Construction Waste Production in Macroeconomic Context

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Abstract. This article aims at presenting the economic impacts of implementing the basic principles of construction demolition waste management in terms of saving construction costs. Emphasis is placed on fulfilling the 3R principle, i.e. reducing waste, reusing it, and recycling resources and products. Construction and demolition waste represents the largest mass waste flow in the EU, e.g. in 2018, it represented 36% of the total waste production in the whole EU-27. The European Union is gradually introducing measures to reduce the production of construction waste compared to the Czech Republic, where the share of construction demolition waste on the total production was up to 42% in 2018. This value exceeds the EU-27 average. The article analyses available statistical data from the national CZSO and the European statistical office EUROSTAT on the waste production classified according to EWC-STAT, which is a classification of waste according to Directive No. 2150/2002. Items monitoring the waste produced by the construction industry are listed on the 41st to 43rd place of the EWC-STAT list of all monitored waste. The data obtained allows comparing three branches of construction production, the 41st Building construction, 42nd Civil engineering, and 43rd Specialized construction activities. Another possibility to obtain data is to use a division according to the waste producer economic activity (CZ NACE). The data obtained in this way is compared with the performance indicators of the national economy. By comparing the size of the construction demolition waste production with the performance of the national economy (especially the GDP indicator), the degree of their interdependence was determined. The aim of the analysis is to assess the relation between the country's economic performance and the production of construction and demolition waste. The next step was to perform an analysis from the point of view of the 3R principle in order to examine the impact of measures to reduce the construction demolition waste production in connection with the already initiated processes of its possible recycling or reuse.

1. Introduction

All over the world, the construction industry consumes a large number of natural resources that are extracted from nature. The extraction and processing of raw materials for the construction industry generate a lot of waste. Moreover, the construction activity itself generates a large amount of construction waste as well. The largest share is accounted for by rubble and other construction waste generated during construction activities, such as reconstructions, demolitions and new constructions. The construction industry is one of the largest sectors of the Czech economy and contributed by CZK 502 billion to its economic production, which represents 9.9% of the total volume in 2018, as shown in Table 1. The fact is that construction, demolition, and renovation work produce about 16 million tons of waste in the Czech Republic every year.

The construction industry is considered to be the largest sector in terms of economic expenditure, environmental impact, resource exploitation, job creation and waste generation. The construction industry faces problems related to the economic and environmental impacts resulting from non-compliance with the principles of resource management. Relatively significant economic and environmental benefits are expected from the minimization of construction demolition waste [1] [2]. The expected benefit for both the environment and the construction industry is cost savings. The key challenge for waste minimization is to design the right management strategy that aims at reducing or preventing construction waste creation. This article focuses on the issue of waste awareness and construction demolition waste management, strategies and current practice in the construction industry in the Czech Republic. It further concentrates on evaluating the economic viability of the application of the 3R principle to construction and demolition waste in terms of cost savings.

Table 1. Development of the GDP of the Czech Republic since 2009 [3]

Years	GDP at current prices (billion EUR)	Share of construction GDP	GDP change in %
2009	148.7	14.3	...
2010	156.7	13.3	5.38%
2011	164.0	12.2	4.66%
2012	161.4	10.5	1.59%
2013	157.7	9.8	2.29%
2014	156.7	10.1	0.63%
2015	168.5	10.3	7.53%
2016	176.4	9.0	4.69%
2017	191.7	9.0	8.67%
2018	207.8	9.9	8.40%
2019	220.9	...	6.30%
2020	221.2	...	0.14%

2. Waste creation prevention - current situation

2.1. Construction industry in the Czech Republic

In June 2020, construction output in the Czech Republic decreased by 2.0% month-on-month in real terms. It decreased by 11.5% year-on-year. Production in building construction decreased by 14.7% compared to the same month last year. Production of civil engineering decreased by 3.2% year-on-year. Smaller companies and sole proprietors, who focus more on building construction, experienced a more significant decline in production compared to larger companies. [3]

The Czech construction industry reached one of its peaks in 2010. In 2018, after several years of decline, the construction industry increased its share in GDP. In no industry, trade and selected services did the GDP value in 2018 grow in absolute terms as fast as in the construction industry. In 2018, the share of the construction industry in GDP was 9.9%. Figure 1 shows the value of construction work at current prices in individual branches of the construction industry during the years 2018-2020. It is obvious that the majority of construction activities is represented by civil engineering and construction work associated with the repair and maintenance of buildings. The figure shows the obvious slowdown in construction activities due to the crisis of 2010. [3]

