

UDC 69.05:004.94:620.9

APPLICATION OF ADDITIVE TECHNOLOGIES IN THE CONSTRUCTION OF ENERGY-EFFICIENT BUILDINGS WITH A POSITIVE ENERGY BALANCE

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DOI: 10.32347/2410-2547.2026.116.181-192

The article is dedicated to the development of additive technologies, using 3D frames from concrete bags, for the formation of energy-efficient housing structures with a positive energy balance.

Keywords: additive technologies, 3D printing, digital modeling, energy efficiency, energy balance, Energy+ house, Betonix house.

1. Introduction

Today, an unprecedented challenge for Ukraine is the restoration of housing infrastructure destroyed as a result of the war. This is not a restoration of Ukraine to a pre-war state, but a deep modernization of the country, taking into account national traditions, world threats and the implementation of innovative trends in creating a sustainable and comfortable living space for future generations. One of these landfills under the auspices of the Academy of construction of Ukraine, where modern construction technologies are developed, is the cottage town "Big Ben", located in the village of Mikulichi, 20 km from Kiev. It was here that the technology of industrial wooden frame housing construction was developed, which makes it possible to build eco-friendly energy-efficient buildings at a high rate based on cluster housing construction strategies [1]. Using this technology, "Optima House" was built in 2015 - the first serial energy-efficient house in Ukraine, created on the basis of the European concepts "Multi-Comfort House" and "Active House", adapted for the domestic market (in 2017 it was awarded the International Alliance "Active House Award" and the domestic Award "Best Ukrainian Ecological Building") [2]. The construction of an energy-efficient "Biden" house for 4 apartments with built-in shelters was implemented [3].

Today, climate change is one of the most acute threats to humanity. Energy consumption by buildings accounts for up to 40% of global demand, and total greenhouse gas emissions account for about 35% of the total. Improving energy efficiency across the entire energy chain, from energy production, distribution, storage and use [4] is a priority for the European Union.

Rational use of energy is seen as a key aspect of reducing environmental damage, reducing greenhouse gas emissions, improving energy security, and reducing utility costs for households. This creates a demand for technologies that can enable fast, cost-effective and scalable construction of energy-efficient residential buildings. One of these innovative technologies in construction is 3D printing technology. Today, there is no sufficient justification for this technology for the construction of energy-efficient residential buildings for the conditions of Ukraine.

2. Analysis of literary sources

In modern housing construction is dominated by traditional approaches that are energy-intensive, expensive, and time-consuming in execution, and do not provide a complete transition to the model of buildings with a positive energy balance. In response to these challenges, additive technologies in construction, primarily 3D printing from concrete mixes, have been rapidly developing over the past decade. Unlike classical construction methods, these technologies allow to form walls and other structural elements without formwork, with high accuracy, flexible geometry and minimal material waste. The advantages of 3D printing technology are considered in [5-7]. A systematic methodology for the research is adopted in this research which includes three main stages: types of printer (3DP), materials and the printing process [8]. There are two main types of printers – robotic arm and gantry [9]. The materials used in 3D printing technology are given in [10]. For 3D printing mainly used compositions on cement binder (3DPC). The printing process is carried out by 3 main methods: layer by layer construction technique (the most widely used); selective laser sintering (SLS) (or concentrated solar [11]), laser stereo lithography (SLA) [12]; spraying (component gluing) [13, 14]. A systematic review of modern approaches to the formulation of the composition of concretes for 3D printing is carried out [15]. The influence of the water-cement ratio, mineral and chemical additives on thixotropy, extrusion stability and the ability to self-support is considered. The authors also analyze methods of testing for suitability for printing, but do not give an assessment of the thermal insulation properties of finished elements. A comparative study of construction using 3D printing with concrete and traditional methods is presented in [16]. There is a decrease in the time of work completion and the total cost of projects when using additive methods. Environmental indicators, in particular the reduction of CO₂ emissions, are presented in high detail, but there is no direct analysis of energy consumption during the building's operational cycle. Work [17] is devoted to the analysis of the potential use of Geopolymers in 3D printing of low-carbon concrete. One-component binding systems are considered as an alternative to Portland cement. The authors emphasize the engineering and environmental feasibility of such compositions. In [18] the emphasis is placed on the use of 3D printing for the formation of energy-efficient buildings. In addition to reviewing the thermal insulation parameters of concrete mixes, recommendations are given for architectural planning taking into account insulation, which directly connects materials science and energy-efficient aspects of construction. Bibliometric and an overview of the technical characteristics of concretes suitable for 3D printing are given in [19]. The importance of experimental methods for determining strength, shrinkage, and thermal conductivity is emphasized. The most common recipes and directions of further development are identified. A generalization of the development of 3D printing technology in Ukraine is given in [20]. The analysis of the literature indicates the presence of separate studies of the composition of mixtures, structural strength, or the economics of 3D printing. At the same time, the task arises in conducting integral studies that would simultaneously cover materials science, thermophysical and energy indicators, as well as their economic efficiency in housing construction, which is the purpose of these studies.

