IMPLEMENTATION OF THE MAIN POSTULATES OF THE CLOSED-CYCLE ECONOMY IN THE CONSTRUCTION INDUSTRY

INTRODUCTION

The construction sector is a key area that has a significant impact on the economy and the environment. This sector contributes to the economy (about 9% of the EU’s gross domestic product (GDP)), provides direct and indirect employment opportunities (18 million direct jobs in the EU) and meets the needs of people in buildings and structures. Moreover, this sector is one of the main consumers of resources: about 50% of the total use of raw materials and 36% of the global use of final energy (KYLILI, FOKAIDES, 2017)

Since this sector accounts for 39% of emissions related to energy and technological processes, as well as from acid rain, the continuation of greenhouse gas emissions at the same rate will certainly lead to a problematic situation. Therefore, any efforts related to global climate change and cleaner production should include this industry as a major player (EBERHARDT, BIRKVED, BIRGISDOTTIR, 2020).

In addition to these environmental impacts, construction and demolition projects also account for about a third of all waste generated in the EU, with a significant part being taken to landfills, which creates serious environmental problems throughout the entire life cycle of buildings, especially during operation. and the stages of the end of the life cycle. Moreover, it is projected that at the current rate of population growth, the middle class will increase from 2 billion to more than 4 billion people by 2030. Therefore, in order to ensure progress, modern and future well-being, it is necessary to create more urban capacities than have been built over the past 4,000 years.

Another important problem is the rising prices of raw materials, which pushes the construction industry to use effective alternative materials, for example, through reuse and recycling. In this context, it can be concluded that there is an urgent need in the construction industry and the need to move from the current paradigm to a more sustainable one, with an emphasis on adopting a closed-loop economy approach to ensure a more sustainable construction sector.

The concept of circular economy (CE), which originated from industrial ecology, tries to combine under one name a set of pre-existing ideas from various scientific fields with common qualities and characteristics, for example, industrial ecosystems and industrial symbioses. It takes place 3R principle (reduction, reuse and recycling), cleaner production, including circular flows of materials of production systems, product and service systems, eco-efficiency, integrated design, green growth, biomimicry, natural capitalism, sustainability of the socio-ecological system, the concept of zero emissions and others.

The CE paradigm is proposed to change the existing “take-make-dispose” model of production and consumption, which threatens the sustainability of human life on Earth and is approaching planetary boundaries. Steps in this direction require closing cycles by reusing waste and resources, as well as slowing down the cycles of materials by developing durable, reusable products (KORHONEN, HONKASALO, SEPPÄLÄ, 2018).
There is no single definition of CE due to its interdisciplinary nature, but there is broad agreement among scientists and practitioners that CE increases the life cycle of components, materials and products through reuse, repair, recycling, etc. In this regard, CE can be defined as an economic system that replaces the concept of end-of-life reduction, alternative reuse, recycling and recovery of materials in the processes of production, distribution and consumption. It works at the micro-level (products, companies, consumers), meso-level (eco-industrial parks) and macro-level (city, region, country and beyond) in order to achieve sustainable development, thereby simultaneously ensuring environmental quality and efficiency, prosperity and social justice for the benefit of present and future generations. This has become possible thanks to new business models and responsible consumers (POMPONI, MONCASTER, POMPONI, MONCASTER, 2017).

The main CE concepts for the reduction, reuse and recycling of materials and components are already widely successfully applied from electrical equipment and furniture to textiles, but their application in the construction sector has a shorter history and to a lesser extent, mainly limited to waste prevention and material management (mainly focused on recycling).

The construction sector was known as one of the three sectors with a high potential for implementing environmental safety strategies, in particular, through the introduction of environmentally friendly products and technologies. The adoption of the CE principle in the construction industry promotes the use of environmentally friendly materials, the maximum recovery of materials and the prevention of unnecessary waste generation and their removal to landfills.

As for construction projects, their implementation requires the participation of a large number of stakeholders in a complex supply chain, where each link in the chain contributes to the environmental impact and the cost of building construction. In this context, it is obvious that governments should play their key role by dictating appropriate guidelines and policies to support the transition to CE in the construction industry (KIRCHHERR, REIKE, HEKKERT, 2017).

