

THE CHARACTERISTICS OF GREEN CONSTRUCTION ECONOMY IN THE LIGHT OF GLOBAL TENDENCIES

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Abstract

The construction industry is an industry of outstanding importance both on a global and national economic level. At the same time, its environmental burden and raw material demand are also significant. Recognizing this also steered the construction industry in the direction of sustainability. One of the tools for this is the circular economy, the implementation of which brings enormous benefits on the way to sustainability.

The aim of the study is to examine the environmental, economic and social aspects of sustainability in the construction industry, as well as to outline the most important factors hindering the transition to a circular economy. Our study shows that what need to be developed are knowledge sharing related to sustainable construction, support for the market access of green innovations in construction, knowledge sharing related to sustainable technologies, materials and processes, information dissemination and training supporting the sustainability knowledge of all players in the sector, flexible regulatory and licensing procedures, and last but not least, connection and more significant cooperation of the participants in the value chain.

These few aspects contribute to that those directly or indirectly in contact with construction processes review their tasks and possibilities. The fragmentation of the value chain can end if everyone realizes that they can do something to put the construction industry on a sustainable path.

Keywords: sustainable construction, circular economy, green construction, green economy, life cycle, green innovation

1. INTRODUCTION

The construction industry is the world's largest industry, employing 7% of the world's working population and accounting for roughly 13% of the world's GDP.[1] We are talking about an industry that has accompanied us since the beginning of humanity, adapting to the housing and infrastructure needs of humanity at all times. Nowadays, however, we can witness a paradigm shift. The industry was also faced with the fact that it is among the most polluting from an environmental point of view, the raw materials necessary for its operation are running out, as is the built-in area required by the built elements. These general trends also led the construction sector to introduce more environmentally friendly solutions and use more sustainable materials during construction activities. Accordingly, the concept of sustainable construction was formed, as defined by Kibert (1994) as "...a practice of creating and operating a healthy built environment that is based on resource efficiency and ecological principles." [2]

To meet these expectations, solutions must be found that take into account the specifics of the construction industry and at the same time satisfy the constantly changing needs of all three segments of sustainability (environmental, social, economic). This results in completely new raw materials, technologies and procedures, as well as the transformation of the execution and quality control of construction investments, as well as the internal operation of construction companies from a sustainability point of view.

In this study, we summarize the most important questions that currently arise in connection with the sustainability of the construction industry.

2. SUSTAINABILITY OF THE CONSTRUCTION INDUSTRY

The sustainability of the construction industry can be examined from many aspects. The sector has an impact on all segments of sustainability and their individual parts have an impact on the construction industry itself.

Below we review the interaction that can be discovered between certain segments of the construction industry and sustainability.

2.1. The environmental sustainability of the construction industry

Determining the ecological footprint of the construction industry is an extremely complex task and its factors range across a very broad spectrum, so for example, environmental impact and carbon dioxide emissions are only parts of it. The professional literature of recent years already deals independently with, for example, the ecological footprint of residential buildings [3] and construction machinery [4].

The ecological footprint measures how much land and sea a human population needs to sustain its way of life. The ecological footprint is a resource accounting tool that measures the Earth's ability to regenerate (or "biocapacity") required by a given activity.[5] Biocapacity is usually expressed in global hectares (written as "gha") or global hectares per capita. In 2008, the Earth's total biocapacity was 12.0 billion gha, or 1.8 gha/person, while humanity's ecological footprint was 18.2 billion gha, or 2.7 gha/person.[6] Rees (2010) noted that "humanity has already exceeded global biocapacity by 30% and is now living unsustainably by depleting infrastructure of 'natural capital'." [7]

Among the various ecological components, most research in the last decade has focused on the water footprint and the carbon footprint.

In relation to the construction industry, a basic preliminary question is the determination of how much and what kind of the world's infrastructure is. In this regard, we mostly only have estimates, but a research published in March this year presented World Settlement Footprint 3D method (WSF 3D), which quantifies the total area, average height and total volume of the building infrastructure.[8] According to this, the world's total construction area is 291,577 km², its average building height is 5.55 m, and its total volume is 1,632 km³. These data can bring us closer to establishing the quantitative indicators of the building infrastructure to be examined globally, or even locally (in relation to a country or a settlement).