3. The aim and tasks of the work

The aim of the work is to substantiate additive technologies for the construction of energy-efficient buildings with a positive energy balance based on a combination of 3D-printed concrete shells with various types of thermal insulation materials. To achieve this goal, the following tasks are formulated and solved:

- determination and evaluation of the characteristics of the setting time of concrete mixes for 3D printing;
- justification of classification features of buildings with a positive energy balance;
- conducting experimental and theoretical research;
- development of the “Betonix” building project as a building with a positive energy balance.

4. Research results and discussions

4.1. Concretes for 3D printing technology (3DPC)

The main technological characteristics of concrete mixes for 3D printing (3DPC) are: mobility, extrudability, shape stability, interlayer adhesion, setting time, and physical and mechanical characteristics of hardened concrete: compressive strength, tensile strength, interlayer joint strength, minimal shrinkage without cracking, creep, water absorption, frost resistance. 3D-printed additive

concrete has many limitations and factors that can create a weak interlayer bond, often referred to as a "cold bond" due to the lack of mixing between layers. The multi-layered nature of 3D printing causes anisotropy of the mechanical properties of concrete (fig. 1).

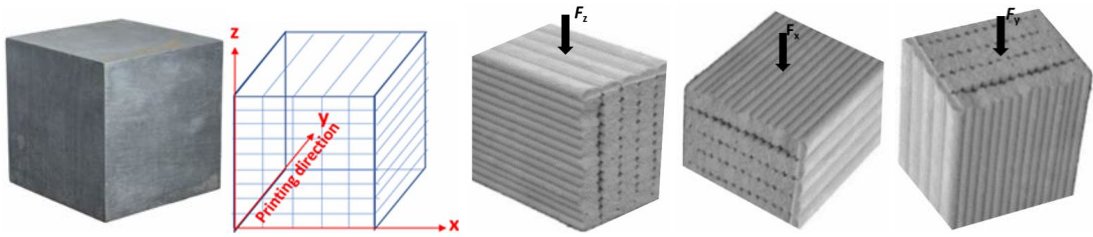


Fig. 1. Scheme of applying forces in determining the compressive strength of concrete, taking into account anisotropy

The strength of the interlayer bond in 3D printing is related to such factors as: material composition, mixing method, surface humidity, application time interval between layers, distance from the nozzle to the structure, printing speed, and other technological factors.

On the basis of our research, using 3D printer in the "Prydniprovskiy Scientific and Educational Institute of Innovative Technologies in Construction" ("PSEIITC") of the Ukrainian State University of Science and technologies (Dnipro) (fig. 2) it is established that the optimal ratio of the height of a single layer of material to the diameter of the printer nozzle is 0.5, and the best parameters of equipment operation are the volume flow rate of the supplied material of 0.1 m³/h and the print speed of 6 cm/s.



Fig. 2. Research 3D printer ("PSEIITC") of the Ukrainian State University of Science and technologies

The distance from the nozzle to the surface of the structure also plays an important role in the strength of the connection of 3D concrete layers. Lower adhesion strength can be obtained with a larger clearance. Studies [21] showed that an increase in the indentation of the printer nozzle (from the upper surface of the formed layer) from 0 mm to 2 mm and 4 mm led to a decrease in the adhesion strength, respectively, by 23% and 35%.

To ensure a continuous printing process, it is necessary that the material has the appropriate curing time indicators. The value of the beginning of setting should be selected in such a way that when printing the next layer, a bond is formed between them. However, immediately after that, a set of strength is needed to avoid deformations from the load of the upper layers. Based on the conducted studies, it was found that for 3DPC mix at a temperature of 20-22 °C, the optimal setting time is as follows: the beginning - no earlier than 20 minutes, the end - no later than 180 minutes.

