INTELLIGENT INTEGRATION OF INNOVATIVE TECHNOLOGIES IN CONSTRUCTION 5.0

BOZHIDAR CHAPAROV AND KATYA ANTONOVA*

University of Economics,
bul. "Knyaz Boris I" 77, 9002 Varna, Bulgaria
e-mails: bchaparov@ue-varna.bg, katia_antonova@ue-varna.bg

Abstract. In the context of global trends for sustainable development, the construction sector in Bulgaria is facing the need for intelligent integration of innovative digital technologies. This study analyzes the technological changes from Industry 5.0 to increase efficiency, competitiveness, and sustainability in construction. Emphasis is placed on the implementation and intelligent integration of construction and information modeling, the Internet of Things, digital twins, artificial intelligence, drones, and 3D modeling, which support process optimization, resource management, and occupational safety. Particular attention is paid to the role of the human factor. The article identifies some challenges related to a low level of digital skills, limited organizational readiness, insufficient investment, cybersecurity, and the implementation of ESG standards. The need for a regulatory framework, human capital development, and coherent linking of technologies, processes, and resources as prerequisites for achieving sustainable and competitive development of the construction sector is emphasized.

Keywords: industry 5.0; construction sector; construction 5.0; digital technologies; intelligent integration.
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1. INTRODUCTION

In the context of globalization, the European Union's policy focuses on environmental protection, reducing the impact on the climate, caring for human health and well-being, preserving biodiversity, etc. In the EU Green Deal, one of the goals is to make Europe a carbon-neutral continent. In this sense, there is also a need for transformation and intelligent integration of innovative technologies of the economic sectors, including the construction sector. In the last decade, the topic of digitalization has become a major factor in the development of industries worldwide, which makes the topic relevant and significant for the Bulgarian economy, and in particular for the

* Corresponding author
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construction sector. In the context of global trends for process digitalization and intelligent integration of innovative technologies in order to increase the competitiveness and sustainability of companies, transformation is imperative.

The object of research in this study is the construction sector in Bulgaria, and the subject is the processes of intelligent integration of innovative technologies in construction.

The authors aim to analyze both the main advantages that the integration of innovative technologies brings to the construction sector, as well as some challenges, including the limited digital competence of those employed in the sector, the lack of standards, the need for a regulatory framework, and the low level of technological investment.

The sector needs to increase efficiency and reduce costs, as well as to reduce the impact of construction activities on climate change. Achieving sustainability, improving quality, working conditions, and occupational safety are key for the sector. The use of innovative digital technologies will allow for more precise planning and optimization of production and process management.

Rapid technological changes are preparing the sector for the intelligent integration of new technologies for the design, construction, operation, and management of buildings throughout their life cycle. In the context of Industry 5.0, key importance to the sector will be the introduction of building information modeling (BIM), 3D modeling and simulations of buildings, the use of drones, sensors, cameras, and the Internet of Things, with IoT devices will be essential for the sector. artificial intelligence and virtual and augmented reality, etc. The smart integration of innovative technologies will have an impact on optimizing the energy consumption of buildings, reducing carbon emissions, increasing workplace safety, monitoring of risk areas, warning of hazardous conditions, and hence fewer accidents and better health and safety of workers. Last but not least, it is essential not only to use the new technologies but also to have a coherent and purposeful connection of different systems, processes, and resources so that they work in sync and create more value. The intelligent integration of innovative technologies into enterprises in the construction sector also makes it more attractive to young and creative employees, which is at the heart of Industry 5.0, where it will be essential for technology to work in sync with humans.

2. SMART INTEGRATION OF NEW TECHNOLOGIES IN THE CONSTRUCTION SECTOR - LITERATURE REVIEW

The development of technology in the context of Industry 4.0 has significantly impacted the construction industry. The technologies implemented within the industry of the fourth generation make it possible to realize the goals of Industry 5.0, which

has at its essence a new understanding of the business processes. Efficiency, competitiveness, and productivity are no longer the only goals. The focus is on three key pillars: human orientation, resilience, and endurance.

