and marketing trick designed to attract the most promising clients, today complex computer modeling has already confidently entered the mainstream practice, ignoring which in a real business process is a dangerously significant risk of being at the tail end of the competitive race: according to some estimates, the effective use of this design measure allows saving an average of 20–30 % of the total cost of construction.

At the same time, a real boom in the last few years has been observed in the use in the construction industry of the latest type of automated computer modeling - the so-called BIM model (Building Information Modeling) – a system of information modeling of construction objects based on three-dimensional visualization of physical objects, as well as parametric (interdependent) accounting of all architectural and design, technological, financial and economic data and information about buildings and other construction objects, which has actually replaced the more simplified system of automated (computer) design CAD (computer-aided design).

It is worth emphasizing that although the BIM system itself was originally developed in the mid-1990s, architects, design engineers, and construction contractors have only begun to actively use the universal capabilities it provides in recent years. For example, the total number of American construction and design companies using BIM grew from 28 % in 2007 to 49 % in 2009 and to 71 % in 2012, and, what is also quite interesting, in 2012 the main users of BIM in the USA became construction contractors (i.e. architectural firms receded into the background). In addition, the official authorities of some US states also began to actively implement BIM models in real practice. For example, in 2010, the states of Wisconsin and Texas presented general recommendations and basic standards for their further mandatory use in the development of new construction projects financed by regional budgets, and later similar steps were taken in a number of other American states, as well as at the federal level.

1.3 Justification of the introduction of new materials and structures and engineering systems in buildings

About the justification for introducing new materials, structures and engineering systems in buildings lies in a number of significant technical, economic, environmental and social advantages that they provide in modern construction. Let's consider the main reasons and arguments:

− increasing energy efficiency: new materials and engineering systems help reduce the energy consumption of buildings. For example, modern thermal insulation materials can minimize heat loss in winter and prevent overheating in summer. The use of energy-efficient engineering systems, such as heat recovery ventilation systems, energy-efficient windows, solar panels and heat pumps, can significantly reduce heating, air conditioning and electricity costs;

− reduced environmental impact: modern building materials can be more environmentally friendly, such as those made from renewable or recycled resources. New designs also reduce the carbon footprint of a building. For example, buildings designed with passive heating and cooling methods in mind have a lower environmental impact;

− ensuring safety and durability: the latest structural materials, such as high-strength concrete, composites or special steels, increase the resistance of buildings to loads, including seismic, wind and other. This reduces risks for residents and increases the life of the building without major repairs;

− improving the comfort and health of residents: innovative engineering systems, such as smart climate control systems, intelligent lighting systems, air and water filtration systems, improve the level of comfort, health and well-being of people. For example, automated ventilation systems can provide optimal levels of humidity and oxygen in rooms;

− economic benefits: although the initial costs of implementing new technologies may be higher, over time they are repaid through reduced operating costs (less energy, water, maintenance). Energy-efficient buildings usually have a higher value on the real estate market, which also contributes to investment attractiveness;

− flexibility and adaptability: the latest designs allow for the creation of modular and easily modifiable buildings. This allows the premises to be adapted to new functional needs with minimal costs and without the need for large-scale reconstruction;

− **implementation of intelligent systems: building automation systems (BMS – Building Management Systems) allow you to manage all engineering systems through a single interface, which greatly facilitates control, optimizes resource use and increases energy efficiency.**

The introduction of new materials, structures and engineering systems in construction is an important step towards creating energy-efficient, environmentally friendly and safe buildings that meet the needs of modern society. It is an investment in the future that contributes to the conservation of resources, reduction of environmental impact and improvement of the quality of life of people.

Next, we will selectively consider the most promising and interesting innovative materials that have either already proven themselves well in the construction industry in recent years or have a good chance of finding wide practical application in it in the near future.

TOPIC 2 NEW MATERIALS IN ARCHITECTURE

2.1 Bioconcrete for vertical landscaping of facades

Concrete is the second most widely consumed substance by human civilization (after water), in other words, it is the most widely used of all man-made materials. For example, in the middle of the last decade, a total of about 7 cubic kilometers of concrete, that is, each inhabitant of the Earth had more 1 cubic meter of this product.

Such colossal volumes of concrete produced by mankind and its widespread use in the construction industry, among other things, make this material a key element in the process of accelerated "greening" of building materials, which has become clearly evident in recent years.

And although concrete cannot actually be considered a super-polluting material, due to the large scale of its production, concrete (or rather, its key chemical component – Portland cement) annually accounts for 5 % to 10 % of total carbon dioxide emissions into the atmosphere.

As for the environmental side of the issue, many of the modern approaches to creating "greener" varieties of concrete are based on attempts to reduce (completely eliminate) the presence of Portland cement in it in one way or another, either by diluting it with various natural and/or artificial additives (for example, fly ash), or by generally replacing traditional Portland cement with other types of cement, the production of which requires significantly less thermal energy.

One of the largest research centers, which for many years has been engaged in the development of new types of concrete that are more “friendly” to the environment, as well as the creation of its engineered-modified varieties with specific properties, is the Concrete Sustainability Hub, CSH (which can be roughly translated as the “Center for Sustainable Concrete”) at the Massachusetts Institute of Technology in Boston (MIT). The specialists of this center were the first in the world to accurately artificially model the structure of concrete at the molecular level (and in the near future they expect to reach the atomic level), which allowed them to find a number of effective methods for creating stronger, more durable and environmentally friendly concrete, and to identify key mechanisms for the subsequent targeted change of its various properties and practical purpose. Thus, in the near future it will be possible to make the same arbitrary modifications with concrete that have long been possible with the same steel or glass.

The deep level of theoretical understanding of the physicochemical properties of concrete achieved by the specialists of the MIT research center must now be "picked up" by leading players in the construction industry for further large-scale practical experiments: according to optimistic calculations by the leaders of the CSH center, the first commercial samples of "new concrete" may appear within the next few years.

However, even if temporarily left aside from this, of course, the main direction of scientific research, it should be noted that progress in improving the quality of ordinary concrete over the past few decades has been significant. The most striking example of how reliable and durable modern concrete-containing building structures have become is the recently erected Burj Khalifa skyscraper in Dubai (UAE), the tallest 828-meter building in the world (which is more than 300 meters higher than the previous record holder, the Taipei 101 skyscraper in Taiwan). In particular, a special brand of concrete was developed specifically for the Burj Khalifa, capable of withstanding temperatures of up to +50 °C for a long time, and, what is especially significant, the main supporting frame of this tower was made entirely of reinforced concrete, while in Taipei 101 it was steel.

In addition, over the past decade, various research groups have developed a large number of new types and grades of concrete and cement with rather unusual and atypical properties and characteristics. Among this diversity, the following interesting new varieties can be noted separately.

In 2005, researchers from the University of Michigan (USA) created “flexible concrete” that, according to their claims, is 500 times more resistant to cracking than traditional concrete and is also about 40% lighter than the latter.

In the same year, 2005, a group of Portuguese architects and designers from Lisbon developed Betao Orgánico (organic concrete). This exotic type of concrete is actually a hybrid combination of organic and inorganic materials, which allows various types of living vegetation to grow on its surface: due to the fact that concrete retains water inside, it can be used as a kind of “energy battery” for green vegetation, which is fed by water during dry periods. Thus, the Portuguese developers managed to create a strange symbiotic product, which, perhaps, can also be called “grass concrete”.

A little earlier, in 2001, Hungarian architect Aron Loshoncy and a group of scientists from the Technical University of Budapest created Litracon (short for “light transmitting concrete”) – translucent concrete. This is a new type of concrete consisting of fine-grained concrete with a 5 % glass fiber admixture. Dosed impregnation of concrete with glass fiber allows sunlight to pass through quite freely (up to 20-meter-thick walls) pass both from outside to inside the room and from inside to outside. Moreover, what is significant is that, despite its unusual characteristics, Litracon is in no way inferior to ordinary concrete in terms of strength.

Finally, a new type of concrete developed by specialists from a small Australian high-tech company, Tececo, is particularly interesting: Porecocrete (Porous Concrete). This is an environmentally friendly concrete composite, the creation of which, in turn, was preceded by another innovative development by Tececo, eco-cement that absorbs carbon dioxide from the surrounding atmosphere. The most important component of Australian eco-cement is chemically active burnt magnesia, thanks to the addition of which regular absorption (and subsequent hardening) of CO^2, as well as water, occurs. Moreover, in addition to magnesia, other useful impurities can also be painlessly included in the composition of eco-cement (for example, the same ash dust, slag, plastic, etc.), while its key property, the ability to absorb CO^2, is preserved.

Porous concrete (Porecocrete) can also potentially become the main end product for eco-cement. In particular, according to many experts, the main potential practical use for porous concrete in the near future will be various road surfaces (primarily urban pedestrian sidewalks). Due to the presence of many pores in this concrete composite material, which remains relatively cool even in very hot, dry weather, it will become a profitable alternative to standard road surfaces, which include various bituminous materials, asphalt or the same ordinary Portland cement.

In 1995, O. Gillitt first proposed a new concept in the field of ecological research on building materials, which defines bio receptiveness as the property of a material to be colonized by living organisms. If plants are able to grow into sprouts and survive for some time, it can be assumed that the material is bio receptive for higher plants. Therefore, bio receptiveness can also be defined as the set of material properties that contribute to the creation, fixation and development of flora and/or fauna. For example, in stony materials this mainly concerns properties such as hardness, porosity, moisture and the chemical composition of the surface layer, which determines the pH. Thus, these three properties determine the bio receptiveness of a stony material.

The problem of improving the ecological state of large cities is one of the main ones for the sustainable development of modern society. The increase in urban regions and the simultaneous decrease in green areas, air pollution caused by increased industrial emissions, require new approaches to solving the problem of increasing green areas. Therefore, much attention is paid to such a non-standard approach to solving this problem as greening roofs and creating vertical green facades. Since the creation of green facade systems using hydroponics or complex structural systems is difficult and very expensive, in the last decade the concept of creating bio receptive building materials that can serve as a direct substrate for the growth of living organisms such as cryptogams, which include: lichens, mosses and algae, has gained great popularity. Bio receptive building materials used to date are expensive, difficult to manufacture and use and have not shown significant effectiveness.

Dolomite binders are obtained by mixing caustic dolomite with a solution of magnesium chloride or the natural mineral bicchulite. Obtaining such binders has a number of advantages compared to traditional Portland cement: energy (the firing temperature of caustic dolomite is almost 2 times lower, 700 ºC and 1,400 ºC, respectively); technological (one-component mixture and simplicity of technology); environmental (the presence of bicchulite in the material creates natural ionization in the room, an atmosphere close to the conditions of the sea coast.