However, there are other variants of setting terms for concrete mixes used in 3D printing: 15-80 minutes-the beginning of curing of the cement - based mixture; 30-100 minutes - the end of curing of the same mixture [22].

The purpose of our work was to determine the formulation of mixtures based on Portland cement suitable for 3DPC according to the criterion of the start and end time of curing solutions with different amounts of accelerator. The research results are shown in Table 1 and in Fig. 3.

Table 1

Mix components for 3DPC

Components of mixtures in WT H., %	No of the mixture composition			
	1	2	3	4
liquid glass	0	5,9	11,9	18,9
portland cement G400	78,4	73,9	68,6	62,4
water	21,6	20,2	19,5	18,7

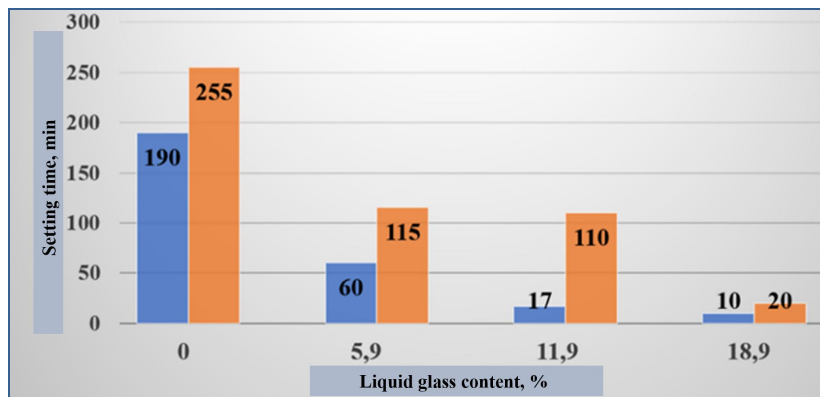


Fig. 3. Terms of setting mixtures for 3DPC

According to the criteria given in [22], only mixture No. 3 with a liquid glass consumption of 11.9% by weight in the concrete mix is suitable for 3DPC.

4.2. Development of the “Betonix” house project as a building with a positive energy balance

The use of 3D printing technology in the formation of new or superstructure elements during the reconstruction of buildings that perform the functions of thermal insulation and solar energy storage is particularly relevant. The technology allows to integrate energy - efficient engineering systems already at the stage of forming enclosing structures, and thanks to parametric modeling-to adapt the architecture to a specific orientation relative to the cardinal directions, insolation and providing microclimate parameters. An important factor is the digitalization of design processes - the use of building information modeling (BIM) technologies, which allows to control energy consumption parameters, analyze the life cycle of structures, optimize logistics and automate the stages of construction and installation work. This allows you to implement the principles of modularity, reuse and scalability in energy-efficient housing projects.

4.2.1. Digital parametric modeling

At this stage, a comprehensive design of the object was performed (fig. 4) using parametric tools of the following software:

- Autodesk Revit-basic modeling of building geometry, import drawings and BIM structure.
- Rhinoceros 3D + Grasshopper-generative design of the shell, ventilation ducts, and contour of thermal floors.
- Ladybug + Honeybee (Grasshopper) - analysis of sun exposure, orientation, and daylight.
- Open Studio + Energy Plus-complete power model of the building: calculation of heat loss, energy consumption, internal loads.

The simulation was performed using the following parameters:

- Climate base-weather data of the Kiev region (ASHRAE IWEC2).
- Temperature scenarios-internal: 21°C, external: -23°C to + 35°C.
- Assessment of annual energy consumption for heating, cooling, ventilation, heating of hot water, electricity for household needs (lighting, electrical appliances).
- Assessment of the coverage of needs due to the heat pump and solar panels.

The energy balance of the building was calculated using the formula:

$$Q_{us} = Q_{heat} + Q_{co} + Q_{vt} + Q_{hw} + Q_{dr} - Q_{gen}, \quad (1)$$

where Q_{us} -energy consumption; Q_{gen} – energy generation from renewable energy sources; Q_{heat} – energy consumption for heating; Q_{co} – energy consumption for air conditioning (cooling); Q_{vt} – energy consumption for ventilation; Q_{hw} - energy consumption for hot water preparation; Q_{dr} -electricity consumption for household needs (lighting, electrical appliances).