The authors drew their attention to the relationship of CE with various other concepts, such as the artificial environment, industrial symbiosis, industrial ecology, ecology and bioeconomics, the waste disposal sector and sustainable development.

The most common research problems were such as energy and energy efficiency in buildings and related environmental issues. Focusing on the use of energy in a building is of great importance, since buildings (residential, commercial and public) are responsible for the consumption of approximately 60% of the world's energy. Energy is the main source of energy throughout the entire life of buildings, as it plays a key role in their functioning during use. The environmental impact associated with the use of energy accounts for 10% of global greenhouse gas emissions.

Improving energy efficiency is probably the most relevant strategy for increasing the service life of buildings, which leads to better living conditions (for example, improving the well-being of residents due to thermal comfort), reducing energy costs for residents, as well as reducing the environmental impact caused by the construction and operation of buildings (for example, CO2 emissions).

Conducting a building lifecycle assessment provides a suitable tool for evaluating CE decision options, helping decision makers to minimize environmental impacts, carbon emissions, energy and costs throughout the building lifecycle.

The appearance of the terms "reconstruction" and "modernization" may indicate that the implementation of energy modernization of existing buildings, as well as the reconstruction and reconstruction of buildings can help solve the problems of the cluster.

Another most common area of research concerns the processing, disposal of waste and alternative building materials in the construction industry (GALLEGO-SCHMID, CHEN, SHARMINA, MENDOZA, 2020).

Many academic studies, interested organizations, as well as state legislation in the field of recycling and waste reduction prove the possibility of significantly reducing the
environmental impact of construction and construction materials through the production of durable products and the wider use of recycled materials instead of natural resources at the production stage. This is becoming more and more relevant, given the growth in the production of construction systems outside the facility and the use of advanced technologies at manufacturing enterprises.

For example, it is estimated that cement production accounts for 5-7% of the CO2 generated as a result of human activities and, consequently, when replacing cement with fly ash or other substances. Pozzolan materials in the production of concrete reduce the carbon footprint.

Waste management is one of the important scales for measuring CE in the construction sector, which can be quantified by assessing the degree of waste generation reduction, increasing the degree of solid waste recycling, reducing the production of hazardous waste, waste management efficiency, taking measures to prevent, process and eliminate waste, using the solid waste statement for the production process.

The third area of research is ensuring sustainability and solving the problem of environmental impact. The CE model is seen as a means to achieve sustainability, and it is perceived as sustainable, as can be judged by the "environment", "climate change", "green economy", "low-carbon economy" and "low-carbon economy".

A sustainable building, in principle, should use a triple practical approach that takes into account the economic, social and environmental aspects of the entire life cycle. The achievement of highly efficient, environmentally friendly buildings with a low level of environmental impact can be tracked in many aspects, including environmentally friendly materials, sustainable operations, sustainable services and sustainable consumption, in order to integrate sustainability concepts into any part of the building life cycle (RODRÍGUEZ-SOLER, URIBE-TORIL, DE PABLO, 2020).

Here we should emphasize the importance of two controversial topics—technologies and innovations for achieving sustainable development. In order to link economic growth with the level of technology development, innovations play a central role, since they can offer solutions to expand the boundaries of economic growth, while taking into account limited resources.

Another important area of research is devoted to CE in relation to urban areas and urban regions. The following terminology is considered here: "closed-cycle economy", "industrial symbiosis", "material flow analysis", "sustainable cities", "smart cities", "urban planning".

"Industrial symbiosis (IS)" is a subset of the academic term "industrial ecology (IE)", which is again a subset of the complex "closed-cycle economics". This is a key concept on the path to sustainable development, as it is related to resource depletion, waste management and pollution. IE studies industrial systems and strives to identify and implement strategies that reduce their environmental impact. One of the main directions of industrial ecology prospects is the quantitative assessment of the positive impact of IE on the environment using life cycle assessment and analysis of material flows (MERIGÓ, YANG, 2017).

As for the city and urban development, in order to realize the CE of the construction sector, building design and technology should focus on achieving the maximum amount of reduction, reuse and recycling of materials, practical strategies for cascading energy and a symbiotic exchange of resources between different firms, industrial sectors, cities and regions.