If we already know the size and structure of the quantifiable global building infrastructure, it could be followed by the calculation of its ecological footprint. As we mentioned, research and regulators are currently examining one segment at a time (e.g. CO₂ emissions, waste generation, soil or noise pollution). On the other hand, in this industry, examining the quantifiable environmental effects of built elements during their entire life cycle is also a challenge. Several methods have been developed to answer this. One of the most well-known of these is the life cycle assessment (LCA) of buildings, which means the evaluation of the effects related to the different phases of the entire construction life cycle process in accordance with the "cradle-to-cradle" principle. [9-11]

LCA evaluates the environmental impacts of different products and services, such as buildings, from the extraction and production of materials, through construction and operation to waste recycling. [12]

A specific sub-methodology of LCA is the life cycle carbon emission assessment (the so-called LCCO₂A, which is also called "carbon footprint analysis"). Regarding the construction process, LCCO₂A is typically examined by science in four building life cycle stages: the product stage, the construction stage, the operation stage and the "end of life" stage. Overall, we see from international research that on a global level, the construction and end-use stages account for the smaller part of the total emissions (Fenner et al 2018). [13] This research found no significant difference between the carbon intensity per unit area of residential and non-residential buildings over the entire life cycle, with an average of approximately 54 kg CO₂-eq/m²/year for both types.

Later on, we will also see that LCA deals not only with the environmental aspects of the construction industry, but also with its economic and social aspects.

In the construction industry, LCA is primarily used in various sustainability rating systems (such as BREEAM-en-Building Research Establishment Environmental Assessment Method , [14] by LEED - Leadership in Energy and Environmental Design, [15] by DGNB -Deutsche Gesellschaft für Nachhaltiges Bauen , [16] the HQE- Haute Quality Environnementale , [17] by GRIHA - Green Rating for Integrated Habitat Assessment , [18]) Comprehensive Assessment System for Building Environmental Efficiency - CASBEE , [19] or the International Initiative for Sustainable Building Environment . [20]

In order to accurately extract the input data required to perform the LCA of the building, usually the Building Information Modeling method (BIM) is used. [21-23]

In addition to the multitude of different methods, several parallel standards with different methodologies have also been developed in connection with the examination of topics of the ecological footprint, such as the greenhouse gas emissions of products or the life cycle assessment, as well as the framework for the valuation of construction works and construction products. [24]

According to some authors, buildings and constructions are globally responsible for approximately 40% of greenhouse gas emissions. [25] The total CO₂ emission of the global construction industry was 5.7 billion tons in 2009, which corresponds to 23% of the CO₂ emission of the world economic activity. The largest CO₂ emissions of the global construction industry occurred in China, the EU-27 was the second largest direct CO₂ emitter (18%), and the USA was third (13%).

According to the 2021 information of the International Energy Agency (IEA (2021), direct and indirect emissions from construction operations fell to around 9 Gt in 2020 after increasing by an average of 1% per year since 2010, mainly due to the Covid-19 pandemic in the service sector due to its lower activity and the decarbonization of energy production [26].

The situation in the field of energy consumption is not favorable either: according to some researchers, the sector is responsible for 50% of primary energy demand and resource consumption. [27] Last year's IEA report also highlights that about 9% of global energy-related CO₂ emissions come from the use of fossil fuels in buildings, another 18% from electricity and heat production used in buildings, and another 10% is related to construction material production.

Therefore, the entire life cycle of the building is directly and indirectly responsible for nearly 37% of global energy-related CO₂ emissions. Research has also proven that the share of the sector is similarly high in terms of waste generated (globally 30%) [28] and water use (globally 15%) [29].