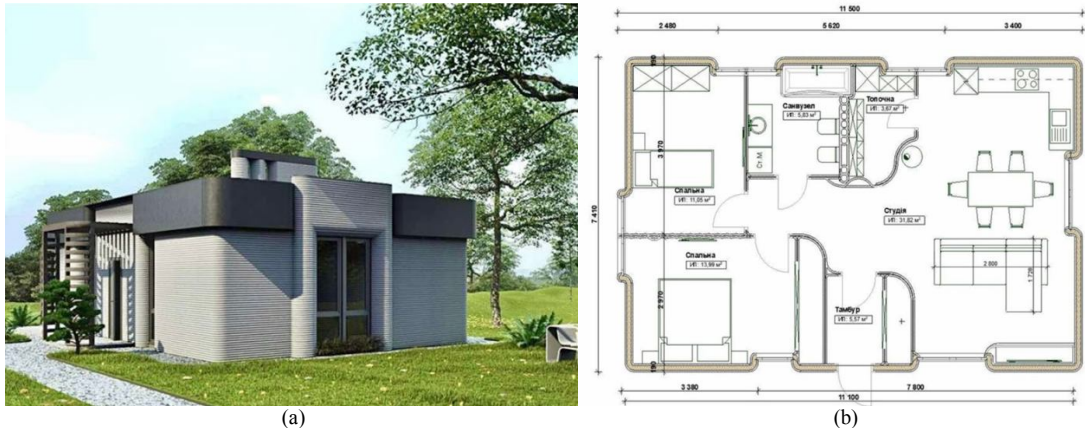


Fig. 4. "Betonix" house: (a) -visualization of the house project, (b) -planning solution

The features of the Betonix house project include the following architectural, planning and design solutions (fig. 4). The modular house has an interior with unique printed elements, which makes it possible to implement original architectural solutions and comfortable living due to the rational layout of the premises. The presence of a capsule room ensures security in the face of a military threat. During construction, a specially developed sand - cement mixture for 3D printing from Henkel is used, which provides a guarantee of the durability of housing.

4.3. Justification of the choice of classification features of buildings with a positive energy balance

In Europe, the following classification of buildings by energy efficiency has been adopted [23]:

Passive House is an energy-efficient building standard that creates comfortable living conditions, is both economical and has minimal negative impact on the environment.

A zero-energy building is a building with high energy efficiency, capable of producing energy from renewable sources on-site and consuming it in equal quantities throughout the year. When generating less energy than is necessary for consumption, the building is called a near zero-energy building (nZEB). This concept of building has become widely known in European countries [24]. Homes with zero energy consumption do not use fossil fuels and get all the energy they need from renewable sources.

In practice, the term "zero energy House" can have different meanings.

Buildings with zero net energy consumption from the grid (zero net energy buildings), which supply the same amount of energy to the grid during the year that they receive from these grid.

Zero carbon buildings that do not use energy that leads to CO₂ emissions, or that compensate for the energy used by fossil fuels during the year by producing enough energy in their own production without CO₂ emissions.

Free-standing buildings with zero stand-alone buildings that do not require connection to any grid other than backup ones. Such buildings can store energy for use at night or in winter.

Houses with a positive energy balance or active houses (energy plus house, energy+) that supply more energy to the power supply systems than they use. These buildings produce more energy per year than they consume.

According to the requirements of the regulatory documents of the European Union regarding the energy indicators of residential buildings [25-29], the specific consumption of final energy for all needs (heating, cooling, hot water, electricity, ventilation) should not exceed 60 kWh/m² per year.

Justification of the classification features of buildings of the Energy+ standard with a positive energy balance is carried out on the basis of the difference between the volumes of energy produced

and used in increments of 10 kWh/m² per year. Let's apply the Energy + building classification formula as follows:

$$E_n = S - C, \tag{2}$$

where E_n - the difference between generated and consumed energy, which determines the category of the House Energy+; S - generated energy for the year (kWh/m²); C - consumed energy for the year (kWh/m²).

The energy category of the building Energy + is indicated by the symbol E_n , and the positive energy balance is indicated by the number: 10, 20, ..., etc. (Table 2).

Table 2

Categories of houses Energy+

House category Energy+	Energy per year, kWh / m ²		
	consumed	generated	balance
En0*	C	C + 0	0
En10	C	C + 10	10
En20	C	C + 20	20
...
EnA	C	C + A	A
...
En50	C	C + 50	50
En60	C	C + 60	60

* Zero-energy building

In the research, the projected house has an area of 72 m². The annual energy demand is taking into account the requirements of EU regulatory documents: 60×72 = 4320 kWh. To cover annual energy consumption, we use SPR-MAX6-450-COM solar panels with a power of 450 W, 24 V voltage with dimensions of 1039×2047 mm. Calculations of the generated energy using an online calculator [30] for different numbers of received solar panels are shown in Table 3.