We should also pay attention to another area of research, which includes green buildings and the ecological supply chain in relation to the construction industry. The authors' works in this field also relate to the "green supply chain", "construction industry", "lean construction", "sustainable design" and "environmental sustainability" (WANG et al. 2020).

Green buildings are designed and built in accordance with environmental principles and have a minimal impact on the environment and human health, usually consume significantly less resources than conventional buildings, and contribute to increasing the productivity, comfort and satisfaction of residents, providing high-quality heat and comfort. The concept
of lean construction pursues the same goal as "green" buildings, and emphasizes the importance of reducing waste, optimizing flows and eliminating unproductive and fruitless processes to achieve the goals of sustainable development.

Basically, the "green" supply chain is associated with the integration of environmental considerations into the supply chain, including reducing material flows and minimizing unintended negative consequences of production and consumption processes. Environmental supply chain management in construction is based on three dimensions: environmental, economic and industrial. Referring to the processes related to construction, from an operational point of view, "green" supply chain management includes "green procurement, eco-friendly production, green distribution (marketing) and reverse logistics" (CABEZA, CHÁFER, 2020).

At the beginning, from 2006 to 2013, the key research areas were mainly related to measures, policies and frameworks for CE adoption at different levels of countries, regions, etc., as well as the importance of the circular economy from a purely environmental point of view.

During 2013-2018, the researchers focused their attention on the problems of building design using CE. In the same period, i.e., 2013-2018, solving the problems of sustainability and sustainable development, as well as energy and energy efficiency in the context of the construction industry, were other areas of research that attracted many authors. Since 2016, some studies have been conducted on the implementation of potential CE assessment methodologies, for example, the use of a building life cycle assessment framework to assess quantifiable benefits in terms of environmental impact and associated costs, as well as material flow analysis to assess the flow of materials during the entire life cycle.

However, there is still no comprehensive set of indicators to assess the adoption of CE in sustainable construction. Recently, in 2017-2020, researchers have focused mainly on the selection of materials for the purpose of choosing or replacing building materials with rounder materials, the development of closed-cycle business models, the connection of CE with new technologies (SOLAIMANI, SEDIGHI, 2020).

Currently, the leading direction is the development and use of alternative building materials in construction. In this direction, we can interpret the growing use of green building materials, biomaterials, various types of aggregates in cement, concrete and asphalt, geopolymers, fly ash, solid waste, plastic and foam, as well as concrete recycled from demolished buildings. The production and processing of these materials should lead to a reduction in environmental impact and a reduction in the use of harmful chemicals. Thus, their use can make a significant contribution to the transition to a closed-cycle economy.

Another relevant topic is the development of closed-cycle business models in the construction industry. The current business models in this area are still based on the linear use of resources, and therefore there is a great need for CE research from a systemic point of view in this area, including research on the use of new business models to ensure the preservation of high residual value.

Other relevant studies concern the links between CE and the Fourth Industrial Revolution (Industry 4.0) in the context of the construction industry. Industry 4.0 is a combination of cyber-physical systems, the Internet of Things, big data and cloud computing, which made it possible for human and machine interaction using information generated by various intelligent devices.

Industry 4.0 is currently considered as a key innovative technology in the process of transition from a linear economy to a closed-cycle economy in the manufacturing industry. Industry 4.0 can reduce emissions and resources of industrial systems by optimizing environmentally friendly solutions, and its integration with the CE can contribute to achieving the Sustainable Development Goals.

Another popular topic touched upon recently is smart cities and their connection with CE and industrial symbiosis. A smart city modeled on the CE principles combines technology, government and society in an urban context, promoting sustainable development with little impact on the environment.
Future research on smart cities should be aimed at industrial symbiosis through the development and implementation of tools for regenerative systems and symbiotic business relationships (HAAS, KRAUSMANN, WIEDENHOFER, HEINZ, 2015).

The concepts of "waste management", "life cycle cost", "recycling", "reuse", "recycled aggregates", "building information modeling", the use of "renewable energy sources", "energy efficiency" and "resource efficiency" have most often become the subjects of consideration by various authors over the past few years. Also, in such studies, it was determined that waste management is closely related to CE, which is determined by the closed nature of CE, which implies recycling and reuse, as well as the transition from raw materials and fossil fuels to renewable energy sources, which leads to increased resource and energy efficiency, while waste recycling serves as a generalized strategy to achieve the CE goal.