As a result of the conducted research, it was found that dolomite brick is characterized by the presence of bio receptive properties, and can become the basis for obtaining a special type of biological concrete, which promotes the growth of pigmented organisms. Such bioconcrete can be used for decorating gardens or parks and as an environmentally friendly way to harmonize buildings with the environment. The use of bioconcrete has a number of advantages (Table 1.1).

Therefore, in the conditions of dense development of modern megacities, bioconcretes can be used for vertical landscaping of building facades, contributing to the preservation of green areas and the restoration of degraded areas, without taking up additional space, improving the urban environment, improving biodiversity, stormwater management, air quality, and reducing the greenhouse effect.

Table1.1 – Advantages of using bioconcretes

Technological	Environmental	Aesthetic
No need for complex substrate designs or hydroponic systems	Bioconcrete absorbs carbon dioxide thanks to plant cover	Good combined with other types of decoration
Roots Plants do not destroy buildings	Reduces CO^2 content in the atmosphere, releasing oxygen	Wide opportunities for phytodesign
Bioconcrete supports and stimulates the growth of biological organisms directly on its own surface	It is a bioindicator of the degree of pollution and the ecological state of the environment.	Possibility selection of certain areas on the facade that are subject to decorative landscaping

2.2 Innovative waterproofing and thermal insulation materials with dual properties

Today, most thermal insulation materials are multi-component systems, therefore, heat transfer in them depends on the thermal conductivity of the solid phase, on convection and thermal conductivity of the gas in the pores and radiation in them. The relative contribution of these components varies depending on the porosity of the material. The transfer of thermal energy occurs spontaneously from one isothermal surface to another in the direction of equalizing temperatures from high to low. Heat transfer can be carried out by convection, thermal radiation or thermal conductivity.

Since in solids, heat transfer is carried out due to the movement of phonons (a phonon is a quantum of vibrational motion of crystal atoms) or electron gas along the crystal lattice, metals that have a large number of free electrons and a perfect crystal lattice are characterized by maximum thermal conductivity. Thermal insulation materials that constitute amorphous or sub microcrystalline structures have a small number of free electrons, so thermal energy is transferred as a result of phonon interactions. Vibrations in non-crystalline solids are inharmonic due to the damping of longitudinal elastic waves during their propagation. For the most part, traditional insulation does not have a screen that reflects the heat flow and does not protect the building from heat loss due to thermal radiation. Solid insulation has a direct dependence on the thickness of its layer.

Special interest are thermal insulation materials that are manufactured in the form of dry building mixtures from inorganic binder and mineral or organic filler, the so-called warm plasters (hereinafter referred to as warm plasters). These materials simultaneously perform the functions of thermal insulation and decoration. Warm plasters are convenient to use on existing buildings, in particular during the reconstruction and restoration of historical objects with rich decor, as additional insulation. Plaster cannot be replaced when applying insulation on curved surfaces of facades, arches, architectural details, window slopes, inclined surfaces. If necessary, it can be used as internal thermal insulation provided that a vapor barrier is installed.

The optimal material that stops thermal radiation, is a thermal insulation with high reflectivity and low emissivity. It is known that the introduction of fillers from glass (ceramic) hollow microspheres into the thermal insulation allows to reduce thermal conductivity, create heat-reflective coatings, provide anti-condensation properties, improve noise insulation properties, reduce the weight of the coating. The selection of the ratio of the amount and size of the filler in the volume of the thermal insulation coating allows to build more than 10 reflective screens from rows of microspheres in a layer 1 mm thick of liquid thermal insulation. Such a number of screens provides up to 50 % reflection of the heat flux falling on them.

The massive spread of specialized thermal insulation materials and products in the construction industry, observed in recent years, has created very serious potential opportunities for the most active players in this industry in the field of optimizing basic energy efficiency indicators.

It is enough to quickly list the most promising innovative materials and technological methods that are actively being implemented in this area, such as expanded polystyrene, acoustic membranes, vapor-air protective layers, various fiberglass insulation systems, etc., in order to come to the obvious conclusion that with the skillful combination of these insulation materials and technologies, construction companies now have a much larger arsenal for flexible management and control over energy consumption.

For example, one of the relatively recent and very promising trends in this segment has been the mass introduction of structural insulated panels (SIPs). These new wall insulation systems consist of rigid foam insulation sheets, which are laid interspersed with layers of oriented strand boards, OSB. As a result of this combination of two different materials, high structural strength of the wall insulation is achieved and, in addition, since practical SIP varieties have different thicknesses, this allows for a fairly wide variation in the thermal resistance of the insulation coating (R-Value, – in the range from 13,5 to 25). Finally, structural insulated panels can also be used as an important element of roof coverings of buildings, in particular, allowing the construction of high beam ceilings.

Another material that has also recently gained considerable popularity in the field of combined thermal insulation is non-removable formwork made of granulated polystyrene foam (English name – Insulated Concrete Forms, ICF). This technology was first patented in the USA in the late 60s of the 20th century, but its mass introduction into the construction industry occurred much later. ICF has excellent energy-saving characteristics, low weight, high structural strength and provides relative simplicity of finishing works. The main types of ICF at the moment are polystyrene foam panels connected by polyethylene or polypropylene ties, as well as with integrated solid elements made of polypropylene or polyethylene. In addition, recently ICF panels reinforced with fiberglass, made of fiber concrete, have also been used.

It should also be noted that, unlike conventional removable formwork, non-removable ICF formwork is not only used as an effective insulator, but also does not carry any structural load. A separate mention in this category of innovative building materials, of course, also deserves a new generation of energy-efficient thermal insulators – vacuum insulation panels (VIP), which were originally focused on improving insulation in areas where high thermal resistance is required, but at the same time space is quite limited. Moreover, what is noteworthy, the basic physical principles of this type of thermal insulation were also, as in the case of ICF, developed back in the 60s of the twentieth century, but their mass introduction in the construction industry began to occur several decades later. The use of finely dispersed porous materials in these panels allows you to solve the problem of creating insulation with an extremely low thermal conductivity coefficient. In the process of heat transfer in porous powder structures, a significant role is played by the gas contained in the pores. The smaller the size of the pores or voids of the material, the better its thermophysical properties.

At present, the main composite materials for vacuum panels are polystyrene foam, polyurethane foam, fumed silica, and various aerogels. We should also note that, according to Canadian experts, VIP can provide almost 10 times higher thermal efficiency compared to traditional thermal insulation materials. However, in fairness, it is necessary to clarify here that a more active use of VIP in the construction industry is still restrained by the remaining uncertainty in the fundamental question of how reliable and long-term thermal insulation is provided by the vacuum shell after the direct installation of these panels.

2.3 Special facing rials based on gypsum-cement, gypsum-sulfur and gypsum-polymer compositions

Special facing and finishing materials based on gypsum-cement, gypsum-sulfur and gypsum-polymer compositions are innovative building materials that are widely used in construction and repair. These materials combine the properties of gypsum, cement and polymer compounds, providing high strength, resistance to external influences and aesthetic appearance of surfaces. Main components:

– zoolog-pso-cement compositions– mixtures that use gypsum, cement and ash. They provide high strength and resistance to moisture and temperature changes, making them ideal for outdoor use;

– gypsum-sulfur compositions– materials that combine gypsum and sulfur. Sulfur gives the material additional resistance to aggressive chemical environments, such as acids, which is important for use in industrial conditions;

– gypsum polymer compositions – these are materials that contain polymers that significantly improve elasticity, adhesion, and resistance to mechanical damage. They are used for interior finishing works, ensuring smoothness and aesthetics of surfaces.

The main advantages of these materials:

– in high speed of setting and hardening;

– resistance to moisture, temperature changes and aggressive environments;

– good heat and sound insulation properties;

– ease of application and the ability to create smooth and decorative surfaces.

These materials are suitable for both interior and exterior work, which makes them versatile and easy to use.

2.4 High-strength low-emission energy-saving glass for the architectural and construction industry

High-strength, low-e glass is an advanced material for the architectural and construction industry, combining several key characteristics, such as strength, energy efficiency and environmental safety. Such glass is used in modern construction projects to ensure comfort and reduce the cost of heating and cooling buildings.

Key features and technologies:

– high strength: glass is manufactured using special tempering or lamination technologies, which provides increased resistance to mechanical damage, shock and vibration. Can be used in places with increased safety requirements, such as skyscraper facades, balconies and windows of high-rise buildings;

− low-emissivity coating (Low-E): has a special metal coating that minimizes heat loss through windows in winter and reflects heat outwards in summer. Provides effective reduction in energy consumption for heating and air conditioning, reducing energy costs;

− energy saving: due to its low thermal conductivity, glass helps to retain heat in the room during the cold season and does not let in excess heat in the summer, which helps to maintain a comfortable temperature inside the building. The use of such glass helps to achieve high standards of energy efficiency and reduce the carbon footprint of the building;

− environmental friendliness: helps reduce energy consumption and thereby helps reduce greenhouse gas emissions. The materials used to make such glass are safe for human health and the environment.

Benefits of use:

− reduction of energy consumption: thanks to its energy-saving properties, glass reduces the costs of heating and air conditioning buildings;

− comfortable conditions: glass minimizes glare and maintains a comfortable temperature in rooms regardless of the season;

− durability: high-strength glass has a long service life and is resistant to weather conditions and mechanical damage;

− acoustic insulation: glass can have improved soundproofing properties, which is especially important for buildings in urban environments.

Application:

− facades and windows of skyscrapers and office buildings;

− transparent roofs, winter gardens, glass partitions;

− buildings with high energy efficiency requirements, in particular passive houses.

High-strength, low-emission energy-saving glass is an important element of modern architectural solutions, providing a balance between aesthetics, comfort and environmental friendliness.

TOPIC 3 ECOLOGICALLY POSITIVE CONSTRUCTION

3.1 Energy efficiency. Types of energy-efficient buildings

Energy efficiency− is the ability of a building, system or device to use energy as efficiently as possible, i.e. with minimal losses. In the context of construction and architecture, energy efficiency involves the use of technologies and materials that reduce energy consumption for heating, cooling, lighting, etc., which allows to reduce the cost of operating the building and reduce the impact on the environment.

