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INNOVATIVENESS IN THE CONSTRUCTION SECTOR OF THE GERMAN ECONOMY

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ABSTRACT

The article considers the role of innovation in construction. The results of a survey of representatives of the construction industry on innovative investments are presented. Theoretical aspects of digitalisation in the construction process are studied, and the passive house concepts are considered. The impact of innovation on the construction sector is analysed, as are the indicators determining the level of innovativeness of construction.

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INTRODUCTION.

In recent years, Germany has been one of the leading countries in terms of introducing innovations in architecture related to sustainability and improving the quality of urban life. Increasing the level of innovation in the construction sector of the economy has economic and social effects. Innovations contribute to improving the qualifications and competitiveness of construction firms and bring them to the same level as the most well-known construction corporations. Innovations in construction production stimulate increased efficiency not by introducing new technologies and equipment but by improving the quality of planning and organisation of construction production and management decision-making. The introduction of innovations provides an opportunity for developing the most effective solution to the complex financial, scientific and technical, design, production, organisational and management tasks in the implementation of investment and construction projects.Innovations in construction include reducing costs and construction time and improving the quality of construction [5].

In this work, the basic principles of the innovation process in construction are considered. The tasks facing construction companies in the field of innovation development are studied and analysed. The first section examines the issues of digitalisation in construction, aimed at increasing efficiency. Statistics evaluating companies' investments in innovation are presented. The section also presents a survey of more than 3000 industry experts in 15 countries on their willingness to invest in new technologies.

The second section studies the issues associated with innovative building materials, through which it is possible to reduce production costs, increase productivity and competitiveness, and, consequently, obtain sufficient profit for further development of the enterprise. We analyse a rapidly developing trend in Europe, including Germany: the concept of the 'passive house' (Passivhaus). On the basis of the analyses, we propose the use of appropriate innovative technologies in passive house construction.

The third section considers the indicators that determine the level of innovation in construction. Innovations in construction should be aimed primarily at reducing costs, improving quality and reducing construction time. Four main indicators of the level of innovativeness of construction are proposed.

In conclusion, according to the research presented in this article, 3 main points are presented, which, in our opinion, should be accounted for in the innovation process and will help ensure the international competitiveness of construction companies in Germany and increase social sustainability by expanding economic power.

INNOVATION AND DIGITISATION.

The innovation performance of the European Union is generally very positive. According to the European Innovation Scoreboard, it has grown by 12.5 percent, on average, across the EU since 2014, with a 13.7 percent increase between 2016 and 2023. At a global level, the EU has a productivity advantage over China, Brazil, Russia, South Africa and India and a productivity gap over South Korea, Canada, Australia, the US and Japan. In 2021, Germany was ranked sixth in the pan-European comparison after the innovative Nordic countries of Sweden, Finland and Denmark, as well as the Netherlands and Belgium [3].

The European Innovation Scoreboard provides a comparative assessment of research and innovation performance in EU Member States, other European countries and global competitors from 2017 to 2023 [5]. The bar chart presents and compares the innovation performance of EU Member States and neighbouring countries.