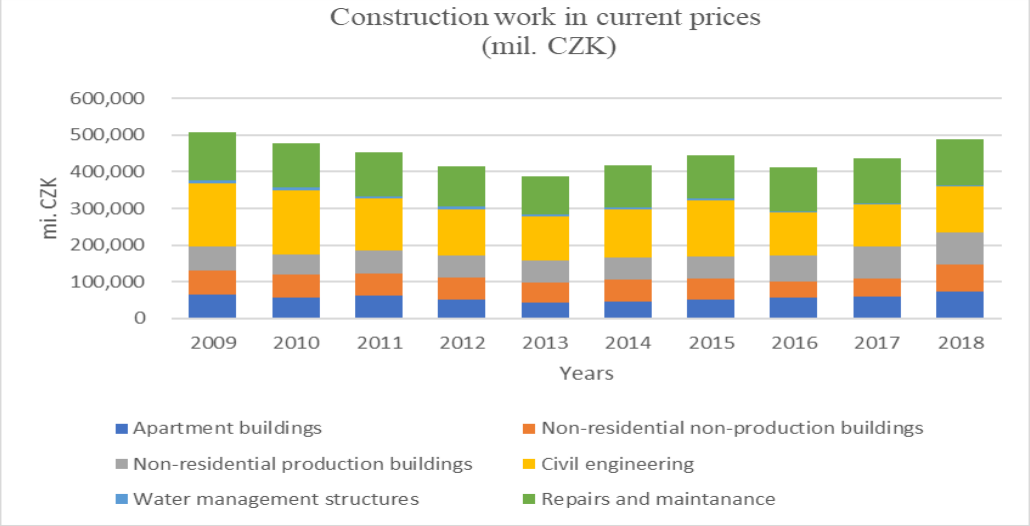

Figure 1. Construction work in current prices in years 2009-2018 [3]

2.2 Construction and demolition waste in the Czech Republic

In EU countries, there is an average of 700 to 800 kg of construction waste per capita (excluding excavated soil) per year; in the Czech Republic, it makes less than 170 kg/year according to official statistics from the Ministry of the Environment compiled by the Ecological Institute. However, based on an extensive ARSM survey, the real minimum value is about 400 kg per capita and year and about 1,200 kg per capita and year including excavated soil. [4]

Table 2 shows the specific amounts of waste produced in tonnes per year. The classification of waste into the given categories is based on the CZ-NACE classification of economic activities. [3]

Table 2. Waste generation by NACE divisions [3]

	CZ-NACE	**2017 tonnes**	**2018 tonnes**	**2019 tonnes**
Waste generation, total		34,381,219	37,665,600	37,031,438
Building construction	41	3,773,525	4,833,641	4,609,805
Civil engineering	42	6,753,954	7,741,203	7,828,947
Specialized construction activities	43	2,964,733	3,224,617	3,100,783

Table 3. Average share of construction waste components [4]

Component	**Share in %**
Excavated soil (loose soil)	65-75
Material from road demolition (material from traffic areas without soil)	10-15
Demolition construction mineral rubble	5-20
Construction site waste	5-15

The proportions of waste components differ according to the urbanization and industrialization of the area; therefore it is necessary to consider the given values only as average values. The quantification of construction waste listed in Table 3 is based on the construction technology, the average age of the demolished buildings and the density of construction. [3] In the case of building constructions, rubble and waste contain a number of substances according to the specific construction. These substances are always closely related to the building and may contain the following categories of material: topsoil,

concrete (possibly with steel reinforcement), brick masonry, mortar, plaster materials, wood, plastics, ferrous and non-ferrous metals, paper, resins and residues of paints and sealants.

Components of construction waste and their quantities are statistically processed and evaluated. Table 4 shows the quantities produced in the Czech Republic in 2012. There is a visible difference between the average values given in Table 3 and the quantities given in Table 4 due to different methods of obtaining this data.

Table 4. Amount of construction waste produced according to the CZSO in 2019 in the Czech Republic [3]

EWC	Waste	Quantity generated in 2019 (tonnes)	Percentage (%)
1701	Concrete, brick, tiles and ceramics	5,019,881	24.3
1703	Bituminous mixtures, tar and tar products	818,071	4.0
1705	Soil (including excavated soil from contaminated sites)	13,996,576	67.6
1706	Isolation and construction materials with asbestos	87,548	0.4
1708	Building material gypsum-based	11,378	0.1
1709	Other construction and demolition waste	763,809	3.7

The material cost component represents about 18% to 65% of the whole construction cost. This shows that the production of construction waste from construction activities is huge in terms of both waste volume and price. For this reason, there is a need for the economic evaluation of waste generated during the consumption of building materials in the construction industry using appropriate waste minimization techniques.