At the heart of Industry 5.0 is a people-oriented approach to their physical and mental health, workplace safety, social justice, personal growth, and well-being [1][2]. A key point is the creation of clear links between people and technology in order to create intelligent production systems, in which, in addition to the capabilities of data analytics technologies and automated feedback in real time, it is also important to personalize human skills and cognitive abilities [3].

Within this transformation, the concept of Construction 5.0 also appeared, which is associated with technological changes, and an important aspect is to explore not only the use of new technologies, but also the relationship with the organizational structure, organizational culture, and processes in organizations [4].

According to the National Strategy for Digitalization of the Construction Sector [5], a long-term goal is to implement policies for a circular economy, sustainable use of resources, a sustainable ecosystem, etc., through digital transformation and management of the built environment. The simple implementation and use of innovative technologies, but the coherent and purposeful connection of different intelligent systems, processes, and resources so that they work in sync and create added value. In the context of Construction 5.0, several directions can be distinguished: (1) connecting technologies, including the Internet of Things (IoT), BIM models, digital twins and process automation, which together give a complete picture of the building; (2) integrated use of data for the design, operation and maintenance of buildings, which are brought together in a single platform; (3) managing the interaction between people and technology; (4) focusing on sustainable management of the use of new technologies (Fig.1).

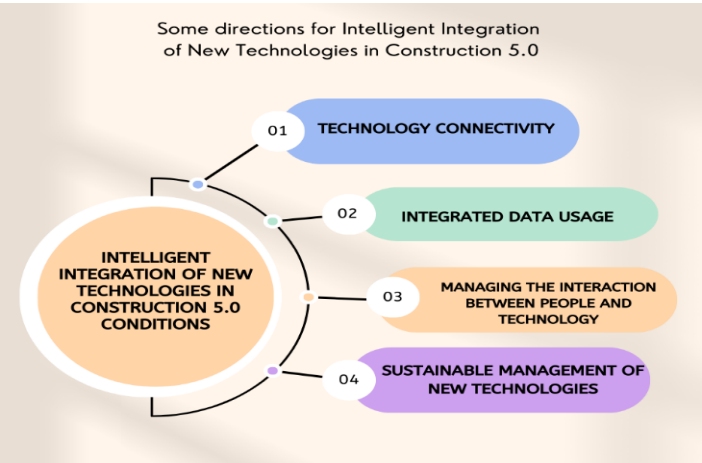

Fig. 1. Some areas for smart integration of new technologies in Construction 5.0

Smart integration implies a "smart" combination of people, technologies, and processes instead of isolated implementation of various innovative tools. The integrated use of IoT sensors (for temperature, humidity, dust, energy consumption, etc.), the data from which is integrated into BIM and digital twins, and in real time, problems can be identified (e.g., high humidity, high energy consumption, etc.), forecasts can be made, and the necessary maintenance can be planned.

The use of drones, databases, and artificial intelligence can help automatically detect deviations and reduce risk – drones scan activities on the construction site, artificial intelligence compares the actual implementation with the construction project, and gives feedback on deviations.

The use of intelligent energy management systems in buildings – implementation of smart thermostats and lighting systems connected to platforms for analysis and cost optimization.

The combined use of sensors, IoT, and 3D scanning leads to the creation of "smart" construction sites and digital twins that allow optimization at all stages of the site's life cycle. The digital transformation of the construction sector and the smart integration of new technologies are becoming key factors in increasing the efficiency, quality, sustainability, and safety of construction activities.

Concerning the second strand, by automating processes with the help of scanners, drones, and cameras, projects and their actual implementation can be compared (as-built vs as-designed), errors can be detected during construction, and a database can be created for future maintenance and providing opportunities for renovation.

The analysis of large databases becomes possible on the basis of the use of construction information modeling, a technological methodology that allows adding more information to projects by taking into account changing processes and giving a vision of the life cycle, as well as stakeholder integration to increase the value of assets [6] [7] [8] [9] [10]. Construction and information modeling are also essential for the creation of Digital Twins. By combining sensor data, IoT systems, and 3D models, it becomes possible to create a digital twin of the object, which is a virtual reflection of the physical object, but makes it possible to update with real-time data, make simulations and predictions, and make decisions, which leads to cost optimization and increases the safety of the object by reducing probable errors.