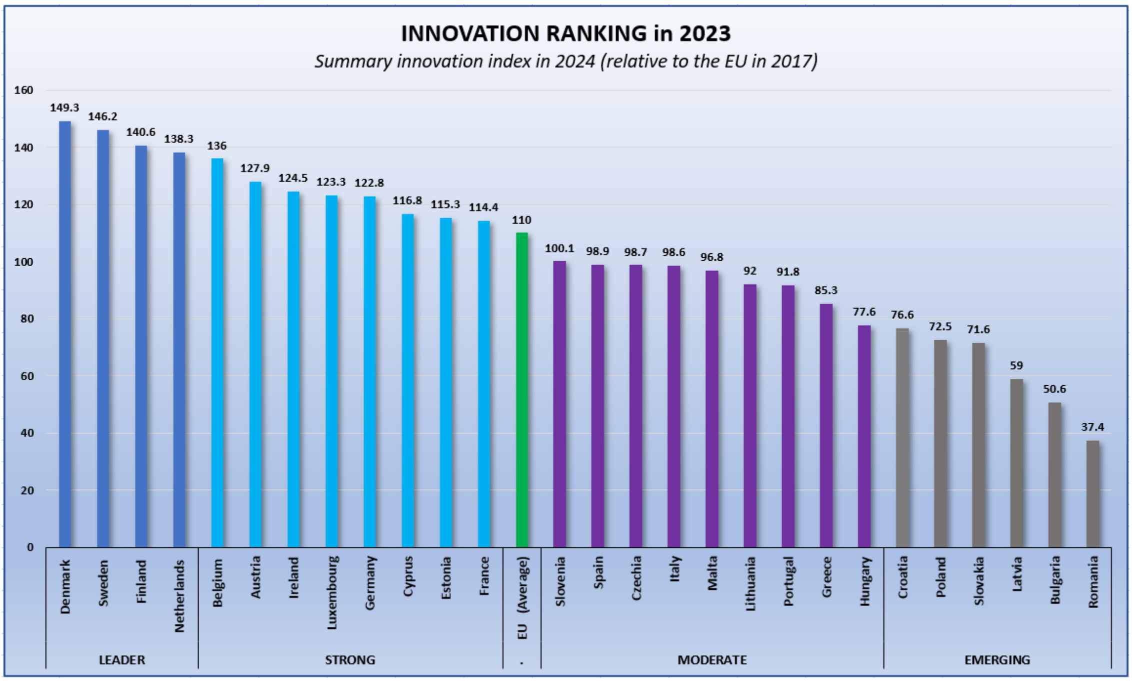

Figure 1. Innovation index [5].

As shown in the chart, Germany ranks 9th among EU countries in terms of innovation, with an index score of 122.8. Moreover, it should be noted that in 2023, construction investment in Germany totalled approximately 487 billion euros. Construction investments include new and value-adding construction work in buildings and other structures (roads, airfields, canals); facilities permanently connected to buildings, such as lifts, heating, air conditioning and garden systems; and services related to the production and acquisition of building construction (services of architects, notaries, brokers). Investors' own contributions and unannounced work on the construction of buildings are also considered investments in construction. In addition, there are land transfer costs associated with undeveloped land [12].

Planning, architecture and building technology, as well as the construction and housing industry, have a significant impact on our society by creating and shaping living spaces. In this respect, they have not only economic but also sociopolitical importance. The Future Construction innovation programme of the Federal Ministry of Housing, Urban Development and Building (BMWSB) provides an important impetus to the construction industry through the programme parts ‘Funding for Future Construction Research’, ‘Future Research of Building Departments’ and ‘Future Model Construction Projects’.

The innovative Future Construction programme is implemented on behalf of the Federal Ministry of Construction by the Federal Institute for Building, Urban and Spatial Research (BBSR) at the Federal Office of Building and Regional Planning (BBR). The Federal Ministry of Construction and BBSR actively support the following:

- ✓ Climate protection
- ✓ Energy and resource efficiency
- ✓ Affordable construction
- ✓ Design quality in the context of (urban) development

The focus here is on knowledge enhancement and knowledge transfer in the fields of technical, construction and organisational innovation. The aim of all the measures is to contribute to the sustainable development of the construction sector as a whole.

Future Construction also supports information and motivation for the target and specialised groups required by the construction policy to actively participate in the transformation of the construction sector towards climate neutrality. One of the leading innovations in construction is digitalisation. For example, the state government of North Rhine-Westphalia aims to promote digitalisation in a targeted manner and play a responsible role in shaping it. To this end, the state government promotes, in accordance with *the principles of the funding programme based on sections 23 and 44 of the State Budget Code (LHO) and the relevant administrative regulations (VV/VVG)*, the development and use of innovative construction technologies and processes, including by research institutes and construction actors, such as the construction industry, municipalities, project developers and builders [10]. Public funding programmes, the use of new methodologies, such as building information modelling (BIM), and the digitalisation of administrative processes are three important drivers of innovation and development [9].