The role of waste reduction is not only played by the designers, contractors, subcontractors, project participants and clients who play a significant role in providing better construction waste management performance but also the government supports it by its legislative documents. In practice, almost every construction company in the Czech Republic uses procedures to minimize construction waste. The most common procedures used by companies were waste sorting, material handling and improved storage methods.

The Government of the Czech Republic adopts legislation, economic instruments and voluntary agreements to meet the goals of ethical, social and environmental behaviour. There is an effort for a step change in the sustainability of the procurement, design and operation of all projects under construction to be driven by innovation [5]. It is stated that "waste is considered relentless"; lack of training and insufficiently defined responsibilities are fundamental issues in the design of buildings [6].

The technologies used in the treatment of construction demolition waste, especially various types of separation techniques used for most materials, often attract advanced technological possibilities and subsequent legislative monitoring based on the principles and the 3R hierarchy in waste management (Reduce, reuse, recycle). This hierarchy is shown in Figure 2. The concept of waste management is governed by the level of hierarchy explained by El-Haggar [7]. This model creates a comprehensive approach in which waste management options can be considered and thus serves as a systematic tool for those who generate and manage waste [8]. El-Haggar [7] notes that if waste is managed efficiently, it can have a positive impact on the environment throughout its life cycle, from its generation to final disposal. Proper construction waste management provides economic and environmental benefits. Construction companies, but also the environment, shall benefit from the process of reducing waste disposal costs.

The economic and environmental benefits expected from waste minimization are relatively high, as they lead to opportunities, recycling and opportunities to sell secondary waste materials as a necessary new source of raw materials. Meeting the reduction targets of the waste that ends up in landfills is another benefit [8]. Landfilling of waste is often associated with fees, so minimizing landfilled waste can significantly affect the total cost of construction. The financial profitability of construction can be minimized if the flow of waste from the construction is effectively managed.

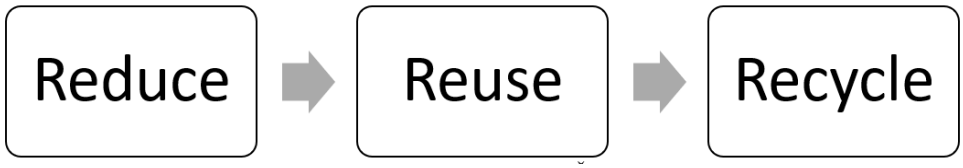

Figure 2. 3R principle

2.3. Procedures used for construction waste reduction in the Czech Republic

Waste minimization in the Czech Republic is not a new concept in the construction industry. Waste management in the Czech Republic involves proper compliance with the list of legislative regulations and standards. The Waste Framework Directive provides the European Union with a legislative framework for the collection, transport, recovery and disposal of waste and contains a common definition of waste [9]. Current procedures in the Czech Republic can be divided into the following categories:

- Waste-free design.
- Waste minimization at the time of purchase.
- Separation of individual types of waste on the construction site.
- Monitoring the waste flow on the construction site.
- Development of construction site audit and evaluation procedures.
- Guidance by legislation.
- Immediate recycling and reuse on the construction site.
- Methodology including waste minimization and a procedure for designers.
- Construction waste qualification and source assessment.

The strategies mentioned above serve to raise awareness of the benefits of minimizing waste generation in the construction industry, including cost savings and positive environmental impact. The main reason for using these procedures is legislative and fiscal measures, which are the main driving force for reducing construction waste. This process is directly proportional to the increasing tax burden across the European Union for landfilling, increasing the cost of waste disposal and complying with the on-site waste management regulation. Unfortunately, current legislation does not impose responsibility on architects for waste minimization, which is by far the most practical way to reduce waste at an initial designing stage, rather than implementing waste minimization measures later in the construction phase [6].

3. Waste management and problems associated with its use in the construction industry

The construction industry in the Czech Republic is facing pressure from environmentalists to address waste management. However, the economic benefits in terms of cost savings are still limited. The following key barriers were identified in several studies, e.g., Osmani [10], Hansen et al. [11] and Saez et al. [12].

These are mainly:

- Non-compliance with legal regulations.

- Lack of data on waste management strategies.
- Lack of qualified human resources.
- Incorrectly defined powers and lack of training.