Types of energy-efficient buildings:

− passive house (Passivhaus) −is a building that provides comfortable living conditions with minimal energy consumption for heating and cooling. It uses heat generated from solar energy, electrical appliances, residents and ventilation systems with heat recovery. The characteristic features of such a house are high-level thermal insulation, efficient triple-glazed windows, airtightness of the building and heat recovery in the ventilation system;

− Zero-Energy Building − this is a building that produces as much energy as it consumes throughout the year. This is usually done using renewable energy sources (solar panels, wind turbines, etc.). The characteristic features of such a building are high energy efficiency, solar panels or other renewable energy sources, and the use of energy-efficient electrical appliances;

− Positive Energy Building −a building that produces more energy than it consumes. The excess energy can be sold to the energy grid or used for other purposes. The characteristic features of such a building are on-site energy production and excess energy generation for off-site use;

− green building (Green Building) a building that is designed and constructed with environmental standards in mind. In particular, it uses materials that have a low carbon footprint, reduces the use of water, energy and raw materials. The characteristic features of such a building are the use of environmentally friendly construction materials, the application of technologies to reduce environmental impact and the presence of water and energy resource management systems;

− active house (Active House) −This is a type of building that not only has high energy efficiency, but also provides a high level of comfort for its occupants through proper lighting, ventilation and the use of renewable energy. The characteristic features of such a building are high levels of natural lighting, ventilation systems with heat recovery and the use of renewable energy sources.

Energy-efficient buildings are a key element in sustainable development strategies aimed at reducing energy consumption and reducing environmental impact.

3.2 “Green” roofs as an important element of energy efficiency

“Green” roofs (sometimes called “living” roofs) are an important element of energy-efficient buildings and play a significant role in reducing the energy consumption and environmental impact of buildings. They are structures on which plants and other green vegetation are grown, covering the roof surface.

Advantages of “green” roofs context of energy efficiency:

− thermal insulation − Green roofs act as natural insulation. The soil layer and vegetation help retain heat in the winter, and in the summer they reduce the temperature inside the building, blocking excessive heat. This reduces the need for air conditioning and heating, which reduces energy consumption;

− reduction of the heat island effect − in large cities with concrete and asphalt surfaces, temperatures are usually high than in the suburbs. Green roofs help cool buildings and surrounding areas, reducing the heat island effect, where temperatures around a city rise due to the abundance of unnatural materials;

− improving air quality − rooftop vegetation absorbs carbon dioxide and releases oxygen, helping to improve air quality. In addition, green roofs filter the air from harmful particles;

− rainwater absorption – help manage rainwater more effectively, as they absorb a significant portion of the precipitation. This reduces the load on storm sewers, reduces the risk of flooding and contributes to more efficient use of water resources;

− increasing the lifespan of the roof − vegetation and soil layers protect the roof surface from ultraviolet radiation, extreme temperatures, and mechanical damage. This helps to extend the life of the roof, reducing the need for repairs and replacements;

− aesthetics and urban development − they add beauty and a natural element to urban environments. This contributes to improving the quality of life by creating areas for relaxation and improving the emotional state of residents.

Types of “green” roofs:

− intensive green roofs − have a thick layer of soil (more than 20 cm) and can support a wide range of plants, including shrubs, trees and flowers. Require careful maintenance and can be used as public spaces;

− extensive green roofs − have a thinner soil layer (5–20 cm) and are usually used for unpretentious plants such as mosses, grasses or succulents. They require minimal maintenance and are lighter in weight, making them ideal for buildings with limited loads.

Green roofs help reduce greenhouse gas emissions by reducing energy consumption and heat production, contribute to improving the health of urban residents and increase biodiversity in cities. They can provide habitat for birds, insects and other organisms, supporting ecosystems even in urban settings. Thus, “green” roofs are an important element of energy-efficient infrastructure, contributing not only to reducing energy costs, but also to improving the overall state of the environment.

3.3 Environmental efficiency of photocatalytic concrete, Smart coating

Photocatalytic concrete and Smart coatings are innovative materials that make a significant contribution to improving the environmental performance of buildings and the urban environment. They not only contribute to energy efficiency, but also help in the fight against environmental pollution.

Photocatalytic concrete contains special additives, in particular titanium dioxide (TiO_2), which is activated by sunlight and triggers photochemical reactions. These reactions help break down harmful pollutants, such as nitrogen oxides (NO_x), into less harmful substances that are then washed away by rainwater. This process is called photocatalysis**.**

Environmental benefits of photocatalytic concrete:

− air purification −helps break down air pollutants such as NO_x, which are one of the main causes of smog and acid rain. This helps improve air quality in cities and reduce harmful effects on human health;

− self-cleaning − prevents the accumulation of dirt, dust and biological formations on its surface. This reduces the need for frequent cleaning and maintenance, which reduces the use of chemicals and water for washing;

− reduction of the heat island effect − usually used in light colors, which helps reflect sunlight and reduce surface heating. This helps reduce temperatures in urban areas and reduces the heat island effect;

− resistance to ultraviolet − retains its properties and appearance longer, as titanium dioxide protects it from the negative effects of ultraviolet radiation.

Photocatalytic concrete is used in various infrastructure projects such as road surfaces, sidewalks, building facades, pedestrian areas and parking lots. Its application is particularly effective in areas with heavy traffic or in industrial areas where air pollution is particularly high.

Smart coating (or smart coatings) are coatings that have the ability to change their properties under the influence of external factors (temperature, humidity, light, electric field, etc.) or have active functional properties that can be used to improve energy efficiency and reduce environmental impact.

Types and environmental benefits of Smart coatings:

− heat-reflective coatings −These are coatings that have the ability to reflect solar radiation, reducing the heating of building surfaces. This helps reduce the load on air conditioning systems and save energy in warm climates;

− solar coatings (photovoltaic) −Integrated photovoltaic coatings are capable of generating electricity from sunlight. They can be used on roofs, facades or other building elements, transforming the building surface into a source of renewable energy;

− hydrophobic and self-cleaning coatings − these coatings are able to repel water and other contaminants, which reduces the need for frequent cleaning or the use of chemical cleaning agents. This reduces the consumption of water and resources, which is important for sustainable development;

− thermochromic coatings − change their color depending on the temperature, which allows you to automatically control the reflection or absorption of heat. In cold weather, they can help retain heat, and in warm weather, reflect it, which helps save energy on heating and air conditioning;

− electrochromic coatings − these coatings change their transparency when exposed to an electric field. They can be used on windows or facades to dynamically control the amount of light and heat entering a building, reducing energy consumption for lighting and cooling.

Smart coatings are used in various fields, from architecture and construction to transportation and industrial facilities. In particular, they are used on building facades, roads, bridges, as well as for covering vehicles and machinery.

3.4 Smoke protection systems

Smoke protection systems (hereinafter referred to as SPS) are a set of measures, technologies and equipment designed to prevent the spread of smoke and combustion products in buildings during a fire. The main task of these systems is to ensure safe conditions for the evacuation of people and access of rescue services to the scene of a fire.

Main functions of smoke protection systems:

1) smoke removal from a building or premises;

2) creating excess pressure in escape routes (e.g. stairwells or elevator shafts) to prevent smoke from entering;

3) smoke localization in separate areas of the building to limit its spread;

4) control of ventilation systems, which can contribute to the rapid spread of smoke.

The main elements of the SPDZ:

1) smoke extraction – exhaust ventilation systems that actively remove smoke from rooms;

2) overpressure systems – fans and ducts that supply clean air to evacuation areas, preventing smoke from entering these areas;

3) fire dampers and curtains – mechanisms that block the spread of smoke through ventilation systems and open spaces;

4) smoke detectors – devices for detecting increased smoke levels and automatically starting the fire extinguishing system;

5) control and monitoring systems – a central control panel or automated system that controls the operation of all elements of the smoke protection system.

Fire escapes are especially important in high-rise buildings, hospitals, shopping malls, underground parking lots, and other facilities where rapid evacuation of people is critical during a fire.

TOPIC 4 NEW CONSTRUCTIONS FOR CONVERSION, MODIFICATIONS AND RESTORATION OF OLD HOUSES HOUSING FUNDS

4.1 A modern view of housing quality

The modern view of housing quality encompasses a wide range of aspects related to comfort, safety, energy efficiency, functionality and sustainability. In the context of increasing demands on the urban environment, new technologies and changes in lifestyle have significantly influenced the rethinking of housing standards.

The main criteria for the quality of modern housing

Energy efficiency and environmental friendliness. Energy efficiency has become one of the key parameters of modern housing. Important aspects are the use of insulating materials, energy-saving windows, "green" heating and cooling systems, solar panels, energy storage systems and the use of renewable energy sources.

Environmental friendliness involves choosing building materials with low environmental impact, minimizing waste, creating waste management systems, and using resources such as water and energy with minimal losses.

Comfort and functionality. Space planning plays an important role in ensuring the comfort of housing. Open layouts, multifunctional rooms and ergonomic design contribute to comfort and improve the quality of life. Inclusion (accessibility for people with disabilities) has become an important factor when designing new residential buildings, where attention is paid to barrier-free environments and flexible interiors.

Technological conveniences. The integration of smart technologies, such as a “smart home,” allows you to control lighting, climate control, security, and other aspects of your living space via your smartphone or other devices.

Safety and health. Security of living space involves the presence of fire protection systems, video surveillance systems, access control systems and emergency sensors (e.g. gas, smoke or water). A healthy environment requires ensuring high indoor air quality, access to natural light, minimizing noise levels and using materials that do not emit harmful substances.

Location and social infrastructure. Transport accessibility and proximity to jobs, schools, hospitals, shops and public spaces are important factors in housing choice. Increasing attention is being paid to access to parks, gardens and recreational areas near housing, which contributes to improving the quality of life and health of residents.

Resilience and adaptability. Sustainable housing should be adaptable to climate change and other external factors, have good infrastructure to reduce the impact of natural disasters (e.g. floods or earthquakes). Flexibility and adaptability of living spaces to changes in family composition or needs of residents (modular solutions, possibility of redevelopment) is also a modern trend.

Trends in modern housing:

− *“smart” housing (Smart Home):* integration of automation systems for controlling lighting, heating, security, household appliances, etc.;

− *micro-housing:* compact living solutions with optimized space for young professionals or single people in cities;

− *co-living:* the popularity of co-op living, where residents share common areas such as kitchens or workspaces while still having private rooms.

The modern approach to housing quality emphasizes individual needs, sustainable development, and technological solutions that increase comfort and safety while minimizing environmental impact.

4.2 Condition of building structures old housing stock

The structural condition of old housing stock is an important issue for urban development and the safety of residents. Many old buildings built in the mid-20th century or earlier, especially in post-Soviet countries, are in poor or even dilapidated condition. Various factors contribute to the deterioration of such buildings, including natural aging of materials, improper maintenance, and changes in climatic conditions.

The main problems of old building structures:

1. Depreciation of materials. Physical aging. The aging of basic building materials such as concrete, wood, metal and brick leads to the loss of their original properties. For example, concrete can crack and crumble, brick can peel due to moisture, and metal elements can corrode. Over decades, structures are exposed to rain, snow, wind, temperature changes and ultraviolet radiation. This contributes to the degradation of building materials.

2. Faults in the foundation and floors. Foundation subsidence due to changes in soil conditions or poor construction can cause cracks in walls, skewing of structures and deformation of floors. Moisture in basements can cause rotting of wooden floors, corrosion of metal elements and deterioration of the foundation.