In addition, according to the European Commission, about 50% of all extracted materials can be linked to the construction industry and come only from material extraction. Construction materials production accounts for approximately 11% of the world's total greenhouse gas emissions. [30] Greater material efficiency can save 80% of emissions. [31] In Hungary in 2019 the annual CO₂ emissions equaled to 37,058,145 tons, of which construction was responsible for 1,274,406 tons (nearly 3.4%).[32]

Due to the incorporation of natural areas, the built environment also has an unfavorable effect on biodiversity. To mitigate this, more and more blue-green infrastructure solutions [33] and many so-called biodiversity-friendly construction methods [34] were developed. These have a positive effect not only on the living world of the green-blue infrastructure, but also on the air quality [35] in relation to the increasing air pollution due to urbanization.[36]

Some authors also point out that climate change modifies the precipitation pattern and the amount of precipitation that falls at the same time often becomes unpredictable.[37] The permeable surfaces of the natural environment have been replaced by impermeable surfaces as a result of urbanization.[38] The increase in impermeable surfaces and the increased rainfall intensity resulted in the increased vulnerability of infrastructural elements, inundations and floods.[39]

In addition, the expansion of the built environment has intensified the Urban Heat Island (UHI) phenomenon, which is characterized by the temperature difference between the central urban areas and the surrounding suburban and rural areas. The resulting heat stress causes health problems for the vulnerable population. [40]

At the same time, not only the construction industry affects the natural environment, but environmental factors also affect the built environment. Due to exposure to climate change, some elements of the built environment are more easily eroded. High temperatures, floods, inland waters, and high UV radiation can result in a significant deterioration in the quality of individual infrastructure elements. Science tries to provide an adequate response to these challenges and to develop weather-resistant or otherwise resilient materials, or to further develop certain features of the existing ones in such a way that they are more resistant.

2.2. The economic sustainability of the construction industry

The construction products sector comprises approximately 430,000 companies with a turnover of approximately €800 billion and a gross value added of approximately €240 billion. It mainly serves the construction industry, which is one of the 14 industrial ecosystems defined in the updated industrial strategy, contributes significantly to the EU economy, has a gross value added of €1200 billion (10% of the total value added) and employs 25 million people.[41]

Accordingly, the sector's economic importance is unquestionable.

In the European Union (EU27_2020) and the eurozone, the weight of the construction industry - in terms of added value - has been 5.0-5.6% since 2011, and in the Visegrad countries it has been between 5.5-8.0%.

In Hungary, according to data from the Central Statistical Office, in 2020 the construction industry accounted for 5.5% of the added value of the national economy. [42]

Within the European Union, the performance of Germany and France in the construction industry is outstanding, at EU level the former accounted for 27% of the added value of the national economic branch, the latter for 16%, the share of other member states was below 10%, the V4's share was 8.3%, and Hungary's had not reached 1%.

The Hungarian economy started to grow in 2013. Between 2013 and 2019, the volume of GDP grew by an average of 3.7% per year, overall by 29%, with more than double of the EU average. The favorable trend was broken in 2020 by the Covid-19 pandemic, after a 4.5% decline, the economy's performance increased by 7.1% in 2021. As a result, similarly to the majority of EU member states, the volume of GDP in Hungary also exceeded (by 2.3%) its pre-epidemic level in 2019.

After 3 years of dynamic expansion, the volume of Hungarian construction industry production decreased by 9.7% compared to the previous year due to the Covid-19 epidemic and the completion of major road and railway development projects in 2020. In 2021, it gained momentum again and the volume of production increased by 13%, mainly as a result of the 17% expansion of building construction, but the construction of other structures also rose by 9.1%. At the same time, the order book of contractors at the end of December 2021 was 13% lower than a year earlier, the demand for building construction fell by 14%, and the contract book for the construction of other structures also decreased by 13%. In addition, despite the COVID-19 epidemic, in 2021, the revenue of more than three quarters of businesses increased compared to the previous year.

Like the national economy as a whole, the Hungarian construction industry has long been characterized by the numerical predominance of small and medium-sized enterprises. In recent years, 90% of registered businesses had fewer than 5 employees. The proportion of organizations with at least 50 employees did not reach 1%.

After the epidemic situation, the Ukrainian-Russian war situation also had its effect. The Hungarian National Trade Union of Construction Contractors contacted the member organizations and other significant actors of the construction industry, 400 companies, and assessed what changes the market conditions brought in 2021, and what expectations the companies have for 2022 in the shadow of the war conflict. [43] 83% of the responding companies highlighted the lack of professionals as the most impeding factor in their activities. However, the Russian-Ukrainian war was not far behind, which 80% of the companies participating in the survey marked as an obstacle. Procurement difficulties were mentioned as the third most common obstacle to business activity (77%). The exchange rate fluctuations

caused by the Russian-Ukrainian war caused losses to 93% of the responding companies. The war causes a shortage of construction materials for 89% a labor shortage for 33%, and a loss of market for 30%. According to the companies' expectations, this year the price increase of construction materials (25%), freight costs (23%), changes in the price of removal and disposal of construction debris (22%), and changes in subcontractor rates (17%) will be the largest. Respondents expect a price increase of 29% for thermal insulation materials and 28% for wood materials among construction materials.