The use of new technologies at construction sites offers many advantages. Digitalisation fundamentally concerns increasing efficiency. This can be done in numerous ways. As a practical example, even if the utmost care is taken, construction defects cannot be avoided in most construction projects because there is much room for error when information is written down with pen and paper or communicated by phone and email. The consequences are increased time and costs. Digitalisation makes these processes faster, safer and more transparent.

Digitalisation in construction is gaining momentum, as confirmed by PlanRadar's study on digitalisation in the construction and real estate sector [11]. The chart below (Figure 2) shows how the 3,000 construction industry representatives surveyed evaluated their companies' investments over the past three years. The most important facts are as follows:

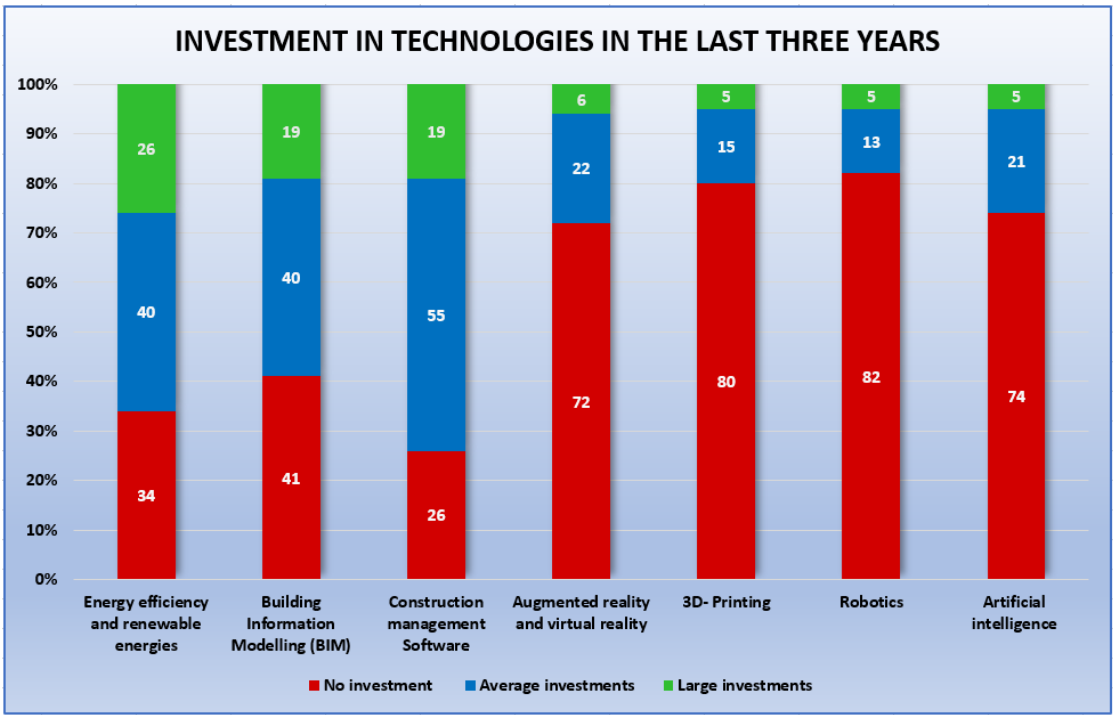

Figure 2. Investment in technologies in the last three years.

The areas of **energy efficiency and renewable energy** (26%), **BIM and construction management software** (19% each) accounted for the largest share of large investments. These three areas were also the most represented in terms of average investment volume [8].

In contrast, **augmented reality and virtual reality** (6%) and **3D print, robotics and artificial intelligence** (5% each) recorded relatively low shares of large- and medium-sized investments over the past three years [8].