3. Condition of retaining walls and ceilings. Cracks in the walls and floors can be a result of foundation subsidence, insufficient structural rigidity, or dynamic loads. Corrosion of reinforcement in reinforced concrete structures is a particular problem for Soviet-era buildings, where reinforced concrete panels and blocks were used. Rotting of wooden structures in old buildings, especially in attics or lofts, is a common cause of reduced load-bearing capacity of floors.

4. Engineering communications systems. Deterioration of water supply, sewage and electricity systems often leads to emergencies such as flooding, short circuits or fires. Gas and ventilation systems in older buildings can be dangerous due to leaks or blockages.

5. Problems with waterproofing and thermal insulation. Poor waterproofing can lead to constant exposure to moisture on structures, causing their accelerated destruction. Insufficient thermal insulation leads to heat loss and moisture condensation, which also contributes to the formation of fungus, mold and destruction of materials.

6. Impact of modernizations and repairs. Incorrect or poor-quality repairs can exacerbate problems. For example, installing heavy modern materials (plastic windows, insulation) without taking into account the bearing capacity of the walls can lead to deformations. Redevelopment without taking into account the structural features of the building can create additional loads on the bearing walls or floors.

The consequences of the neglected state of structures are:

− increased risk of emergencies;

− deterioration of living conditions;

− increase in maintenance costs;

− reduction in housing costs;

− building evaluation and reconstruction;

− strengthening of structures and modernization of engineering systems;

− thermal insulation;

− façade works.

Many countries are implementing programs to modernize the old housing stock, including replacing dilapidated buildings with new ones. In some cases, old buildings are demolished and new housing complexes are built in their place, taking into account modern building codes and technologies. However, in historic areas, where the preservation of architectural heritage is a priority, reconstruction is carried out while preserving the original appearance.

The structural condition of old housing stock is often critical and requires serious measures to improve their safety and comfort. Maintaining and modernizing such buildings requires significant financial and technical resources, but it is necessary to ensure decent living conditions for their residents.

4.3 Latest designs for conversion, modification and restoration

New designs for the transformation, modification and renovation of buildings play an important role in architecture and construction, especially in the context of adapting existing structures to modern needs, improving their functionality and reducing their negative impact on the environment. These technologies and materials allow for significant improvements to buildings without the need for demolition, making reconstruction processes more efficient and economical.

The main directions of the latest designs:

− adaptive designs − allow buildings to change their form or function according to the conditions or needs of the inhabitants (modular structures and transformable interiors);

− reconstruction using lightweight materials – allows for effective renovation of buildings without significant load on existing structures (composite materials: fiberglass, carbon or other light but strong materials allow to strengthen load-bearing structures, facades or even change the configuration of the building without significant reconstruction; panel systems: technologies using external panel systems (for example, ventilated facades or multilayer walls) allow to improve the thermal insulation properties of buildings while updating their appearance);

– *3D printing technologies − allow you to quickly create both individual parts of a building and entire structures;*

– *with melting materials and technologies* (focus on using environmentally friendly and sustainable materials that help reduce the building's carbon footprint and increase its energy efficiency);

− *there are energy facades and technology integration (*Modern facades can be not only aesthetically appealing, but also functional – they generate energy, improve thermal insulation, or even collect water. Photovoltaic panels: integrating solar panels into facade systems allows buildings to generate energy without losing aesthetic appeal. Intelligent facades: technologies that allow building facades to change their properties depending on conditions – for example, darkening under the influence of the sun or letting in more light in winter to increase energy efficiency;

– *building restoration systems using robotics* (allow to speed up the processes of renovation and modification of buildings. Facade robots: robotic systems for cleaning, repairing and painting facades significantly reduce maintenance costs. Robotic material laying systems: the use of robots for precise laying of bricks or blocks, which ensures high-quality finishing and increases the speed of construction).

The latest designs for conversion, modification and renovation provide the opportunity to make the most of existing buildings, updating them for modern needs. Thanks to innovative materials, 3D printing technologies, adaptive solutions and energy-efficient facades, architects and builders can significantly extend the life of buildings while reducing the environmental impact.

4.4 Feasibility study and research of the implemented design measures solutions

Feasibility study of implemented design solutions is an analysis that combines technical and economic aspects in order to assess the effectiveness and feasibility of implementing certain engineering or management solutions. This allows us to understand whether a specific project is worth implementing and whether it will achieve the expected results in terms of cost, time and resources. The procedure for feasibility study includes several key stages:

1. Analysis of technical aspects of the solution: the constructive implementation of the project, its manufacturability, availability of materials and necessary resources, and the possibility of using modern technologies are considered.
2. Cost estimation: the costs of implementing the project are calculated, including the cost of materials, labor, equipment, and other resources.
3. Forecasting economic benefits: the economic benefit that the implementation of the solution will bring is estimated. This may include increased productivity, reduced costs, improved product or service quality.
4. Risk analysis: possible risks and their impact on the success of the project are considered. The possibility of increased costs or failure to complete the plan within the established deadlines is assessed.
5. Return on investment: the payback period is analyzed, which shows how quickly the project will start generating profit or economic benefit.

After conducting a feasibility study, decisions can be made regarding further development of the project, its adjustment, or rejection of implementation.

TOPIC 5 INNOVATIVE BUILDING STRUCTURES OF THE MODERN CONSTRUCTIVE SYSTEM “MONOFANT”

5.1 Energy approach in design building structures of the modern structural system “Monofant”

The energy approach in building design aims to optimize energy use during the design, construction, and operation of a building. This approach takes into account not only the structural strength and stability of the structure, but also energy efficiency, resistance to external influences, and resource-saving solutions.

The “Monofant” system is one of the modern structural systems used in construction and has a number of innovative features. This system combines several key principles:

1) *monolithic structure:* “Monofant” involves the use of monolithic structures, which allows you to create continuous, solid elements of concrete or reinforced concrete. This ensures high strength and durability of the building;

2) *high energy efficiency*: thanks to the design and materials features, the system allows to significantly reduce energy losses, in particular heat losses. This is achieved through improved thermal insulation and reduction of cold bridges;

3) *optimization of material use:* The energy approach requires minimizing material consumption and reducing the energy required to produce them. In the “Monofant” system, this is achieved by using lightweight but strong materials, such as modern concrete mixes with additives that improve their properties;

4) *reducing environmental impact*: the approach takes into account environmental aspects - reducing CO^2 emissions and other harmful substances during production and construction;

5) *integration with engineering systems:* Modern “Monofant” designs can be integrated with heating, ventilation and air conditioning systems, which allows for maximum comfort for users with minimal energy consumption.

Principles of the energy approach at “Monofant”:

1) energy conservation: one of the main objectives is to reduce energy demand during the operation of the building thanks to well-designed elements that reduce heat loss;

2) energy balance: the system takes into account renewable energy sources, such as solar panels or geothermal systems, which allows for a balance between energy consumption and production;

3) life cycle analysis: during design, the full life cycle of the building is taken into account, from the production of materials to their disposal after the end of operation.

The modern “Monofant” structural system with an energy approach can serve as an effective solution for the construction of energy-saving and durable buildings, meeting modern requirements for energy efficiency and environmental friendliness.

5.2 Design features of building structures of the modern “Monofant” structural system

The “Monofant” structural system is distinguished by its innovative approach to building design, combining modern materials, engineering solutions and energy-efficient technologies. The main structural features of this system can be considered through the following aspects:

1.Monolithicity of structures.

The “Monofant” system is based on the use of monolithic structures, which involves pouring concrete on site without joints or seams. This ensures high strength, rigidity and durability of the building. Monolithic structures are able to withstand significant loads, are resistant to deformation, and also have high seismic resistance.

2. Use of reinforced concrete.

Reinforced concrete is the main material in the “Monofant” system. The combination of concrete, which provides high compressive strength, and steel reinforcement, which adds tensile strength, allows you to create strong and reliable structures. Reinforced concrete elements can be made either monolithic or prefabricated, depending on the specifics of the project.

3. Minimizing the number of columns and reinforcement.

One of the important features of the “Monofant” structures is the reduction of the number of supporting elements, in particular columns and beams. This allows for more open spaces without planning restrictions. At the same time, the structure distributes the load evenly, which allows for a reduction in the number of additional reinforcing elements.

4. Integration with thermal insulation materials.

The “Monofant” system uses modern thermal insulation materials to reduce heat loss. Typically, thermal insulation is integrated into the internal structure of the structure or applied to external surfaces. This reduces heating and air conditioning costs and increases the energy efficiency of the building.

5. Lightweight and durable construction.

Thanks to the use of the latest materials and technologies, the structures in the “Monofant” system have a low weight, which simplifies their transportation and installation. At the same time, the system maintains high strength and stability.

6. Economical use of materials.

The “Monofant” system is also notable for its efficient use of materials, which allows for a reduction in their volume while maintaining the necessary performance properties. Thanks to precise engineering calculations and modern technologies, it is possible to minimize waste during construction.

7. Free organization of space.

Because the structure requires a minimum number of supporting elements and columns, interior design becomes more flexible. This allows for the creation of large open spaces without unnecessary obstacles, which is important for modern office or residential buildings.

8. Resistance to external influences.

Thanks to the use of modern materials and technologies, “Monofant” structures are highly resistant to external factors such as humidity, temperature changes, corrosion and seismic loads. This increases the service life of the building and reduces the need for regular maintenance.

9. Adaptability to different types of buildings.

The “Monofant” system is versatile and can be used for various types of buildings, from residential buildings to commercial and industrial facilities. Structural elements can be adapted to the specific requirements of each project, providing an individual approach to architectural and functional solutions.

10. Integration with engineering systems.

The "Monofant" design allows you to easily integrate various engineering systems, such as heating, ventilation, power supply, and others. This facilitates the laying of communication networks and reduces the costs of their installation. In general, the "Monofant" system is a high-tech structural system that provides reliability, energy efficiency, and flexibility when designing modern buildings.

5.3 Modern building construction production technologies "Monofant" structural system

The technologies for manufacturing building structures within the modern "Monofant" structural system include the use of the latest methods and materials to achieve maximum efficiency, strength and energy saving. These technologies can be divided into several main aspects:

Monolithic construction

One of the main technologies of the "Monofant" system is monolithic concreting. This is a technology in which building structures are poured into special molds or formwork at the construction site. The advantages of this approach are:

- seamlessness: monolithic structures have no seams, which increases their strength and resistance to external factors, such as moisture or vibration;
- flexibility in forming structures: you can create any geometric shapes, including non-standard elements of facades or interior space.

Prefabricated monolithic structures

This technology combines the advantages of prefabricated elements and monolithic concreting. Prefabricated reinforced concrete elements (e.g. columns, beams or panels) are transported to the construction site and connected to monolithic elements, which ensures speed of construction and high installation accuracy.