Table 3

Annual energy generation, kWh, by house category

House category Energy+	Annual		Per day average annual rate	Panels	
	required	calculated		quantity, PCs	area, m ²
En0*	4320	4553	12,48	9	19,60
En10	5040	5059	13,84	10	21,78
En20	5760	6071	16,64	12	26,14
...
En50	7920	8094	22,19	16	34,85
En60	8640	9106	24,96	18	39,20

In Fig. 5 shows data on energy generation for the En50 building, which indicate that in November, December and January, energy generation is not sufficient to cover the required average daily 11.64 kWh with a specific consumption of 60 kWh/m² per year. According to the Net Billing mechanism [31 - 33], a rational building will be En0, houses of the Energy+ category are effective for the owner according to the "green tariff" mechanism.

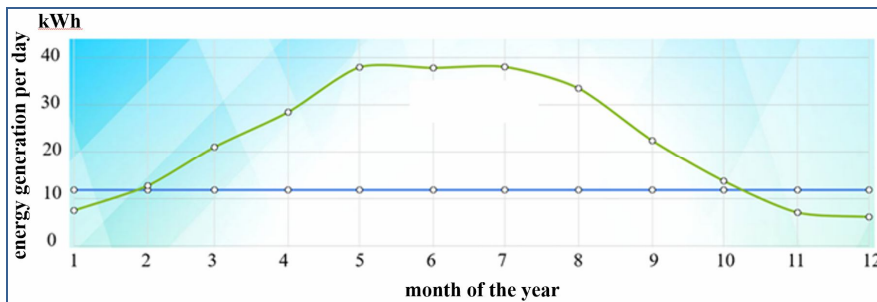


Fig. 5. Daily energy generation for building En50

4.4. Experimental studies

4.4.1. Sample formation and testing

At the first stage of experimental studies in the laboratory, a series of fragments of wall panels with a size of 1000×1000 mm was made by 3D printing. The House provides for the installation of insulation inside the printed walls, which does not require interior and exterior decoration (fig. 6).



Fig. 6. 3D printing wall elements: (a) - with insulation, (b) - wall fragment

The following sample design was determined:

- the outer layer is a 3D-printed concrete shell (40 mm thick) created using a mixture based on Portland Cement with thixotropy modifiers (Henkel plasticizers);

- internal thermal insulation layer - replaceable: XPS (eXtruded PoliStyrene), EPS (Expanded PolyStyrene), polyurethane foam (PF), eco-wool, mineral wool (thickness 150; 170; 200 mm). Test samples were examined and parameters were determined using the following methods:

1. Thermal conductivity-according to the hot box method EN ISO 8990.
2. Heat loss visualization-infrared thermography (Fluke Ti32).
3. Mechanical characteristics of concrete - according to EN 1991-1-1.
4. Fire safety-ASTM E84.
5. Sound insulation - ASTM C423.
6. Vapor permeability-EN ISO 12572.
7. The thermal resistance of the wall was determined by the formula:

$$R = \sum d_i / \lambda_i, \quad (3)$$

where R - is the thermal resistance, $m^2 \cdot K/W$; d_i - is the thickness of the i -layer, m; λ_i - is the coefficient of thermal conductivity of the i -layer material, $W/m \cdot K$.

The results of studies of various heat-insulating materials that can be used in the project are shown in Table 4.

Table 4

Results of the thermal resistance determining

Variant	Material	Coefficient of thermal conductivity λ , W/m ² ·K	Insulation thickness d , m	The thermal resistance R , m ² ·K/W
1	PF	0.023	0.15	6.52
2	PF	same	0.17	7.39
3	PF	«	0.2	8.7
4	Eco-wool	0.039	0.15	3.85
5	Eco-wool	same	0.17	4.36
6	Eco-wool	«	0.2	5.13
7	Mineral wool	0.037	0.15	4.05
8	Mineral wool	same	0.17	4.59
9	Mineral wool	«	0.2	5.41
10	XPS	0.031	0.15	4.84
11	XPS	same	0.17	5.48
12	XPS	«	0.2	6.45

To ensure the energy efficiency indicators of buildings "Zero-energy" and "Energy+", the thermal resistance of enclosing structures R must be at least: wall fences – 7, coatings – 10, windows - 1, $\text{m}^2\cdot\text{K}/\text{W}$. These conditions are met by wall fences in variant 2 and 3.