However, available resources are not the only deciding factor regarding the digitalisation of the construction industry. According to a PlanRadar survey of 3,000 interviewees in 15 countries, the introduction of new technologies poses challenges for companies. Below is a chart of those interviewed. [11]

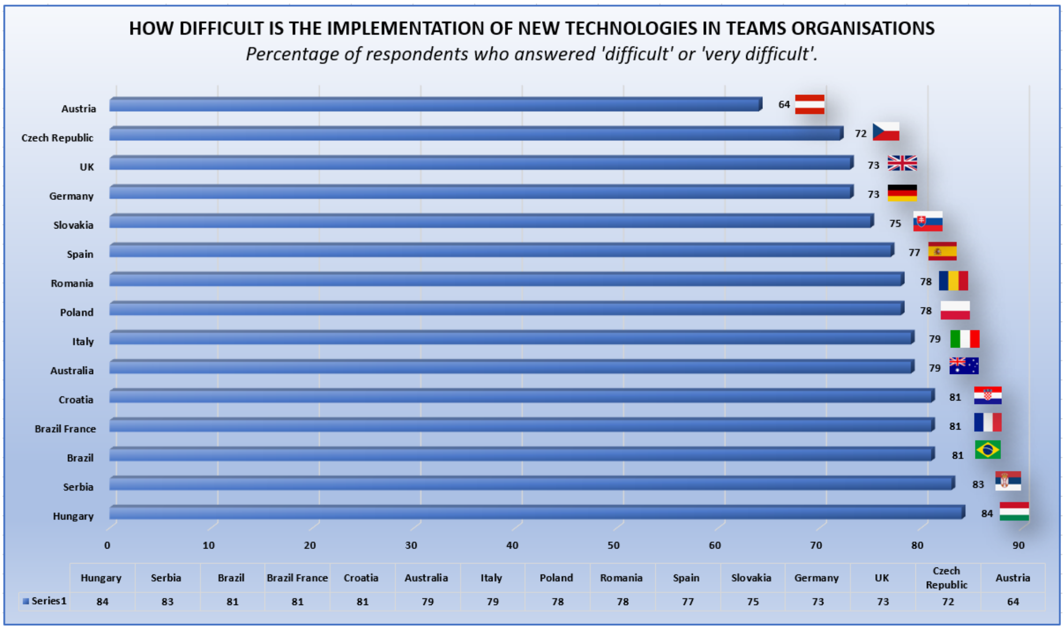

Figure 3. Innovation index [5].

Certainly, a company that does not invest in new technologies jeopardises its competitiveness in the medium term.

The use of new technologies is also a matter of competitiveness. Innovation in construction transforms the construction site, increases profits and helps win design tenders. Innovations that bring economic benefits and increase the competitiveness of a particular construction company ultimately also realise the wishes of customers with maximum efficiency. Therefore, new construction technologies are actively promoted and utilised worldwide.

INNOVATIVE CONSTRUCTION MATERIALS AND TECHNOLOGIES.

The primary task of developing complex building material production is the modernisation of industrial capacities. Owing to the use of progressive production capacities on the basis of innovative technologies, it is possible to reduce production costs, increase productivity in the production of materials and structures, increase competitiveness, and, consequently, obtain sufficient profit for further development of the enterprise.

The increasing volume of construction necessitates the transition to highly efficient formwork systems to improve the quality, speed and reliability of erection of buildings and structures. High-quality heat-insulating materials, such as gas-foam concrete and rockwool, reduce heat losses in residential buildings and make structures more energy efficient. The wide application of such technologies increases the profitability of construction organisations.

For example, Germany's first 3D printing of a 2-story house concrete apartment block in Beckum in 2021 revealed where the road to innovation can go. The wall rope robot presented in 2021, which the Department of Mechatronics and the Institute for Building Operations and Construction Management at the University of Duisburg-Essen developed together with the Weimar Institute for Applied Building Research and the Kalk-Sand Research Association, also fits into the innovation process. The wall rope robot is able to build walls fully automatically from commercially available sand-lime bricks, move stones in different formats, retract lintels and automatically apply mortar. The innovative projects were funded under the funding program 'Digitalisation of the construction industry and innovative construction' [9].

Currently, special attention is given to increasing the energy efficiency of buildings. The requirements for applied thermal insulation materials are constantly increasing, and the norms of heat permeability and related parameters of individual building structures as a whole are becoming stricter. The thermal insulation of buildings and structures has several practical goals: increasing the level of comfort, heat and sound insulation; saving fuel resources; and reducing operating costs. However, the strategy of building energy efficiency includes not only the insulation of structures with the help of heat-insulating materials but also special engineering solutions for ventilation and heat supply systems.