Manufacturing technologies for prefabricated elements

Prefabricated elements in the "Monofant" system are manufactured in factories from reinforced concrete. This ensures high quality (controlled production conditions at the factory allow for precise adherence to technical norms and standards) and waste minimization: (factory production allows for efficient use of materials, reducing the amount of waste).

3D printing with concrete

One of the innovative technologies that is being used in modern construction, including the "Monofant" system, is 3D concrete printing. This technology allows you to quickly create individual structural elements or even entire buildings using robotic systems. The main advantages are time savings (printing structures is much faster than traditional methods) and minimal material waste (the technology allows you to use the material as efficiently as possible).

High-tech concrete mixtures

For the structures of the "Monofant" system, special high-strength concrete mixtures are used, to which additives are added to improve properties. These can be plasticizers, hardening accelerators, waterproof components or microfibers that improve the structure of the concrete. In addition, the use of lightweight concrete allows you to reduce the weight of structures while maintaining their strength.

Reinforcement of structures

To increase the strength of building elements, the "Monofant" system widely uses reinforcement with traditional steel reinforcement (used to strengthen structures to provide resistance to tension and compression), as well as composite materials (which are lighter, corrosion-resistant, and have a longer service life).

Formwork systems

To form monolithic structures, modern formwork systems are used, which can be removable or non-removable. Removable formwork is removed after the concrete hardens, which allows it to be reused. Non-removable formwork remains part of the structure, often made of thermal insulation materials, which further increases the energy efficiency of the building.

Thermal insulation materials

An important aspect of the production of "Monofant" system structures is the use of modern thermal insulation materials that are integrated into the structure. Expanded polystyrene, mineral wool or aerogels are used to reduce heat loss and increase the energy efficiency of buildings.

Concrete compaction technologies

To increase the density and strength of monolithic concrete, compaction technologies are used. Namely, vibro-compacting and self-compacting concrete (the latest concrete mixtures that do not require vibration, as they have high fluidity and fill the formwork themselves).

Ecological and renewable materials

The modern "Monofant" system also includes environmentally friendly materials and technologies. Secondary materials (using recycled concrete or steel reduces environmental impact) and ecological additives (to reduce CO^2 emissions) special cement mixtures with low carbon content are used during production).

Innovative quality control systems

The production of building structures in the "Monofant" system is accompanied by the use of modern quality control technologies, such as concrete hardening sensors (used to control the curing process and monitor the temperature inside the concrete mass) and laser scanning systems (ensure high accuracy in the installation of prefabricated elements).

The production technologies in the "Monofant" structural system are based on modern innovations in building materials, production processes and engineering solutions. These technologies are aimed at increasing efficiency, reducing costs, improving energy efficiency and reducing the environmental impact of construction.

5.4 Foreign experience in implementing similar constructive solutions

Foreign experience in implementing structural solutions similar to the "Monofant" system demonstrates a wide range of technologies and approaches in construction based on the use of monolithic, prefabricated and combined structures. Many countries are implementing innovative solutions to achieve energy efficiency, strength and cost-effectiveness of buildings.

Monolithic frame systems in Germany

Germany actively uses monolithic-frame structures, similar to those used in the "Monofant" system. The main principles of these systems are high energy efficiency and resistance to external influences. German energy saving standards require the integration of thermal insulation materials and renewable energy technologies. For example, thermoactivated plates are often used in buildings to accumulate heat. Due to the harsh climatic conditions, building structures in Germany must be resistant to temperature and humidity changes, which is achieved through the improvement of concrete mixtures and special additives.

Prefabricated construction technologies in Sweden

Prefabricated-monolithic structural systems are common in Sweden, combining prefabricated elements (panels, columns, beams) with monolithic structures. This allows for shorter construction times and increased efficiency. Sweden uses recycling technologies for building materials such as concrete and steel, which reduces environmental impact.

Integrating 3D printing in construction in the US

The United States is one of the leaders in the implementation of innovative construction technologies, such as 3D concrete printing, which is an analogue of the "Monofant" system in the speed and efficiency of building construction. This allows you to reduce construction time and reduce waste, as materials are used with maximum precision. This technology reduces the cost of labor and building materials, as the process is automated.

Earthquake-resistant structures in Japan

Japan widely uses monolithic-frame systems, which are an analogue of "Monofant", with an emphasis on seismic resistance. Japanese structures must withstand significant seismic loads. Monolithic reinforced concrete frames and special dampers integrated into the structure of the building can reduce the destructive effects of earthquakes. To reduce the weight of buildings and increase stability, the latest lightweight concrete mixtures and reinforcing materials are used.

Introduction of prefabricated and modular structures in France

In France, modular and prefabricated structural systems are actively used, which are an analogue of the “Monofant” system in terms of speed of construction and energy efficiency. Individual structural elements are manufactured in the factory, which allows to reduce the construction time on site. French building codes require high energy efficiency indicators, so the modules are equipped with thermal insulation materials and renewable energy systems, such as solar panels.

Fast and economical construction in India

In India, monolithic construction technologies using formwork systems have become widespread due to the need for mass construction. Monolithic structures are poured using special formwork systems (removable and fixed formwork), which allows for the rapid construction of multi-story buildings. These technologies allow for reduced material costs and construction time, which is especially important for large-scale residential projects.

Multi-storey reinforced concrete structures in China

China is actively introducing monolithic-prefabricated structures for the construction of multi-story buildings and skyscrapers. Parts of the building are manufactured in factories and quickly assembled on site, which reduces construction times. China is one of the leaders in the construction of large-scale residential and commercial facilities using modern structural systems.

Adaptation to historical architecture in Italy

Italy is known for its historical architecture, so the introduction of modern construction technologies similar to “Monofant” is aimed at preserving historical buildings and restoring old structures. Monolithic frame systems are used to reconstruct historical buildings, while preserving their architectural features. The latest strengthening technologies are used, such as the addition of composite materials and the use of modern reinforcement systems.

Foreign experience in implementing structural solutions similar to the "Monofant" system shows the wide variability of modern technologies in construction. From monolithic and prefabricated structures to 3D printing and earthquake-resistant systems, global practices demonstrate that the combination of innovation and efficiency is a key factor for modern construction.

TOPIC 6 IMPLEMENTATION OF BIM TECHNOLOGY INTO THE ARCHITECTURAL AND CONSTRUCTION INDUSTRY OF UKRAINE

6.1 A new approach to digital information management applied in construction and urban planning

The construction industry of Ukraine has a number of interrelated problems, one of which is the lack of a systematic process of creating and exchanging digital information. Fragmentation, chaos, and opacity of data narrow analytical capabilities for finding and making strategic decisions and assessing their final effect, and also create barriers to the systematic implementation of new methods and modern technologies in the industry as a whole.

Today, the construction industry has the following problems that need to be solved: significant resource intensity of the construction process; inefficiency in managing the design, construction, and operation processes, in particular due to the low level of communication between the participants in these processes; inefficient use of material resources directed to construction, in particular the use of raw materials and related construction products that are not reusable; lack of approaches to effective management of the life cycle of objects as a complex of stages (periods) of the existence of a construction object that are sequential in content and time - from the concept of its creation (search, design, construction) to the termination of operation (liquidation), including the reuse of its parts (elements) for a new purpose; outdated regulatory support in construction, which does not correspond to the current level of construction technologies; significant consumption in the construction sector of energy produced from fossil fuels (from non-renewable sources), which leads to significant pollution of the environment; accident rate of objects in operation.

In the investment and construction activities of economically developed countries of the world, structural changes are gradually taking place, based on a shift in focus from the design and construction process to effective planning and management of the entire life cycle of an object as a complex of stages (periods) of the existence of a construction object that are sequential in content and time - from the concept of its creation (search, design, construction) to the termination of operation (liquidation), including the reuse of its parts (elements) for a new purpose.

The development of an effective and competitive national economy in Ukraine requires a systemic, comprehensive reform of the construction industry, one of the important components of which is its gradual digital transformation.

Analysis of the best global and European experience shows that today, the most progressive digital technologies in construction include building information modeling (BIM) technologies, which provide a modern approach to digital information management used in the field of construction and urban planning and are based on the use of a shared digital representation of the object to facilitate the design, construction and operation processes in order to create a reliable basis for decision-making.

The essence of BIM technologies is the development and shared use of a building information model of a construction object (BIM object model), which is a set of structured and unstructured information containers (data sets) within a holistic information system containing the necessary geometric, physical, functional and other characteristics of the object, on the basis of which documentation is developed that accompanies the life cycle of the object (design and estimate documentation, recommendations for operation).

6.2 Parameterization of architectural solutions in the BIM environment designing

In Ukraine, BIM technologies are already used in the activities of individual organizations, which are mainly determined by two-dimensional design, during which information is stored and transmitted separately in paper and/or electronic format. Therefore, the gradual, systematic implementation of BIM technologies requires state regulation.

It is planned to be implemented in stages, taking into account the application of BIM technology levels (BIM level), which are characterized by compliance with the minimum necessary criteria for determining the degree of use of BIM technologies during the implementation of construction projects.

At the initial stage of the systematic implementation of BIM technologies, it is planned to create appropriate conditions (implementation of regulatory and technical regulation, development of regulatory and technical support), training of architectural entities (construction customers, responsible executors of works related to the creation of architectural objects, owners (managers) of objects), implementation of pilot projects in the design and construction of objects for various purposes.

This will facilitate the introduction of streamlined management of digitally ordered building information, in particular that created in two-dimensional and three-dimensional systems within a common data environment, i.e. BIM Level 1.

In the future, a gradual mass transition to the use of BIM Level 2 is envisaged, which covers the processes of creating and managing coordinated and structured BIM models of an object, which simultaneously consist of object-oriented three-dimensional geometric and attribute data created by various participants in the construction process throughout the life cycle of the object within a common data environment.

After creating the necessary prerequisites in accordance with the Concept and the action plan for its implementation, it is planned to further introduce BIM technologies in Ukraine to BIM level 3 (characterized by full integration, interoperability and interaction of data, models, processes for the purpose of managing the life cycle of the facility), establish criteria for the use of BIM technologies during the construction of individual facilities (depending on their cost, complexity, class of consequences (liability), in particular during the implementation of construction projects carried out with the use of state support, as well as spread the practice of introducing the operation of facilities (in particular within the framework of the implementation of pilot projects) using BIM technologies.

