Innovative Technologies in Construction Sector that Meet Criteria of Sustainable Development

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Abstract. In the changing world, the construction sector undergoes significant changes. New innovative technologies must be introduced, so this sector meets the requirements of sustainable development. In this article, we provide a comprehensive overview of various aspects of methods and techniques that when applied help to achieve the ambitious goals in terms of sustainability. Those aspects are methods applied to the support the design process of buildings, innovative building materials, modern installation systems, building management systems, and systems for managing the process of building operation.

1. Introduction

Nowadays, most buildings in Poland are created using technologies and methods that have been established decades ago. With these building methods, it is impossible to ensure the sustainable development of the world. To change that it is necessary to implement new, innovative technical, economic, and social solutions.

Innovation is considered as any change that is beneficial to the entity that introduces it. The challenges posed to the modern construction sector are, to a large extent, related to the concept of sustainable development. One of the main trends of innovation is the transition towards a more resource-, and energy-efficient way of constructing as well as operating and implementing the principles of the circular economy. In this article, we present the selected innovative technologies used in the construction sector that meet the criteria of sustainable development.

2. Modern methods of supporting the design process of buildings

The contemporary investor not only pays attention to the construction costs but also to the costs of maintaining the facility and its renovation. Therefore, already in the design phase, the object must meet the investor’s expectations and has as little impact as possible on the environment throughout the entire life cycle of the building. Computer-supported designing of buildings, especially the Building Information Modelling (BIM) methodology (technique) is of great use in that case.

BIM is software dedicated to the creation and management of information on the building project. It is based on a 3D model of the building and cross-industry cooperation. This technique is used not
only in the design phase of a building, but also for the full life cycle analysis of the building in terms of construction processes, operation, management, and demolition. The BIM methodology turned out to be extremely versatile, allowing architects, engineers, contractors, and subcontractors to collaborate on small details, using the same database and computer model. The model includes architecture, construction, and all functional systems of the building, such as heating, ventilation, and air conditioning - HVAC, and electrical installations. This approach allows all participants in the design process to visualize and analyse design decisions and to detect disruptions and errors before construction begins.

Simulation software combined with BIM allows engineers to investigate how a building and its parts operate under specific conditions, analyse daylight distribution in the building, the influence of wind, heat travel through barriers and air through leaks. BIM is implemented during the construction phase and even during the operation of the building. An example of the application of BIM is shown in Figure 1.

![Exemplary application of BIM](image)

**Figure 1. Exemplary application of BIM [1]**

### 3. Innovative building materials

The number of innovative building materials that have appeared in recent years on the market is enormous, and it is difficult to even to signal all the existing trends. Therefore, we focus on these innovative building materials, which application significantly limits the impact on the environment.

#### 3.1. Building materials made of waste

Recently, many technologies have been developed for the production of building materials that use different types of waste: industrial, municipal and construction one.

These materials are, among others:
- bricks fired from clay, with an admixture of up to 1% of cigarette waste (cigarette butts),
- elements created during the polycondensation process, at room temperature of materials such as river sand, industrial waste, silica, water, and alkalis,
- geopolymers created, among others, from blast furnace slag, cement dust, furnace ash, volcanic ash,
- roof shingles made from production waste,
- concretes based on recycled aggregate.

#### 3.2. Smart concretes

Smart concretes include material that can absorb sunlight and then return it. They can be used in swimming pools, car parks, road safety signs, and many other applications.
Some of the smart concretes can absorb dust from the environment, thus limiting air pollution.

For complex architectural solutions in modern construction projects, the smart concretes that are ultralight composites from carbon fibre can be applied. The use of carbon fibre-reinforced concrete allows to reduce carbon dioxide emissions and even to bind them.

Another of the innovative technologies rely on adding special bacteria to the concrete, during mixing, which, under the influence of water penetrating the fissure, produce limestone to autonomously fill the cracks [2].

3.3. Thermal insulation
Among the thermal insulation of the particular interest are:
- smart insulation, whose thermal conductivity varies depending on external conditions,
- vacuum panel insulation,
- transparent insulations that combine the features of materials with the good optical transmission (light transmittance) and thermal insulation at the same time,
- aerogels, which are formed by removing liquid from the gel and replacing it with gas. Thanks to this the substance they become ultra-light because they contain 90% air [3],
- all types of insulation that can be created from locally available materials such as hemp straw mats or wood wool boards.

3.4. Modern windows
Modern windows are no longer a simple building partition, but have become a complicated device with:
- multi-chamber frames filled with innovative insulating materials,
- self-cleaning windows,
- a warm spacer frame, reinforced with glass fibre, covered on the outside with a thin, technologically advanced foil,
- smart window panes, reinforced with PVB foils, which not only protect against burglary but also prevent injuries when the glass is broken, suppress noise and filter most UV rays,
- shading elements, such as blinds integrated with the window.