4.4.2. Implementation of part of the project on the construction site.

The project provides for the construction of the foundation for a real residential building "Betonix" with the implementation of engineering heating, water supply and sewerage systems:

- reinforced concrete pile field with grillage and anti-radon protection;
- thermal insulation layer made of XPS;
- integrated inertial low-temperature heating systems (under floor heating);
- embedded communications according to the project for future 3D printing of walls.

The production of the foundation, which acts as a heat accumulator in a system with a heat pump, was carried out taking into account the parameters of future 3D printing in the following sequence (fig. 7):

1. Preparation of a pile reinforced concrete field with grillage, a sand base with channels for engineering pipes.
2. Pipeline installation (PVC Ø50-160 mm).
3. Laying of XPS boards (50 mm)
4. Under floor heating system (PEX Ø20 mm, pitch 150 mm)
5. Metal mesh reinforcement
6. Concreting the foundation plate.

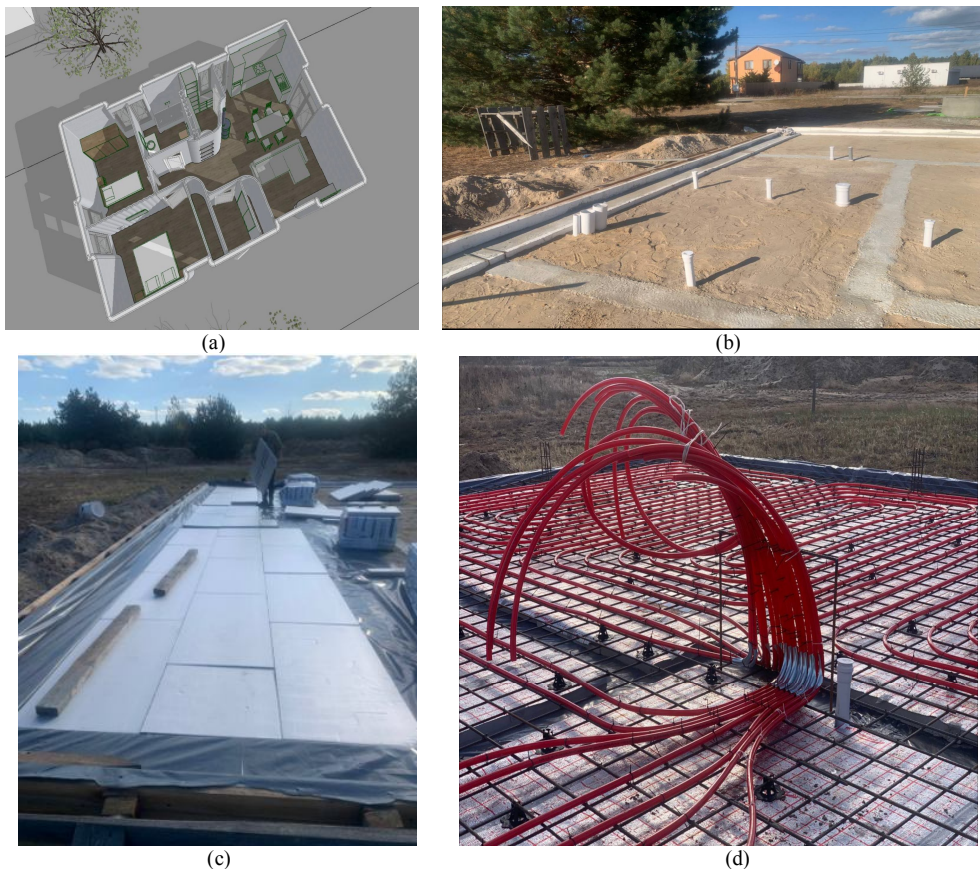


Fig. 7. (a) visualization of the interior of the house; (b) – grillage of the completed foundation; (c) – floor insulation; (d) – engineering communications.

4.5. Technical and economic comparison: 3D printing and traditional construction.

Technical and economic indicators of construction using 3D printing technology and traditional technology were studied. The research results are shown in Table 5, Table 6.