6.3 Prospects for involving the latest information systems in architectural design

The outlined problems of the construction industry within the framework of the Concept are proposed to be solved through regulatory, legal and technical regulation of the processes of implementing construction projects and operating buildings and structures and implementing comprehensive measures in the following areas:

− research − conducting analytical work in the necessary areas to systematize information, forecast and evaluate results;

− regulatory and legal − making necessary changes to legislative acts in the field of application of VIM technologies;

− regulatory − development of technical regulations (construction standards and regulatory documents on the use of BIM technologies);

− technological − implementation and support of systems and platforms necessary for the implementation of BIM technologies;

− educational − ensuring the training of specialists in the field of VIM technologies, creating educational programs and courses;

− communication − involving the maximum possible number of interested persons, implementing events, creating and supporting information resources;

− organizational − coordination of the work of interested central and local executive bodies, local governments, technical standardization committees, scientific institutions and organizations, and experts;

− practical − implementation and monitoring of pilot project results, development of reuse projects.

The problem can be solved within the Concept in the following ways:

− regulatory and legal regulation of the implementation of BIM technologies in Ukraine at all stages of the life cycle of construction facilities;

− changing approaches to the development of project documentation, pricing and implementation of procurement procedures taking into account the life cycle of the construction object;

− establishing criteria for the use of BIM technologies during the construction of individual objects (depending on their cost, complexity, class of consequences (liability) in accordance with the best international and European experience;

− regulatory support for the application of BIM technologies during the design, construction and operation of buildings and structures, in particular, revising building codes, ensuring the adoption of national standards harmonized with international and European standards regarding requirements for elements of BIM models of an object at different stages of the life cycle of a construction object;

− introduction of methods for effective management of the life cycle of construction objects;

− encouraging organizations to use BIM technologies in their activities, in particular by introducing incentive measures, implementing free training programs and expert support;

− introduction of unified system processes for creating and exchanging digital information about construction objects at all stages of construction project implementation – from design to operation in order to ensure optimization of constructive solutions and processes of design, manufacturing, construction and operation, energy efficiency of buildings and their environmental friendliness, resource efficiency, transparency and efficiency of financial costs, ensuring integration with existing electronic systems for providing services and information in the construction industry (Prozorro public procurement system, Unified State Electronic System in the Field of Construction, etc.), development of manuals, regulations and protocols on the principles and requirements for modeling, exchange and management of data used in BIM modeling, taking into account the best international experience, phased implementation of pilot construction projects implemented with state support, application of BIM technologies, in particular within the limits of existing budget programs, creation of a national infrastructure of geospatial data and urban planning cadastres, promotion of the process of digital transformation of the construction industry, as well as ensuring the creation of a state data storage and management system, revision and development of educational programs for specialties related to BIM technologies in institutions of higher and pre-higher vocational education, creating mechanisms for retraining and certification of BIM technology specialists, promoting the creation of additional courses in BIM technologies (design, construction, operation) to train the necessary number of specialists in this field, creating information resources, conducting information and educational campaigns, trainings and seminars.

6.4 Main global approaches to implementing the Smart city concept

"Smart City" is a concept that is interpreted differently. Some perceive it as a city with good economic indicators, with progressive urban development, for some the presence of solar panels on the city council building and Wi-Fi in trolleybuses are important, and some associate it with robots and flying cars in the city infrastructure.

If you search the Internet for how to make your city smart, you are unlikely to find an answer to this question. There is no ideal and finally approved concept. Each city has its own characteristics, challenges and problems, to solve which different tools are developed and implemented accordingly.

Nowadays, the concept of a “smart city” is becoming more relevant every day. In various forms, it has been implemented or is being implemented in 2,500 cities around the world. There are two options for creating a Smart City. The first is to create a “smart city” from scratch, that is, building a city taking into account the concept of “Smart City”. Examples: Masdar (UAE), Songdo (South Korea);

The second option is the gradual introduction of smart technologies into already established urban systems. It is expected to be the most common method.

Each city chooses and defines the directions of smart development independently. Amsterdam, which, by the way, is among the top five "smart cities" in the world, attracts a lot of attention and interest. It began its smart history in 2009, when the authorities focused on the problems of energy conservation and reducing CO^2 emissions, and over time the number of directions has increased. Thanks to innovative approaches in many areas, Amsterdam can boast of technological development, improved financial performance, service level and general level of culture.

There are many proven and successful smart technologies that can be adopted and implemented in cities. Their benefits are beyond doubt. For example:

− Singapore's smart parking networks record the number and location of cars, sending data about available spaces to the application;

− Barcelona has a smart water irrigation system and a network of “smart” garbage cans;

− The Dubai Polis mobile application helps citizens pay fines online and report violations.

And how are smart things going in Ukraine, taking into account global experience, in recent years, the implementation of both complete “smart city” concepts and individual tools has begun in some cities of Ukraine.

Within the framework of Kharkiv Smart City, 36 projects are envisaged, including “Smart-transport” (“smart” traffic lights and stops, mobile application for urban transport), “Smart-energy” (use of alternative energy sources), bike paths and bike rental with the ability to pay online, systems “E-medicine” and “E-government”, information application “Tourism”.

Without such systematic work, it is impossible to build a truly smart city. The city has created the Department of Digital Transformation and the Kharkiv Reform Office.

One of the first steps towards “smart” city management was the introduction of Mobile ID technology or “mobile passport” – an electronic method of personal identification using a mobile phone, one of three officially recognized by the state in Ukraine. Kharkiv − the first city in Ukraine to introduce this technology.

The “Diya. Business” consulting zone has been opened, where entrepreneurs can receive free and, in some cases, paid consultations on developing and improving their business. These services can currently be obtained online on the “Diya. Business” portal.

Kharkiv ranks first in terms of the number of IT companies and specialists. One of the main areas of the cluster's work is cooperation with local authorities. Work is also planned to improve the digital literacy of the population. Today, digital transformation aims at two things. The first is service. Digital transformation should be implemented in every area where a resident comes into contact with the city. The second is effective management. Digital transformation is also a tool that will allow departments, city council employees, and municipal enterprises to manage their processes even more effectively. The concept will include re-equipping libraries into digital libraries and ASNs into access points. We want all citizens to have access to digital technologies. Today, online registration of entrepreneurs has been introduced in Kharkiv. Now not only individuals and entrepreneurs can receive assistance online, but also the general public. Today, you can open and close your business in 10 minutes without coming to ASNs, or make any changes to your registration data.

Although some of the services provided for in the concept of smart cities are already operating in Ukraine, in particular, digital tickets for public transport, video surveillance systems on the streets and in the metro, electronic document management, online registration in hospitals and government agencies, etc. The general trend is not yet nationwide.

The first problem that Ukrainian cities face on the path of Smart development is the lack of a strategic vision. In fact, for the successful implementation of this concept, Smart solutions must be officially enshrined in the development strategies of each individual settlement. This is the path followed by most megacities in developed countries.

The second problem is the lack of funding, because the implementation of this concept depends not only on the government, but also on business investments. So, Smart cities technically cannot appear only with budget funds. And today, business, investors and patrons do not take an active part in the development and implementation of Smart cities concept. However, the situation may change as a result of further changes on the front, as foreign partners have already expressed a desire to join the reconstruction of Ukrainian cities.

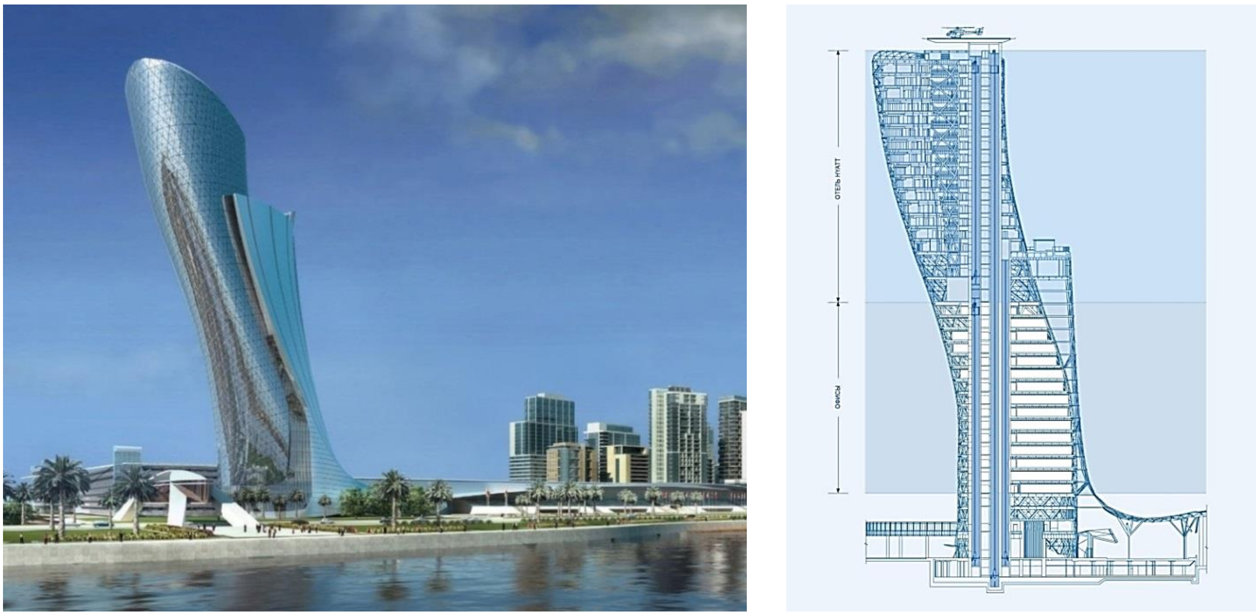
The third problem of Ukraine is the lack of qualified and experienced personnel who are able to launch and support innovative solutions. And we are talking not only about actual workers who can implement the world Smart experience in Ukraine, but also about a single state body that would regulate these issues. After all, today ministries, representatives of municipal authorities, non-governmental organizations and individual experts are working on the creation of smart cities. And, unfortunately, there is no single system that would regulate the directions, pace and tools of development.

In today's realities, the presence of a Smart concept is a strategic necessity. And no matter how unfortunate it may sound, the present can provide a good basis for the development of a system of smart cities in Ukraine. Thus, the country has the opportunity not only to restore completely destroyed cities, but also to build them in a new way, taking into account modern trends and world experience. In addition, in the future, this concept will not only make Ukraine more innovative, competitive and attractive for Ukrainians and foreign citizens, but will also attract a significantly larger number of investors to the development of the state.