3.5. Other modern material solutions
In addition, it is worth to notice solutions such as:
- phase-change materials using the known phenomenon of absorption and heat transfer during phase transformation,
- hygroscopic materials that change their form depending on the humidity of the air,
- building elements responsive to weather conditions,
- semi-transparent wood, produced at low cost, arises from veneer, through processes at the nanoscale [4],
- Bioplastic, which is made by combining wood chips, gypsum and oat bran with a fungus called Ganoderma lucidum,
- hydro ceramics, or a combination of clay and hydrogel, which is a material that can lower the temperature inside the room that surrounds it by as much as 6 °C the temperature inside the room that surrounds it.

4. Modern installation systems
Modern installation systems are designed to provide the building with heat, cold, electricity, cold and hot water, sewage, provide adequate lighting, ventilation air exchange and thermal comfort. Among these systems, there are also many innovative solutions.
4.1. Thermal insulation
The innovative installations generating electricity within a building include:
• photovoltaic cells that use thin-film technologies - it can be a photovoltaic glaze or glass with a special coating that can change from transparent to coloured, while converting solar energy into electricity,
• sprayed solar cells with zinc and phosphorus nanoparticles that can be applied to surfaces with painting techniques,
• Building Integrated Photovoltaic Building (BIPV) combining multifunctional conversion of solar energy into electricity through photovoltaic cells and take part as construction elements of the exterior of the building, such as roofing, wall cladding or glazed surfaces,
• solar hybrid cells combining electricity generation with hot water production,
• micro power plants placed on the roof of a building,
• trig generation devices producing heat energy and cooling from biogas.

4.2. Ventilation systems
In terms of ventilation systems, the use of mechanical ventilation with heat recovery or hybrid ventilation will become common in new and deeply thermo-modernized buildings [5].

4.3. Water supply and sewage disposal systems
Among the water supply and sewage disposal systems, as innovative methods should be considered [6, 7]:
• heat recovery from gray swage,
• gray water systems for flushing toilet bowls,
• rainwater management systems.

4.4. Lighting systems
Innovations in the field of lighting systems include:
• mass use of LEDs and OLEDs,
• systems for optimal use of daylight,
• lighting that dynamically changes the color of light and its intensity depending on the user's needs,
• use of optical fibers, dimming systems, and presence detectors.

4.5. Innovative heating systems
Nowadays, many innovative heating technologies could be used to produce thermal energy for the building [8]. Among them there are:
• reversible heat pumps,
• pulsating gas condensing boilers,
• micro-cogeneration devices,
• heating pipelines,
• infrared heaters.

The immediate future undoubtedly belongs to heating installations based on renewable energy sources.

5. Building management systems
Building management systems [9] are primarily cloud-based computer tools for project management and optimization of critical processes, such as planning, construction crew tracking, and document management. Digital planning and monitoring of progress, combined with mobile access to information about best practices, enable building management teams to access the information they need to succeed. There are computer systems that analyse historical data from subcontractors, material suppliers, project plans, and data from the main implementer to determine risk factors. These systems can determine which elements of the analysed project are the most vulnerable and require the attention of the contractor and allow to assess the reasons for the specific level of risk.

6. Systems for managing the process of building operation
Automatic computer control systems for all installations and processes are the basis of a modern investment in the construction sector. Lighting, ventilation, heating, cooling, domestic hot water preparation, etc. processes and installations, properly designed and operated, will allow to significantly save energy, water, and fuel consumption and minimize waste while providing comfort to building users and reducing the negative impact of these facilities on the environment. Until recently, individual installations did not cooperate, and even though they performed their tasks, they did not allow comprehensive servicing of the entire building. Today, thanks to BMS technologies, existing, and designed systems can be integrated, thus creating intelligent buildings.

The intelligent building is a high-tech facility, with an automatic, very flexible system for managing its use. Moreover, it has sensors, detectors and one integrated management subsystem for all installations in the building. Thanks to information coming from various elements of the system, it is possible to react to environmental changes inside and outside the building, maximizing functionality, comfort and safety, and minimizing operating costs. Smart building systems cannot negatively affect people in their environment [10].

7. Conclusions
The construction sector, like any other branch of the economy, uses technological, material, and organizational innovations. Next generations of materials are quickly replaced with even more innovative solutions. Thanks to innovative materials and construction solutions, it is possible not only to manage energy more efficiently, reducing CO$_2$ emissions but also to build more durable, safe, and functional buildings. Due to the issues of climate protection and dwindling resources of non-renewable energy sources, a particular highlight is the complex technological solutions, leading to the creation of passive, zero-energy, positive-energy buildings. The decision to use a specific construction technology and the choice of construction material is of crucial importance for the building's architecture,
investment economics, and its impact on the environment. The construction industry places increasing emphasis on these innovative solutions, whose task is to improve the quality of construction works, taking into account the principles of sustainable development. This is due to the increasingly strict regulations in the field of environmental protection and greater environmental awareness of investors.

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