Integrating new technologies and combining their precision with people's skills and creativity not only makes it possible to increase the productivity and efficiency of processes, but also draws attention to the essence of the technological revolution 5.0, namely, prioritizing sustainability, environmental protection, and the well-being of employees.

The development of smart systems for collecting, processing, and storing data on existing and newly built buildings and infrastructure with a view to managing them in accordance with the objectives of protecting the environment, reducing climate

risks, improving human health, and maintaining biodiversity is of utmost importance for the sector.

One of the innovative approaches to collecting information is through the use of sensors, devices that capture and transmit data about various physical parameters, such as temperature, humidity, vibration, movement, pressure, dust level, etc. The mentioned parameters are essential to optimize the construction process, to diagnose probable problems, and to increase work safety[1].

The Internet of Things (IoT) connects sensors, devices, and analytics platforms in a single system network, which allows real-time tracking and processing of data on the use of materials, energy, human resources, and logistics[2], and with the help of 3D scanning, deformations or deviations are detected in the early stages of the process, as well as the creation of a database for future maintenance and renovation of buildings.

3. SOME CHALLENGES TO THE SMART INTEGRATION OF NEW TECHNOLOGIES IN THE CONSTRUCTION SECTOR

The construction sector plays an essential role in Europe's economy, creating almost 10% of gross domestic product and providing around 20 million jobs, mainly in micro and small enterprises [11]. Due to its economic importance, effective and sustainable management, as well as the competitiveness of enterprises in the sector, are essential, and their development is also important for achieving the European Union's (EU) long-term target of 80 to 95% reduction of greenhouse gas emissions by 2050, with the envisaged reduction by 2030 being approximately 40-50% [12].

The intelligent integration of new technologies implies significant opportunities to improve the efficiency, quality, and sustainability of construction activities. The integration of modern technologies and systems creates conditions for more precise planning and design, better coordination and cost reduction, etc., but the process is also accompanied by some challenges.

The construction industry is known for its conservatism in terms of introducing new technologies, and the lack of necessary digital skills among employees makes the process even more difficult. Despite the larger amount of initial investments, by introducing and integrating innovative technologies, reducing administrative costs for design, coordinating construction documents, tracking productivity and quality of construction, as well as ensuring a greener process by reducing material and energy costs, and reducing the carbon footprint on the environment can be achieved.

[1] More than 10,000 sensors have been installed at the new airport in Istanbul to monitor the structure in real time, an approach that is already being applied in some large infrastructure projects and in Bulgaria.
[2] An example of this is the **BIM4EEB** Programme (EU Horizon 2020) deploying IoT and BIM technologies for building renovation, enabling real-time monitoring of energy efficiency.

In our opinion, in a generalized form, the challenges to the intelligent integration of new technologies in the construction sector can be systematized into five main groups: (1) technological readiness; (2) organisational and administrative readiness; (3) human factor readiness; (4) cybersecurity and data management; (5) the requirements of ESG (Environmental, Social, Governance) standards (Fig. 2).

Fig. 2. Some challenges facing the intelligent integration of new technologies in the construction sector

In our opinion, one of the challenges to the integration of digital technologies in the enterprises of the construction sector in Bulgaria is related to the fact that at the end of 2024, 98.06% of construction enterprises are micro and small, which implies a low attitude towards investments in new technologies. According to the Digital Economy and Society Index (DESI), Bulgaria ranks 26th (37.74%)—the EU-27 average being 52.3%—with the level of digital skills in the country being one of the lowest in the EU. According to the EIB Investment Survey 2024: European Union overview (2024), the share of EU enterprises using digital technologies continues to grow. As of 2024, their relative share is 74%. Leading in their introduction are larger companies, including those in the manufacturing sector, but in the construction sector, the digitalisation process lags behind [14]. According to the EIB Group's 2024 Investment and Investment Finance survey for Bulgaria [13], 55.0% of firms have fully or partially implemented at least one of the digital technologies in 2020, below the EU-27 average (63.0%). About 17.0% of construction firms have adopted the Internet of

Things, 12% have introduced the use of drones, 8% use 3-D printing, and only 2.0% of construction firms use augmented or virtual reality.