TOPIC 7 CONSTRUCTIVE ENGINEERING SYSTEMS OF UNIQUE BUILDING THE WORLD

7.1 Leaning Tower of Capital Gate in Abu Dhabi, UAE

The building (Fig. 7.1) is a symbol of the new business district Capital Center. Functional purpose: floors 1–18 – office premises; floors 19–33 – 5-star Hyatt hotel (internal area of about 20 thousand m^2). The skyscraper was listed in the Guinness Book of Records as the building with the largest inclination in the world. The deviation from the vertical axis is 18 degrees. At the initial stage of construction of the shaft, a calculated inclination of 350 mm was set. As the floors increased, the core was brought to a vertical position.



a b

Figure 7.1 – Capital Gate Building, Abu Dhabi, UAE:
a – general view; b – section by functional zones

Foundation reinforced with 490 piles at a depth of 20 – 30 m. The piles experience compressive forces from the side of the departure, and tensile forces from the opposite side. The piles are connected from above by a monolithic reinforced concrete grillage. Structural system: core-shell. The function of the outer load-bearing shell is performed by diagonal lattices "diagrid" (Fig. 7.2), which also form the silhouette of the building. The first 12 floors have no curvature. The following levels are arranged with a gradual increase in protrusions from 30 cm to 140 cm. The core is reinforced with rods.

Figure 7.2 − Diagonal grids “diagrid”

Each floor is different in plan from the other.

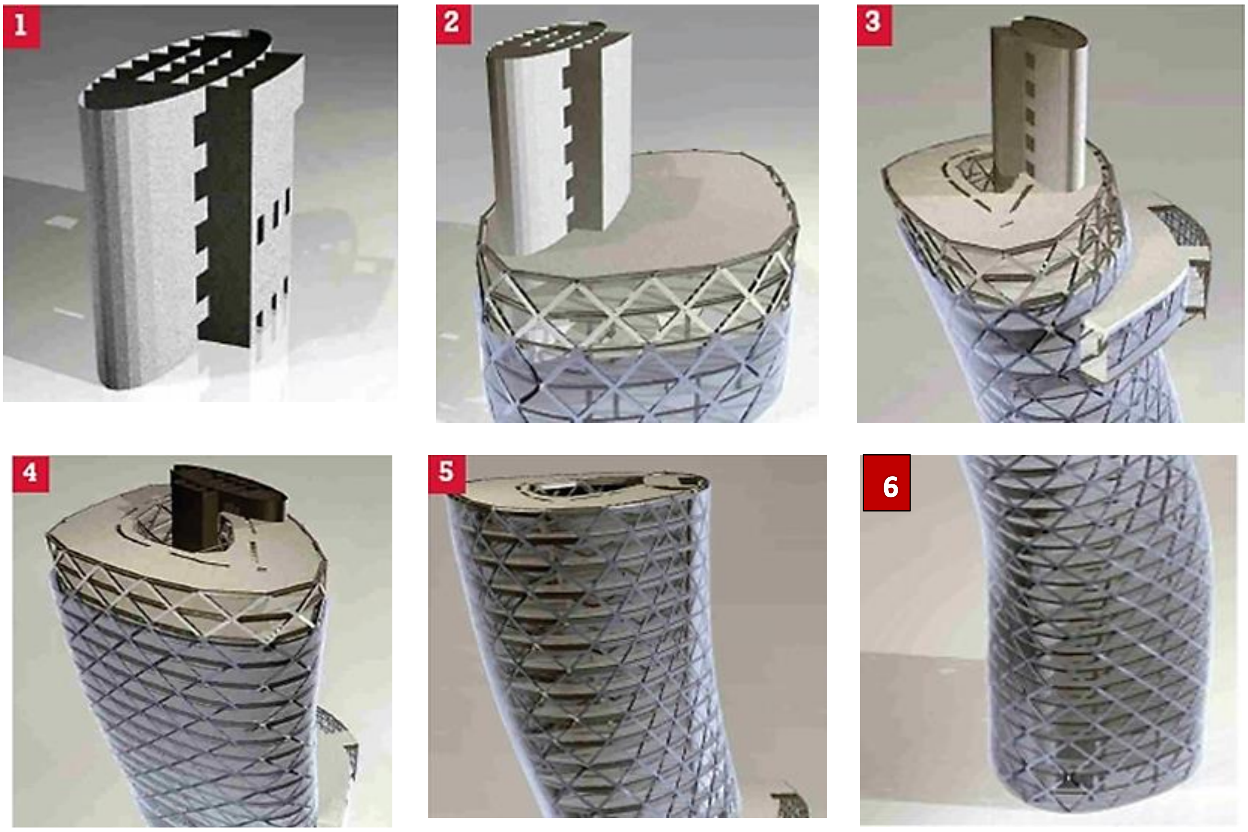


Figure 7.3 − Cross-sections of the building at different levels

The floor structure is formed by steel beams connecting the core and the external diagonal bracing. The diagonal bracing is connected to the beams at the level of the floor slabs, 720 such sections create the outer diagonal lattice.

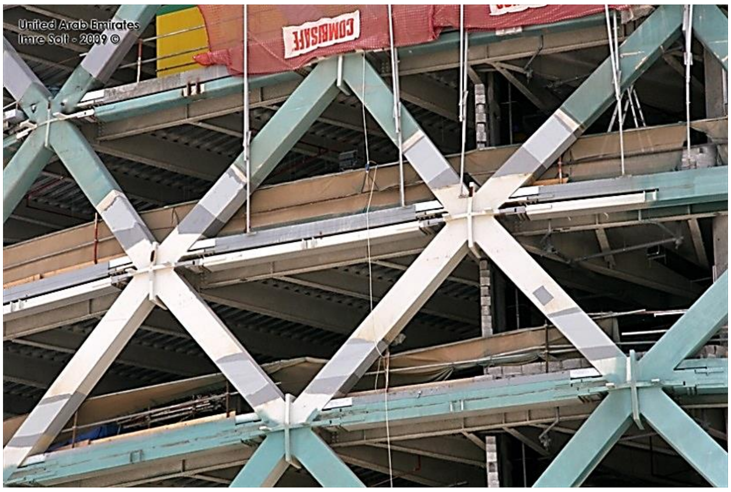


Figure 7.4 − Steel beams connecting the core and outer lattice

Abu Dhabi has light winds, which the tower resists with a dense network of core walls and cantilever beams on the 17th technical level. Sun protection as a separate system. The rounded shape helps resist torsion.

A massive concrete ring of beams transfers the weight of the diagonal trusses to the foundation.

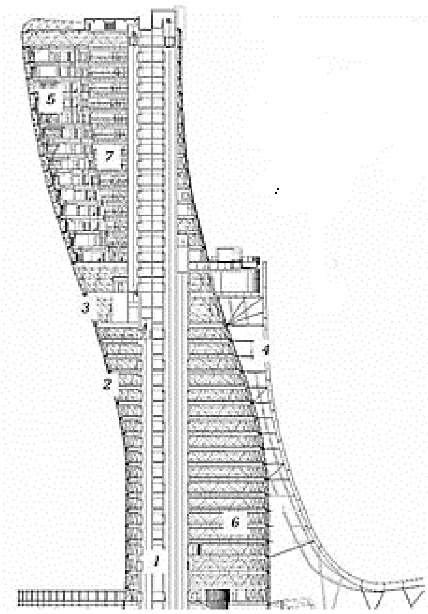


Figure 7.5 − Section of Capital Gate: 1 – core; 2 – steel diagonal lattice; 3 – truss to resist overturning forces; 4 – sun protection device; 5 – hotel; 6 – offices; 7 – atriums

728 glass panels are mounted on top of the lattice. Each panel consists of 18 panes of glass and weighs about 5 tons. In total, there are 12,500 panes of glass on the tower's facade.

Figure 7.6 − Capital Gate glass facades

7.2 Taipei 101, Taipei, Taiwan, China

In 2006, Newsweek Magazine named the skyscraper one of the New Seven Wonders of the World. One of the Technical Wonders of the World in 2005, according to the Discovery TV channel. The building houses the world's fastest elevators and the world's largest inertial spherical damper. Until 2010, when the Burj Khalifa skyscraper was put into operation, Taipei 101 was considered the tallest building in the world. Height 509.2 m (including spire).

The one hundred and one floors, with a total internal area of 412,500 m², house financial business centers. The foundation is 380 piles, some of which are driven 30 m deep and reach the bedrock. Each pile has a diameter of 1.5 meters and can bear a load of 1,000–1,300 tons.

A 6.8 magnitude earthquake struck Taipei on March 31, 2002. An inspection of the building showed that no damage had been caused to the tower by the earthquake, and construction resumed.

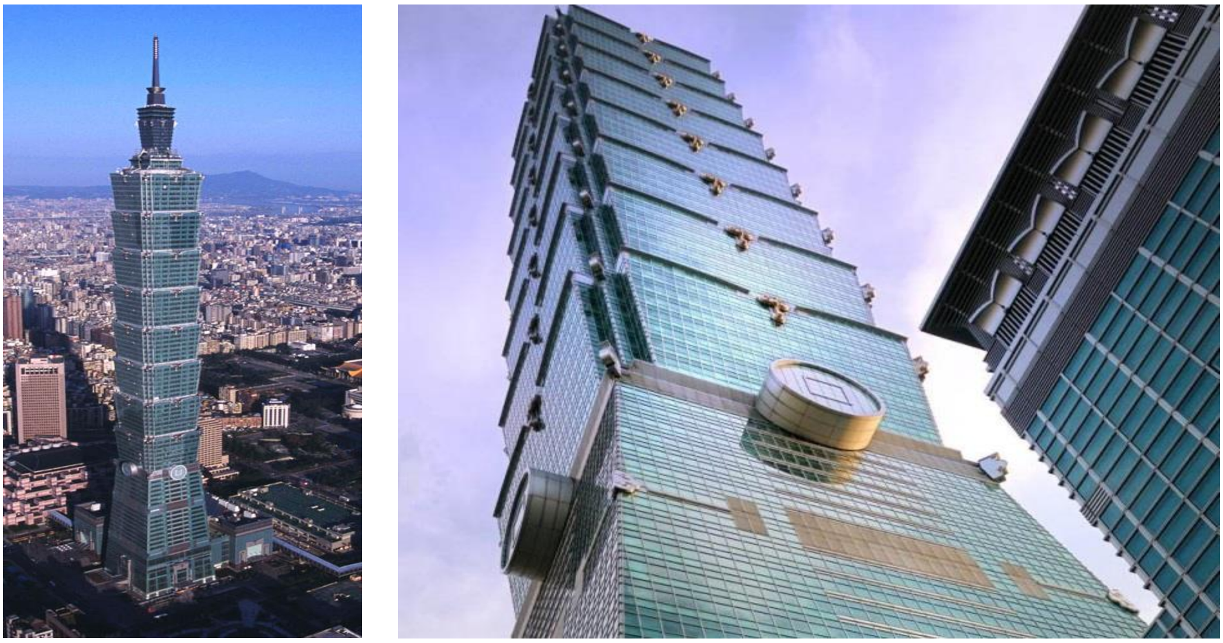


Figure 7.7 − Exterior view of Taipei 101

Structural system of a skyscraper – frame-truss construction. The building has 101 above-ground floors and 5 underground. The building consists of 8 distinct tiers of 8 floors each, located above a 25-story base part.