One rapidly developing trend is the passive house (Passivhaus) concept, in which heating is provided using the heat released by people, household appliances and alternative energy sources and is reduced via the use of supply and exhaust ventilation, with recuperators and the use of natural energy sources, such as the sun, for heating and hot water. Passive houses are not only comfortable and convenient but also made of environmentally friendly raw materials [11]. The essence is to achieve maximum energy efficiency with minimum investment. The experience of European construction shows that, under certain conditions, passive houses can become the future of residential architecture because they combine the characteristics of economy and environmental friendliness.

The passive house refers to not only an energy-efficient house but also an entire building standard that uses passive energy-saving methods. In Europe, heat and electricity prices are rising every year, and people are looking for alternative, better ways of supplying their homes with energy. It is important to achieve not only savings but also maximum comfort at any time of year. Passive houses are designed to cope with these tasks.

Historically, energy-efficient buildings existed long before the passive house standard was invented. Passive houses originated from northern cultures, such as that of Siberian people. They built their dwellings in such a way that the rooms would consume a minimum amount of energy resources and at the same time effectively retain heat for a long time. Owing to their round shape and the materials used for panelling, dwellings such as the chum and yurt allowed people to live comfortably even in harsh climatic conditions.

In the modern period, the idea of an energy-efficient house was first proposed in 1988 by German researcher Wolfgang Feist. In 1996, the Passivhaus Institute (Passivhaus Institut Darmstadt) was established in Darmstadt, Germany. The Institute's specialists have developed a frame technology for the construction of passive houses from the products of recycling construction and inorganic waste, such as concrete, glass and metal. In Germany, there are special plants that process such waste into building materials for passive houses. Germany is currently a leader in the design of energy-efficient buildings. More than 6,000 such houses have been built in Germany as part of a special state programme.

The aim of the passive house standard is to eliminate the use of active heating almost completely or, in areas with a favourable climate, completely. In this case, where does the heat inside a passive house come from? Ideally, such a house should be an independent energy system that requires absolutely no expenditure to maintain a comfortable temperature regime. The heat generated by people living in the house and household appliances is used to heat living spaces, and the cooling mechanism is designed according to the peculiarities of the building structure and the properties of the building materials

The principle of passive dwelling provides an effective scheme of heat preservation by enclosing structures such as walls, floors, ceilings, and foundations. The heat transfer coefficient of such structures in standard houses is quite high. Because of this, houses give off much heat to the outside, and more time and energy is necessary to fully heat a room. In a passive house, this problem is solved by external thermal insulation. Internal thermal insulation is undesirable because it prevents thermal inertia, or the even spreading of heat throughout a room. The final heat loss of a passive house is, on average, 20 times lower than that of standard buildings.

Let us take a closer look at what a ‘passive house’ consists of. The main criteria for building a ‘passive house’ are shown in Fig. 4.

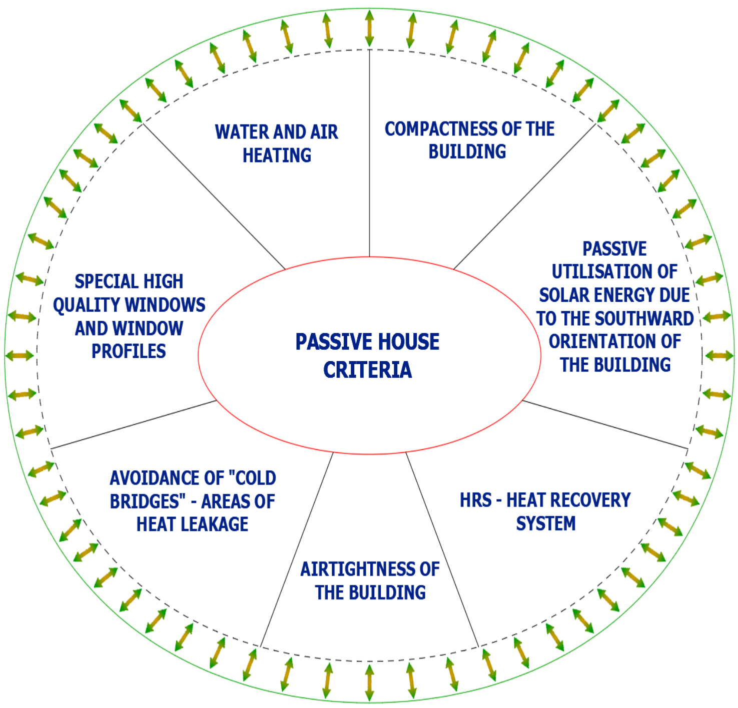

Figure 4. “passive house” criteria.