Conclusions. Thus, we can conclude that CE in the construction sector is an urgent area that is attracting more and more attention. Researchers consider such issues as "sustainability", "sustainable development", "life cycle assessment", "green buildings", "energy efficiency" and "recycling", "waste management", "life cycle cost", "resource efficiency", "reuse", "renewable energy sources", etc.

Also, such issues as energy efficiency and energy efficiency in buildings; recycling, waste disposal and alternative building materials; sustainable development; circular economy in urban regions; green buildings and a green supply chain in the construction industry are coming to the fore.

Also, the development and use of alternative building materials, closed-loop business models, the concept of a "smart" city, Industry 4.0 and their relations with CE are relevant research points that can be considered as areas of future research. Further study of these interdisciplinary research topics will expand the understanding of more effective implementation of CE concepts in this sector, which is useful in promoting sustainable construction and solving environmental problems of the sector.

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Implementation of the main postulates of the closed-cycle economy in the construction industry

Resumo
O artigo considera as características da implementação dos principais postulados da economia do ciclo fechado na indústria da construção. Sabe-se que a indústria da construção civil é responsável por um impacto significativo no meio ambiente devido ao consumo de recursos e energia, bem como à formação de resíduos. A Economia Circular (CE) pode aumentar significativamente a sustentabilidade desse setor. Nesse caso, é necessário realizar uma análise científica quantitativa da evolução do uso do CE no setor da construção civil, a fim de identificar novas tendências e destacar o desenvolvimento desse tema de pesquisa. Foi revelado que os pesquisadores têm prestado muita atenção à “sustentabilidade”, “eficiência energética”, “avaliação do ciclo de vida”, “energia renovável” e “reciclagem” nos últimos cinco anos. Além disso, foi determinado que o desenvolvimento e o uso de materiais de construção alternativos, o desenvolvimento de modelos de negócios de circuito fechado, cidades inteligentes, Indústria 4.0 e suas relações com a CE são áreas relevantes de pesquisa que podem ser consideradas como temas potenciais para futuras pesquisas.

Palavras-chave: Economia circular. Construção. Desenvolvimento. Meio ambiente. Potencial econômico.

Abstract
The article considers the features of the implementation of the main postulates of the closed-cycle economy in the construction industry. It is known that the construction industry is responsible for a significant impact on the environment due to the consumption of resources and energy, as well as the formation of waste. The Circular Economy (CE) can significantly increase the sustainability of this sector. Accordingly, it is necessary to conduct a quantitative scientific analysis of the evolution of the use of CE in the construction sector in order to identify new trends and highlight the development of this research topic. It was revealed that researchers have been paying close attention to “sustainability”, “energy efficiency”, “life cycle assessment”, “renewable energy” and “recycling” in the last five years. In addition, it was determined that the development and use of alternative building materials, the development of closed-loop business models, smart cities, Industry 4.0 and their relations with CE are relevant areas of research that can be considered as potential topics for future research.

Keywords: Circular economy. Construction. Development. Environment. Economic potential.

Resumen
El artículo considera las características de la implementación de los principales postulados de la economía de ciclo cerrado en la industria de la construcción. Se sabe que la industria de la construcción es responsable de un impacto significativo en el medio ambiente debido al consumo de recursos y energía, así como a la formación de residuos. La Economía Circular (CE) puede aumentar significativamente la sostenibilidad de este sector. En consecuencia, es necesario realizar un análisis científico cuantitativo de la evolución del uso de la CE en el sector de la construcción con el fin de identificar nuevas tendencias y destacar el desarrollo de este tema de investigación. Se reveló que los investigadores han estado prestando mucha atención a la “sostenibilidad”, la eficiencia energética, la evaluación del ciclo de vida, la energía renovable y el reciclaje en los últimos cinco años. Además, se determinó que el desarrollo y uso de materiales de construcción alternativos, el desarrollo de modelos de negocio de circuito cerrado, las ciudades inteligentes, la Industria 4.0 y sus relaciones con CE son áreas relevantes de investigación que pueden considerarse como temas potenciales para futuras investigaciones.

Palabras-clave: Economía circular. Construcción. Desarrollo. Medio ambiente. Potencial económico.

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