On the one hand, it was necessary to design a flexible structural system, and on the other hand, to add strength to the house to prevent lateral displacements (lateral shift) from wind loads.

Four pairs of super-strong columns measuring 2.4 m × 3 m in cross-section, one on each side, and a core of 16 columns together hold the building upright. Between floors 35 and 77, the concrete columns, encased in a steel shell, gradually decrease in thickness, and higher66 floors become all-steel. Every 8 floors there is a technical compartment, which houses intersecting steel outrigger trusses. The damper is an 800-ton pendulum, fixed on the 93rd floor. At the level of the horizontal centerline, eight viscous damping devices are attached to the ball.

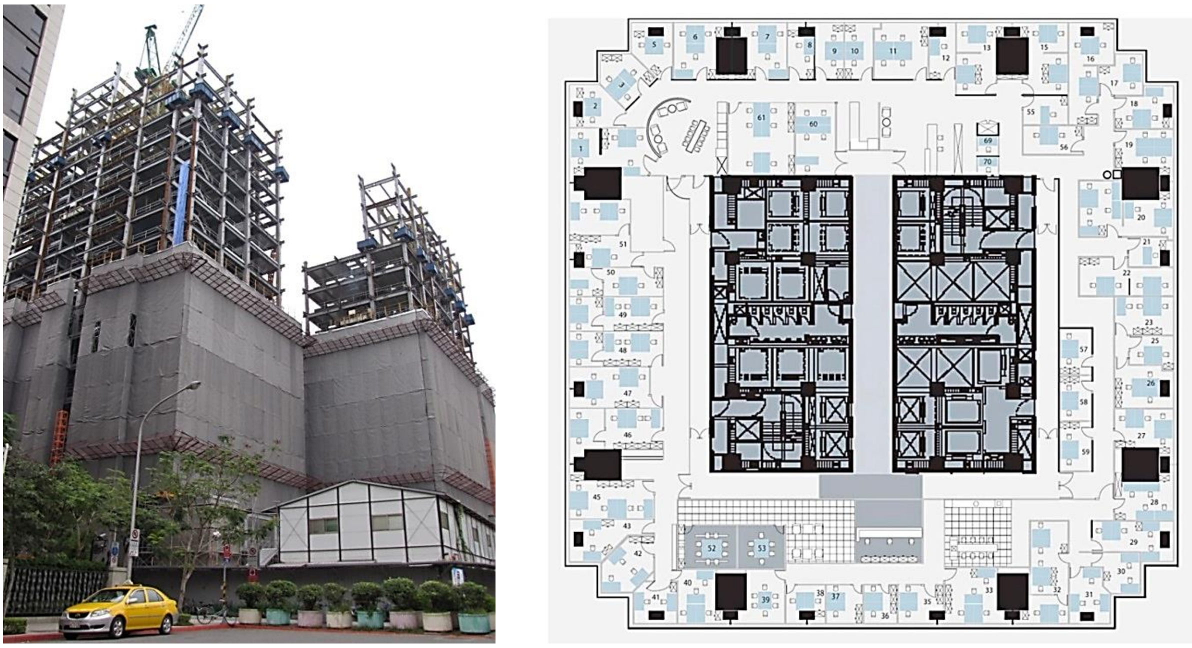


Figure 7.8 − Structural system and floor plans of Taipei 101

Under normal conditions, the amplitude of the oscillations is within 10 cm. In the event of a catastrophic earthquake or typhoon, the ball will swing with an amplitude of 1.5 m. This is the first specially tuned monolithic damper to be openly incorporated by an architect into the interior of a building.

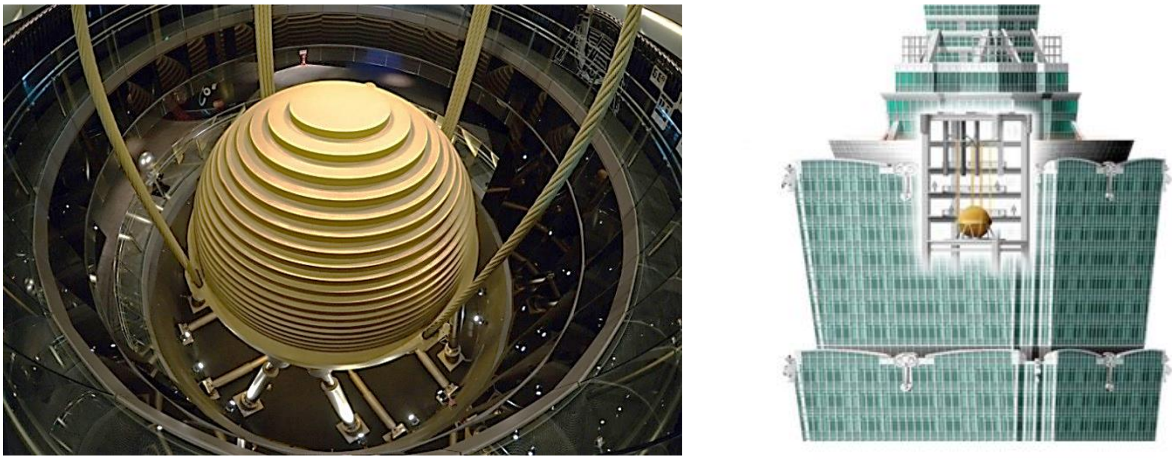


Figure 7.9 − Spherical damper in Taipei 101

Elevators rise at a speed of 16 m/s and descend at a speed of 10 m/s. There are a total of 61 elevators in the building, including two-story and two high-speed observation elevators.

The tower is covered with double glazing in a distinctive blue-green color. It protects employees from heat and ultraviolet rays.

7.3 Burj Khalifa, Dubai, UAE

A dizzying skyscraper in the Downtown area of Dubai (UAE), a so-called "vertical city", which is considered one of the most elite and desirable residential buildings in the world. The construction process of the tower began on January 6, 2004 and lasted just under six years.

Figure 7.10 – Appearance of the Burj Khalifa

The construction of the Burj Khalifa involved three of the world's largest mobile cranes with a lifting capacity of 25 tons each, plus about 12,000 workers worked there every day. A huge amount of materials was used in the process: about 320,000 cubic meters of concrete and more than 60,000 tons of steel reinforcement. A special brand of concrete was even developed specifically for the Burj Khalifa skyscraper, which can withstand temperatures up to +50 ° C. All concrete work was completed at the 160th floor level, and then the construction of the one hundred and eighty-meter metal spire began.

When viewed from above, the skyscraper, with its wide foundation, forms Y-shaped. The tower then gradually tapers upwards, reducing its area. The skyscraper was deliberately given an asymmetrical shape to minimize the possibility of it swaying in the wind.

The building reaches 828 meters, making it the tallest in the world. The Burj Khalifa tower, which is almost three times the height of the Eiffel Tower in France and twice the Empire State Building in the United States. In addition, the Burj Khalifa can boast several other world records. It is the tallest free-standing structure in the world, which has the world's highest open-air observation deck, the elevator with the longest run in the world (504 m) and the highest service elevator. The building has 163 floors (the most in the world). The area of the Burj Khalifa is equal to the area of 17 football fields. Another dizzying fact is how much the materials of the skyscraper weigh. Just compare: the weight of concrete is equivalent to the weight of 100,000 elephants, and the total weight of aluminum used in the construction of the Burj Khalifa is equivalent to the weight of five A 380 aircraft.

Burj Khalifa is the first of the tallest towers in the world to have residential accommodation. The residential wing on levels 19 to 108 houses 900 residences: studios, as well as apartments with one, two, three and four bedrooms. The skyscraper also has exclusive hotels, office space, gyms, boutiques, restaurants, 2,957 parking spaces and much more. The highest floor with an apartment occupied by people at an altitude of 385 m is located here.

The air in the skyscraper is specially cooled and constantly saturated with a pleasant aroma, which is supplied through holes in the floor. An exclusive fresh scent was created specifically for the Burj Khalifa tower, which is another beneficial advantage of this architectural wonder.

The building is well-designed to reuse resources, which is very important, especially in a desert climate. With the help of a condensate collection system, about 40 million liters of water are accumulated here every year, which is then used for irrigation, landscaping, the operation of the cooling system and to supply the Dubai Fountain.

The foundation of the Burj Khalifa is a massive system of powerful piles and a thick monolithic foundation slab, 192 bored piles, the diameter of which is about 1.5

meters, are buried approximately 47 meters into the soil. A powerful foundation slab, 3.7 meters thick, rests on the tops of the piles under the entire area of the building and is located at a depth of 7.55 m from the top layer of soil. That was the most appropriate solution for such a house.

The minimum center-to-center distance for a tower pile is 2.5 times the pile diameter. Therefore, numerous tests were conducted to ensure that the tower base was stable and stable both vertically and laterally, provided that the base acted as one overall system, including piles and soil. The soil to which the loads from the foundations and the entire building are transferred usually consists of medium-dense sands, which lie on rocky soils.

Figure 7.11 – Burj Khalifa Foundation Diagram

Numerous laboratory tests were conducted to identify the exact geotechnical characteristics of the soils. The tests can be roughly divided into two classes: conventional tests, including moisture content, yield strength, particle size distribution, specific gravity, unconfined compressive strength, point load index and direct shear tests; and complex tests, including triaxial compression, column resonance, cyclic undrained triaxial testing, cyclic simple shear and direct shear constant normal stiffness (CNS). These tests were carried out by various research and university laboratories in the UK, Denmark and Australia. A number of analyses were used to assess the foundation response for the Burj Khalifa and the foundation slab. The basic structural model was developed using the finite element method (FE) software ABAQUS by the specialist British firm KW Ltd.

Numerous geotechnical soil studies were conducted before designing the house and its foundations. During the research, approximately 33 holes were drilled. Various drilling methods were used. In addition, approximately 60 compression tests were carried out, as well as seismic and wind studies. Static load tests were carried out in two ways: 7 test piles were tested before the foundation was built; 8 piles were tested during the foundation construction phase. In addition, dynamic load tests were carried out, involving 10 piles of the house and 31 piles of the monolithic foundation slab, i.e. approximately 5 % of the total number of piles in the house.

Groundwater in the area of the designed house was at a level of 2,5 m from the top layer of soil. The soil at the construction site of the house has a rather complex horizontally layered profile, the geotechnical properties of which vary greatly with depth. That was the main factor in determining the size of the foundation. The bearing capacity of the piles is achieved mainly through the friction forces of the concrete pile surface against the sand and rock.

Various finite element software packages were used to analyze the entire foundation system. The estimated settlement of the building at the design stage was approximately 75 mm, but monitoring carried out during construction showed only about 30 mm, when about 75 % of the total load had already been applied. All this speaks of the enormous and correct work carried out by the engineering team during the design and construction of the Burj Khalifa tower.

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