From an economic point of view, the construction industry can therefore be considered a vulnerable sector in many aspects: while the epidemic situation has less effect on the Hungarian construction industry, the current war and energy crisis has more effect on the construction industry as well, which is significantly mitigated by domestic renovation and housing construction subsidies.

At the same time, construction and infrastructure investments have many economic benefits. The green building project impact on the local economy. It creates new jobs through the project, supports local raw materials sourcing, integrates local producers, services. Adding to this is the indirect economic effect that, in the case of buildings affected by sustainable solutions, the characteristics of the given building typically improve, thereby providing more pleasant and healthier working conditions for employees, which can result in higher efficiency and productivity. Thanks to this, the construction industry can become one of the leading sectors of the green economy if it can subject its use of materials, procedures and technological solutions to the principles of sustainability. The construction industry is also a quasi-background sector for the other sectors, as it provides superstructures and infrastructure for their operation, and with its sustainable solutions it increases also the quality of services. Thus, the sustainable solutions of the construction industry essentially contribute to the sustainability transition of other sectors as well.

Several methods have been developed in the literature to evaluate the economic sustainability of the construction industry [44]. Perhaps the best known of these is Life - Cycle Costing (LCC). LCC is a method for assessing the total cost over time of a product, project or system, [45] which takes into account all costs –, including initial costs, future costs, and resale or disposal costs. [46]

Regarding construction industry investments, a number of project management solutions [47] have also been developed, which aim to reduce the costs projected over the entire life cycle. The concept of sustainable investments extends from the preparation of investment projects to the end of the superstructure's operation and "lifetime". The superstructures can last up to several lifetimes, so we can only estimate their sustainability effects in advance. On the other hand, we see that projects that take sustainability aspects into account are also more sustainable in an economic sense. Well-prepared project preparation [48], which also takes sustainability aspects into account, determines the entire life cycle: carefully chosen raw materials, technologies, mitigation of transport routes, the use of local suppliers, the preparation of project-level waste management plans, the use of energy supply systems appropriate to the function of the superstructure and through many other sustainability tools, construction projects can become more economical, by optimizing the use of resources and exploiting the synergies of capacities, they can also become more sustainable in an economic sense.

For this, it is essential to develop and support the knowledge and innovation of the sustainable construction industry and the market for sustainable products and services. The global sustainable building materials market is estimated to grow to \$425.4 billion by 2027.[49]

2.3. The social sustainability of the construction industry

As we have already indicated, the construction industry is in many respects an industry that cannot be replaced: it provides housing, jobs, accommodation, infrastructure elements to the population, the state and other industries. At the same time, the examination of the social sustainability of the construction industry has only come to the forefront of research in recent years. Most literature sources mainly deal with environmental or economic sustainability.

There are many points of view known regarding the social sustainability of the construction industry: according to some, the construction industry creates facilities in the context of social sustainability that promote well-being, help in understanding the needs of the people living there, [50] encourage social

integration, and promote the improvement of the population's quality of life.[51] Others also highlight that socially sustainable construction projects can create a harmonious living environment while reducing social inequalities.[52]

The construction industry is an important social value-creating sector.[53] However, only a few authors undertook a comprehensive examination of the sector's social aspects.

As we mentioned, during the social sustainability of the construction process, the emerging needs must be taken into account: the needs of the users of the facility, the closer and wider population, the residents of the settlement or district, the needs of those participating in the construction process and the construction value chain.