In addition to the thermal insulation of surfaces, windows play an important role in preserving and maintaining the temperature in a passive house. To compensate for heat loss in the form of infrared radiation to the outside through the windows, such houses have special window panes filled with inert gases, which allows them to save energy. Shutters, curtains and blinds also help retain heat at a very basic level.

An important consideration is the orientation of windows to the outside world. According to the practice of building energy-efficient houses, the southern orientation is optimal for both winter and summer. East and west orientations are recognised as unfavourable. On the northern side, the window area is usually small and sufficient only for lighting. Solar collectors can be installed on southern facades and roofs without shading. The integrated collector reduces the heat loss of the facade and roof while allowing solar energy to be utilised for domestic use.

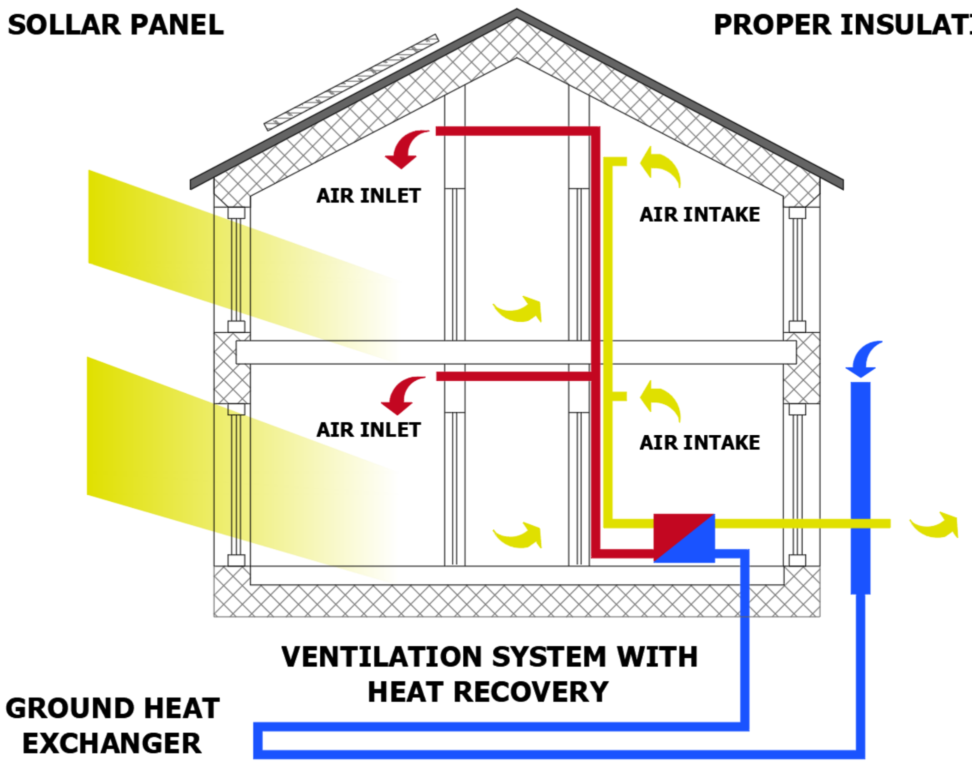

Figure 5. Schematic diagram of passive house operation.