Table 5

Technical indicators

Parameter	3D Printing	Traditional Construction
Construction Speed	3 - 5x faster(e.g., a house in 24 hrs)	Slower (weeks to months)
Labor Requirements	70–80% fewer workers (automated)	High labor dependency
Design Flexibility	Complex geometries(organic shapes)	Limited by formwork & manual labor
Material Waste	30–60% less waste(additive process)	High waste (formwork, offcuts)
Structural Strength	Anisotropic (weaker interlayers)	Isotropic (uniform strength)
Layer Height/Resolution	5–30 mm layers(visible striations)	Smooth finishes (plaster, troweling)
Max. Building Height	Currently 1–2 stories(research ongoing)	Unlimited(skyscrapers possible)
Reinforcement Integration	Challenging (requires hybrid methods)	Easy (rebar cages, pre-tensioning)

Table 6

Economic indicators

Parameter	3D Printing	Traditional Construction
Upfront Costs	High(\$200K–\$1.5M for printers)	Low (no specialized equipment)
Labor Costs	50–70% lower	High (30–50% of total cost)
Material Costs	Comparable(cement, but less waste)	Higher due to formwork & overordering
Transport/Logistics	On-site printing reduces transport	High (prefab elements, bulk materials)
Project Scalability	Best for small/medium projects	Suitable for all scales
Maintenance Costs	Low(automated systems)	High (labor-intensive repairs)
ROI Timeline	5–10 years(for printer investment)	Immediate (no capital expenditure)

The data presented in Table 5, Table 6 show that in terms of technical and economic indicators, the technology of 3D printing of construction objects has advantages over traditional technology.

Conclusions

1. One of modern innovative technologies in construction is 3D printing technology. Energy-efficient houses formed using this technology are able to achieve a positive energy balance, have high technical and economic indicators and can be scaled during the post-war restoration of the country's housing stock.

2. 3D-printed additive concrete is affected by many factors that sometimes create a weak interlayer bond. The multi-layered nature of 3D printing causes anisotropy of the mechanical properties of concrete. The strength of interlayer bonding in 3D printing is related to technological factors. Based on the research, it was found that the optimal ratio of the height of a single layer of material to the diameter of the printer nozzle is 0.5, and the best parameters of equipment operation are: the volume flow rate of the supplied material is 0.1 m³/h, the print speed is 6 cm/s. Increasing the indentation of the extruder nozzle (from the upper surface of the formed layer) from 0 mm to 2 mm and 4 mm leads to a decrease in the adhesion strength, respectively, by 23% and 35%.

3. Based on the results of the conducted studies, the formulation of a mixture based on Portland Cement was determined, which is suitable for 3DPC according to the criterion of the start and end time of solution setting. The optimal mixture is a mixture containing 11.9% liquid glass by weight, as a setting accelerator. In this case, the setting time of the mixture is as follows: initial – 17 minutes, final – 110 min.

4. The proposed classification of Energy+ buildings. The parameters of solar panels for a house with an area of 72 m² in the conditions of Kiev are determined as renewable energy sources that provide various categories of buildings of the Energy+ standard.

5. Additive technologies make it possible to form highly efficient wall structures with integrated thermal insulation. The optimal combination for creating Energy+ standard buildings is a 3D-printed concrete wall structure combined with PF layer thickness of at least 17 cm.

6. Technical and economic indicators of construction using 3D printing technology and traditional technology show that the technology of 3D printing of construction objects has advantages over traditional technology.

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Стаття надійшла 15.12.2025

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ЗАСТОСУВАННЯ АДИТИВНИХ ТЕХНОЛОГІЙ У БУДІВНИЦТВІ ЕНЕРГОЕФЕКТИВНИХ БУДІВЕЛЬ ІЗ ПОЗИТИВНИМ ЕНЕРГЕТИЧНИМ БАЛАНСОМ