The examination of the literature shows that the most commonly recognized social needs in construction projects are privacy, quality of the internal environment, health, social participation, safety, accessibility, identity, physical resilience, satisfaction, cultural values, etc., while among developing countries, mostly cultural heritage, open spaces, health and well-being, satisfaction, privacy, etc. are concerned. [54] These needs are always significantly influenced by the social, economic and regulatory characteristics of the given country.[55]

Here we should also mention that green buildings increase the level of satisfaction of their residents [56] and their return of investment is more favorable in the long term as a result of the integration of environmentally sustainable design and green features.[57]

Among the methods developed in terms of social sustainability in the construction industry, the most well-known is the social performance assessment (S-LCA), which can assess the social and socio-economic aspects of services, projects and products, taking into account the actual and potential positive and negative impacts during the life cycle. [58] S-LCA involves stakeholders in goal and scope definitions, data collection and interpretations, which differs from the previously mentioned LCA and LCC methods. [59] S-LCA indicators can be sustainable behavior, health, safety, number of deaths, human rights, responsibility, architectural quality, architectural diversity, added social value, future value, historical continuity, cultural heritage, governance, socio-economic impacts, and labor policy. [60] Some certification systems already examine these social aspects when evaluating the sustainability of buildings (e.g. DGNB or WELL). [61]

Finally, we would like to emphasize that sustainability efforts related to the construction industry and construction can be effective if all three aspects of sustainability are taken into account.[62] The Life cycle sustainability assessment (LCSA) methodology [63] contributes to the evaluation of green building projects or circular building strategies from a broader sustainability point of view. [64]

3. THE CHALLENGES OF THE CIRCULAR ECONOMY FOR THE CONSTRUCTION INDUSTRY

The above-mentioned sustainability of the construction industry has many advantages: environmental, economic, and social. However, to achieve these, change is needed. The transition to a circular economy can be one of the tools for this change. At the EU level, the circular economy is one of the main policy priorities, which appears in the 2015 circular economy action plan and in the new circular economy action plan published in 2020 as part of the European Green Deal, with regard to the construction industry, as a particularly resource-intensive sector. [65]

The linear production and consumption model, which includes the take-make-dispose philosophy, pairs economic growth with excessive resource consumption.[66] The circular economy represents an economic system that aims to reduce waste and the use of resources.[67] In essence, CE creates a closed-loop cycle by focusing on the recycling and reuse of resources , creating a restorative system through long-term planning, maintenance, repair, renovation and minimization of waste and GHG emissions.[68] As a result of CE, the output of each circular process becomes the input of another process.

Numerous studies deal with a comprehensive analysis of the scientific literature examining the aspects of the circular economy in the construction industry.

George et al. in their study [69] investigated the strategies for the application of CE at the building level. According to the study, one group of CE strategies deals with improving the management of materials flowing in and out of the construction process. [70-71] The second group of strategies deals with the design and construction of flexible, adaptable and demountable buildings, extending their useful life by reinterpreting the reuse of spaces and parts. [72] A third large group of CE strategies is the development of new organizational and management structures, new business models, green deals, and digital collaboration tools created along the value chain of the construction industry. [73]

The transition to CE cannot be achieved solely through product or process innovation. Fundamental changes are needed in the underlying value-creating system (Angelis (2021) [74]), which applies to the players of the construction process, the customers, suppliers, the users of the superstructures and the players of the construction policy system.

The transition to a circular economy is also a special opportunity for the sector: it includes renewal, new perspectives, alternative materials, solutions, digitization and modernization. However, the transition is not an easy process. The most important challenges for the construction industry in terms of the transition to a circular economy are the following:

- a) terminological gaps: reviewing the literature sources of the last three years of green construction (Scopus, WoS), we found that the construction industry definition of the circular economy is still missing and the resulting interpretation problems result in a lack of effective CE practical knowledge within the construction industry. Even terms used in the international literature, such as green construction and sustainable construction, are used interchangeably by several authors, despite the fact that their meanings are not the same.[75]
- b) supply chain complexity: construction projects mostly have extensive, complex supply chains.[76] This means that the value chain is extremely complex, with thousands of players in the case of more complex investments. The actors of the individual stages of the value chain (design, construction, maintenance, reuse or recycling) usually do not know each other and move within the boundaries of their own supplier tasks and responsibilities. It is not surprising that the this way fragmented value chain is dominated by short-term goals, profit making and obtaining as many orders as possible. The development of sustainability strategies covering the entire value chain and the effective sustainability project management that implements them play a key role in resolving this.
- c) lack of knowledge of sustainable technological solutions: the sustainable construction industry and the sector's transition to a circular economy is one of the central issues of research affecting the sector. Studies are published every day that present a new construction technology, raw material or scientific connection subordinated to this target system. Mhatre et. al's (2021) study, for example, found that, compared to 2007, thirty-five times more studies were published in connection with the construction circular economy in 2020.[77] With this extremely fast development curve, the education system serving the construction industry cannot keep up. In today's university disciplines, in addition to economic connections, the teaching of technological solutions is still in its infancy. However, in order to properly integrate sustainability principles into all segments of the value chain, they must be known and applied by everyone who comes into contact with the construction process.[78] For example, the European Commission also found that approximately 80% of the carbon footprint of products is due to the design process.[79] Accordingly, having knowledge of product design, modular construction, and efficient production processes can be one of the cornerstones of the transition to a circular economy.[80]