On the basis of the analyses of leakage and heat sources and the passive house criteria, we propose the use of the following innovative technologies in construction:

1) The use of solar collectors, which serve to heat water throughout the year.
2) The use of special timers and sensors, such as motion sensors.
3) The use of solar panels as alternative sources of electricity for lighting and heating the house.
4) Obligatory check of all wooden elements for dryness: if the wood has a high degree of humidity, then when drying, it can form cracks, and all the work on thermal insulation will be wasted. In addition, the roof must be perfectly insulated and airtight (with insulation thickness of at least 30 cm).
5) The use of supply and exhaust ventilation with heat recovery via a ground heat exchanger, which is preheated by the accumulated air in the ground. Fig. 6 shows a diagram of supply and exhaust ventilation.
6) There should be more windows on the southern façade than on any other façade of the house. It is not recommended to install windows of very large area because they can be the cause of increased losses of heat or cold, and in the summer, they may necessitate the cooling of the premises. The installation of windows is a very important component, and the occurrence of cold bridges should be completely excluded. The profile must necessarily have and provide:

- High thermal resistance;
- Tightness of the joint with the structural elements of the building.

7) Doors in the house must meet the following requirements: sound and heat insulation, watertightness, safety, and maximum tightness.

8) Use of frame walls with waterproofing film, a vapour barrier membrane, linen mats, ecowool and exterior parts made of cellular concrete.
9) Increasing the thermal resistance of the foundation through the use of airtight sheathing, additional thermal insulation, and the use of thermal liners made of construction materials with low thermal conductivity.
10) The application of an automated control system for technical devices of the building, which reduce the temperature of the room at night or when people are absent.

With so much technological know-how in passive houses, one might assume that their costs would be significantly higher than those of standard housing options. This is not true: on average, the cost of building an energy-efficient house does not exceed the cost of erecting a conventional building of similar size and shape by more than 10%. Approximately one percent of this sum is recouped each year through the high savings in light and heat.

Today, passive houses are particularly common in Central and Northern Europe because of their generally moderate climate and high prices for electrical heating. In some countries, such as Denmark and Germany, government programmes have been developed to bring all regular buildings to a low consumption level. This is no coincidence, as energy-efficient buildings have several advantages that governments and inhabitants of developed countries are interested in.

Passive house engineering systems ensure comfort at any time of the year because of the special ventilation system used, which helps bring fresh air into the room, cool the room in summer and heat it in winter. Owing to this and the thermal insulation, the temperature is distributed evenly throughout all rooms of the house. The absence of excessive humidity and temperature fluctuations has a favourable effect on the internal preservation of rooms. In addition, a passive house frees its inhabitants from dependence on inflation and the constant rise in energy prices, as the house has much lower energy costs than a conventional house does. Another advantage of this type of housing is its environmental friendliness: the implementation of a set of measures that ensure the ‘passivity’ of the house significantly contributes to the protection of the environment. Saving the total energy and heat resources contributes to more rational spending because standard brick houses have high heat loss rates and, by and large, warm the street at the residents' expense.

Of course, passive houses are not perfect. The operation of such a house must be paid for in any case, and such houses can sometimes become profitable only in the long term. In Europe, the passive house construction standard has long been widely used.

As a result of the use of innovative technologies in construction, the cost of operating such houses is many times lower than that of conventional houses. This makes the passive house a promising direction for economic development. The widespread use of related technologies is becoming a factor in modernising the construction economy in the country.

Despite the advantages of introducing innovative technologies, it is also necessary to consider the potential negative impacts of economic, social and environmental nature. For example, the use of engineering equipment in new houses, created on the basis of the most recent achievements in science and technology, can lead to higher construction costs. However, in the process of operation, energy savings are achieved, which significantly covers the costs at the construction stage. Therefore, the overall positive effect of the introduction of innovative technologies in the construction sphere of economic activity is obvious. The continuous improvement and transformation of construction technologies, methods of work and management of the construction process is vital for the successful functioning of the national economy.

INDICATORS DETERMINING THE LEVEL OF INNOVATIVENESS IN CONSTRUCTION.

Importantly, construction is a sphere in which innovation activity is necessary [9]. The introduction of modern materials and technologies not only affects the efficiency of construction but also optimises production costs when adopted with skill. The use of new technologies to shorten the construction period of the object provides the opportunity to save significantly on direct costs and overheads in terms of the wages of workers, energy resources, costs for the protection of the object under construction, etc. [9]. Consequently, increasing the innovation in the construction of residential real estate objects to achieve cost reduction and quality improvement is the main direction of transformation in the construction sector of the economy.