According to Babatunde et al. [15] [16] Among the main obstacles to the digitalisation of the sector are the different levels of technological readiness, the reluctance of owners and investors to transform their work processes into modern digital practices, as well as the lack of the following:

- sufficient information among stakeholders;
- unified formats for digital design and electronic submission of projects;
- qualified personnel;
- a common database and centralised information exchange systems;
- electronic systems for administrative services in the sector;
- electronic cadastral maps.

According to the SWOT analysis developed for the purposes of the Strategy for the Digitalisation of the Construction Sector [5], some of the weaknesses are related to:

- the low level of competence in the construction sector;
- high costs for maintaining specialized software products and cloud technologies;
- lack of competencies to work with specialized software products;
- low level of digitalization of public administration in the part of specialized construction software products;
- lack of information exchange between stakeholders.

Another problem we identified is related to the human factor, including a growing shortage of skilled labour and a lack of digital skills. Those employed in the construction sector at the end of 2024 are 203,590 thousand people, which is about 5.6% of all employed in the Bulgarian economy. According to Eurostat data, only 57% of the population aged 16-19 in Bulgaria has digital skills, compared to the level for the EU-27 is 82%, and in terms of the level of digital skills of adults, our country ranks last in the European ranking.

The problems related to information and administrative readiness are expressed in the lack of sufficient knowledge of the principles and methodologies of construction information modeling (SIM). The main obstacles to the introduction of SIM, identified by the public administration, are related to the lack of the necessary information for the digitalization of the entire process in construction, the reluctance of civil servants to transform their work processes into modern digital practices, the lack of uniform digital design formats and centralised information exchange systems in a Common Data Environment (CDE), a low level of staff digital skills and a high administrative burden.

The growing reliance on new digital technologies raises the question of information security. The sector faces risks such as cyberattacks, data leaks, and breaches of personal data protection regulations (GDPR). This implies the need to develop cyber resilience standards and implement policies for secure data management, including encryption, multi-factor authentication, and cybersecurity staff training [17]

[18]. A challenge for enterprises in the sector is also the achievement of sustainable development in the context of the requirements of ESG (Environmental, Social, Governance) standards.

In summary, the challenges to the smart integration of digital technologies in the construction sector are related to the lack of a clear vision of the goals, the lack of organizational flexibility, and the lack of attitude and readiness for changes on the part of Bulgarian construction companies.

4. CONCLUSION

For modern construction processes, the importance of the intelligent integration of NOE and digital technologies for data collection and analysis, as it not only improves efficiency but also lays the foundation for sustainable and smart construction. The construction sector in Bulgaria has the potential to accelerate this integration by adopting some good practices, as well as by securing European funding.

Some of the necessary changes are related to:

1. A change in the regulatory framework is needed. The new challenges of the business environment imply the identification of a new way of influencing factors.

2. Consolidation of data from different registers into a single public register of spatial planning, investment design, and construction permits.

3. Creating an opportunity for administrations for official access to information and unification of standards, as well as the possibility of storing data in a single information environment, which will ensure transparency and improve awareness.

4. It is necessary to encourage the use of SIM through the introduction of regulatory requirements, training, and certification of specialists. The introduction of SIM will ensure the automation of work processes, including filing, reviewing, storing, authorising, etc., as well as issuing digital guarantees, certificates, permits, etc.

5. The use of intelligent artificial intelligence systems, robots, and autonomous machines for defect forecasting, monitoring, risk management, and cost optimization.

6. The integration of new digital technologies implies the achievement of sustainable development goals and the requirements of ESG standards in an environmental (precise measurement of the carbon footprint, traceability of materials used and effective waste management [19]), social (increasing occupational safety contributes to the protection of the workforce and improving the working environment [20]) and economic aspect (increases transparency and accountability through integrated systems for data exchange and monitoring of the life cycle of sites [21]).

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