This is also important because there is no uniform circular economy methodology or general remedy that can be applied to all projects in all construction industry segments: you need to know the specific project and the sustainable construction methods that can be linked to its implementation. Countless factors must be taken into account during the implementation of a

project, so another important issue of knowledge sharing is ensuring the acquisition of sustainability knowledge.[81]

- d) low customer demand for sustainable construction practices: customers are often unaware of sustainable construction solutions and their benefits. [82] As a result, most clients will only support sustainable building practices if they conform to traditional building practices. [83] An electronic platform on which different sustainable construction industry solutions and green innovations are presented along the same lines can be suitable for solving both the previous point and the problem mentioned in this paragraph.
- e) the high cost of sustainable practices: the cost of sustainable construction solutions has been investigated by many studies. In general, the estimated cost of sustainable construction is 1-25% higher than that of a conventional building.[84] In part, this can be explained by the fact that the sustainable building materials available on the market are also more expensive, such solutions are more complex and require more specialists.[85] At the same time, some authors have also drawn attention to the fact that CE is expected to generate economic growth as well, including job creation and contribution to countries' GDP , [86] resource efficiency, material cost savings, and savings due to CE waste management costs, increased income from waste sales to CE . [87]

In terms of job creation and GDP growth, the Ellen MacArthur Foundation (2015) highlighted that if resource efficiency is increased by 30%, CE will increase GDP by 1%, creating approximately two million jobs worldwide by 2030 . [88]

- f) the complexity of the processes related to sustainable construction: as we mentioned, the transition to a circular economy in many respects, lack of information, knowledge, fear of the new, or the pursuit of momentary advantages diverts investors from the processes of building sustainable buildings. Excessively complex and complicated technologies and prior authorization and certification procedures often hinder the entry of sustainable construction innovations into the market.
- g) long administrative processes can lead to the prolongation of sustainable construction processes: according to Graeber, the bureaucratic process of integrating new and modern technologies in construction projects can increase the completion time of projects [89] and unsettle the clients, therefore it is also necessary to review the regulatory and licensing aspects of construction sustainability.
- h) the current business models: investors often prefer the use of cheaper and less sustainable solutions, aiming for a short-term return. However, this does not necessarily follow the lifespan for which the building was designed. For this very reason, most authors emphasize the importance of long-term, whole-life business planning. In this regard, the literature names five general business models for the transition to CE: these are the lifetime model, [90] the circular input model, [91] the product as a service model, [92] the platform model, [93] and the waste value model. [94] The sustainability of the construction industry requires the transition of construction companies to a sustainable business model, the transformation of their business policy, business management and reporting methodology from a sustainability point of view, [95] and to learn about and embrace green innovations in construction.

4. CONCLUSIONS

The aim of this study is to highlight the challenges faced by the construction industry and at the same time draw attention to the fact that sustainability holds many opportunities for the sector as well. Our study also aimed to create a connection between the circular economy and sustainability. The circular economy is one of the tools for a sustainable transition, which presupposes a rethinking of the construction process as a whole. However, it is not sufficient in itself for a sustainable transition, it also requires a change in the sustainability-related perspective of those who participate directly or indirectly in the value chain. A sustainable model based on the environmental, economic and social effects of the circular economy, which has a very important role in closing the material loops and can create economic

and social interactions in the entire vertical of the construction process and value chain. However, in order to transition to a circular economy, there are still many tasks ahead of us: regulators, corporate business models, the system of training and further education, as well as the communication and social acceptance of the benefits of sustainable construction must be developed.

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