Notably, the implementation of innovations is a complicated process. The construction sector of the economy has high inertia.

First, the real effectiveness of innovations can be determined only after a long period of operation of the building, during which the shortcomings of the applied structural and technological solutions can be revealed. In this context, participants in investment and construction activities should use the right approaches when choosing new building materials and technologies for the construction of residential property.

Second, the reason for conservatism in relation to innovations is the high responsibility of builders for the final result, as due to the use of inefficient technologies or errors in design, there is a risk of danger to the lives of many people.

Third, the long history of development of the construction sphere, during which various materials, designs and technological solutions are tested, has resulted in certain 'consumer stereotypes', which are often difficult to modernise.

The considered innovative measures are characterised by indicators that determine the level of innovativeness of construction (Fig. 6).

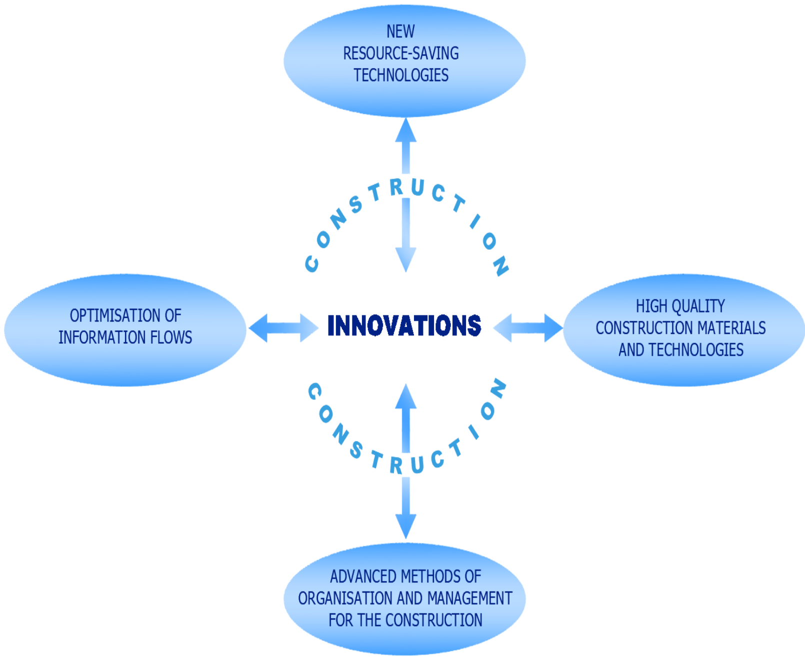

Figure 6. Indicators influencing the level of construction innovativeness.

Thus, increasing the level of innovativeness in the construction sector of the economy is the most effective tool for reducing costs, reducing construction time and improving the quality of construction, indicating the high socio-economic importance of innovation.

CONCLUSIONS.

In summary, the introduction of new innovative solutions in construction is necessary. Without innovations, it is impossible to develop the construction industry. Construction companies need to work closely with research centres to analyse the implementation of certain technologies in production.

In its future research and innovation strategy, the federal government defines the goals and priorities of research and innovation policy for the coming years.

Three points are particularly important here:

✓ Facilitating the transfer of research. The transition from research to application must be strengthened. Innovative solutions arising from science must reach people's lives. This is why the federal government seeks to optimise and expand innovation and transfer structures in the future research and innovation strategy.

✓ Becoming more open to technology. We must increase the openness to technology in all areas of society. We want to foster the development of different technologies that offer suitable solutions to the diverse challenges we face. This ensures freedom of action for us and future generations. To achieve these goals, the federal government is revamping research and innovation policies across all agencies.

✓ Striving for technological leadership. We want to maintain our technological leadership in certain areas and expand it and regain it in other areas. Key technologies must be understood, developed and produced in Germany and the European Union.

The future strategy initiates an important process in this respect. It lays the groundwork for Germany and Europe to play a decisive role in crucial issues in the coming years.

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