Стаття присвячена використанню адитивних технологій, зокрема 3D-друку з бетонних сумішей, для формування енергоефективних конструкцій житлових будівель із позитивним енергетичним балансом. Обґрунтовано переваги поєднання 3D-друкованих оболонок із високоефективними теплоізоляційними матеріалами (PU, ековата, мінеральна вата, EPS) у контексті зниження тепловтрат, підвищення енергоефективності та швидкості будівництва. Описано трирівневу методологію дослідження — лабораторні випробування, цифрове моделювання (Revit, Rhinoceros, Grasshopper, EnergyPlus) та реалізацію на реальному будівельному майданчику з урахуванням параметрів майбутнього друку. У роботі розглянуто сучасні підходи до застосування технологій будівельного 3D-друку як одного з перспективних напрямів післявоєнного відновлення житлового фонду України. Показано, що використання адитивних технологій дозволяє значно скоротити терміни будівництва, зменшити витрати матеріалів, підвищити рівень автоматизації будівельних процесів та забезпечити гнучкість архітектурно-планувальних рішень. Особливу увагу приділено питанням забезпечення енергоефективності будівель шляхом інтеграції теплоізоляційних матеріалів у структуру 3D-друкованих стінових елементів, а також поєднанню конструктивних систем із відновлюваними джерелами енергії. Представлено результати досліджень оптимальних технологічних параметрів 3D-друку, термінів тужавиння бетонних сумішей для 3DPC, теплоізоляційних характеристик стінових елементів, моделювання генерації електричної енергії сонячних електростанцій з різною кількістю сонячних панелей, техніко-економічної ефективності технології 3D-друку у порівнянні з традиційною технологією. Встановлено оптимальні параметри процесу друку, зокрема співвідношення висоти шару до діаметра сопла принтера, швидкість друку та характеристики міжшарової адгезії. Наведено результати експериментальних досліджень теплоізоляційних властивостей різних видів утеплювачів та визначено найбільш ефективні конструктивні рішення для будівель стандарту Energy+.

Ключові слова: адитивні технології, 3D-друк, цифрове моделювання, енергоефективність, енергетичний баланс, будинок Energy+, будинок Betonix.

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APPLICATION OF ADDITIVE TECHNOLOGIES IN THE CONSTRUCTION OF ENERGY-EFFICIENT BUILDINGS WITH A POSITIVE ENERGY BALANCE

The article is dedicated to the development of additive technologies, using 3D frames from concrete bags, for the formation of energy-efficient housing structures with a positive energy balance. The advantages of lining 3D-laminated shells with highly efficient thermal insulation materials (PU, ecowool, mineral wool, EPS) in the context of reduced heat loss, increased energy efficiency and fluidity wakefulness. A three-tier research methodology is described - laboratory testing, digital modeling (Revit, Rhinoceros, Grasshopper, Energy Plus) and implementation on a real everyday life with the parameters of the future. The robot examines current approaches to the development of modern 3D technology as one of the promising directions for the post-war renovation of the housing stock of Ukraine. It has been shown that the use of additive technologies makes it possible to significantly speed up the work cycle, reduce the wastage of materials, increase the level of automation of everyday processes and ensure flexibility architectural and planning solutions. Particular attention is paid to ensuring energy efficiency through the integration of thermal insulation materials into the structure of 3D-laminated wall elements, as well as the integration of structural systems from renewed energy sources. The results of the study of the optimal technological parameters of 3D frames, the terms of pressing concrete mixes for 3DPC, the thermal insulation characteristics of wall elements, the modeling of the generation of electrical energy from solar panels are presented. Power station with a varied number of solar panels, technical and economic efficiency of 3D technology compared to traditional technology. Optimal parameters for the hand process have been established, ranging from the relationship between the height of the ball and the diameter of the printer nozzle, the fluidity of the hand and the characteristics of inter-ball adhesion. The results of experimental studies of thermal insulation authorities of various types of insulation materials were compiled and the most effective design solutions were identified to meet the Energy+

Keywords: additive technologies, 3D printing, digital modeling, energy efficiency, energy balance, energy+ house, betonix house.

УДК69.05:004.94:620.

Назаренко І.І., Перегінєць І.І., Савицький М.В., Берник І.М., Савицький О.М. Застосування адитивних технологій у будівництві енергоефективних будівель із позитивним енергетичним балансом // Опір матеріалів і теорія споруд: наук.-техн. збірник. – К.: КНУБА, 2026. – Вип. 116. – С. 181 – 192. Табл. 6. Іл. 7. Бібліогр. 33 назв.

UDC 69.05:004.94:620.9

Nazarenko I.I., Pereginets I.I., Savytskyi M.V., Bernik I.M., Savytskyi O.M. Application of additive technologies in the construction of energy-efficient buildings with a positive energy balance // Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. – К.: KNUBA, 2026. – Issue 116. – P. 181 – 192. Tabl. 6. Fig. 7. Ref. 33.

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