Non - compliance with legal regulations
Constantly updated legal regulations and standards put pressure on the producers of construction demolition waste to reduce the amount of waste produced. Nevertheless, there is no significant reduction in the amount of waste produced.

Lack of data on waste management strategies
Individual construction companies, mostly the small ones, do not have enough suitable information on modern waste management strategies. An important element of a proper waste minimization strategy is its incorporation since the very beginning of the project.

Lack of qualified human resources
Human resources are an important part of the proper implementation of a waste management strategy. Unfortunately, the lack of qualified persons in the field of waste management process management causes problems both in the actual implementation of the strategy and during its monitoring by the state authorities.

Incorrectly defined powers and lack of training
Improperly defined competencies in designing waste management strategies are becoming an increasing challenge. Sufficient training is a simple tool to help designers and architects design waste reduction measures in construction projects [10].

In the Czech Republic, the construction industry has made a positive contribution to waste minimization over the years. The 3R principle (reduction, reuse, recycling) implementation contributed to this result. In particular, the impact of waste management legislation, landfill taxes and their impact on construction waste management cause a number of controversies [13]. A management tool such as SMART Waste, developed in the UK, or EU Directive 2008/98/EC helped the construction industry to efficiently handle and better manage waste generation on the construction site and to assess the associated consequences of cost savings. Tools such as SMART Waste and EU Directive 2008/98/EC make it possible to carry out an audit, manage waste and analyse the costs associated with waste management.

Fees and taxes for waste management and disposal were introduced in the Czech Republic. These additional costs support reuse and recycling strategies. If the construction industry has to minimize waste production as a part of its main activity, further measures are needed to save reuse and recycling costs [14]. The main reason for waste generation is its relation to designing, other contributing factors are related to the inefficiency in the building material use [15]. An important step for the construction industry is to understand these key factors and be able to mitigate the scope of the emerging problem.

4. Possible increase in construction economic efficiency related to waste management

4.1. The cost-saving viability of waste reuse and recycling

The increase in construction economic efficiency related to waste management is based on the idea of minimizing the cost. It enables to reduce the total construction costs in this way. Savings can be determined through the Cost-benefit analysis [16].

CBA can be used to estimate the economic efficiency of construction waste flow throughout the processing chain. Several studies have confirmed that the economic impact of recycling can be measured through industrial production, total income, value added and the number of jobs created [17; 18]. The

analysis estimated the net benefits of evaluating the economic viability of reusing and recycling waste. The net benefit can be calculated using the following relation [19]:

$$N_B = T_B - T_C \quad (1)$$

Where:

N_B	Net benefits
T_B	Total benefits of reusing and recycling construction waste
T_C	Total costs of reusing and recycling construction waste.

The goal of waste management from an economic point of view is the expected cost savings associated with minimizing the generation of construction waste and its recycling.

4.2. Efficiency in cooperation

In order for the waste minimization process to continually improve, it is necessary for all stakeholders to communicate closely with each other and to share their knowledge and experience. There is no consensus on what partnership relations are in the construction industry. Partnership relation can mean possible cooperation in improving technologies or developing new processes and technologies that would bring benefits to all cooperating parties. Several studies supported this concept as an approach to improving the construction industry [20; 21; 22].

These studies define partnership relation as a commitment between two or more parties in which there are a common understanding and development of trust in favour of construction improvement. The construction industry supply chain should consider "partnership" as a tool for eliminating this issue in order to guarantee optimal benefit from "zero waste".

4.3. Waste reduction design

Designers of all buildings are obliged to comply with legislative regulations. The designer during the project designing should take into account all aspects of the project in order to minimize waste and, above all, achieve construction cost savings. Recyclable building materials must be incorporated into the design at the initial stage of the project. A proactive approach to waste reduction options recognizes that some key project solutions are most likely to achieve favourable results in cost savings and environmental solutions.

4.4. Implementation reasons

The legislator should provide a comprehensive approach to the implementation of waste management legislation. The EU Waste Framework Directive is the basis for waste management in the EU [23]. The Czech Republic respects EU legislation and created its own legislation on its basis. Competent authorities should better inform their citizens about the benefits of the 3R principle in all industrial fields.

European Union legislation forces the Member States to introduce increasing landfill fees to minimize this type of waste disposal. The government should support companies that produce secondary materials from construction waste. An important role of the government is to guarantee that the construction industry does not increase the amount of construction waste.

However, the construction industry faces a key challenge such as imperfect management in the economic and environmental impacts of waste generation. It can be assumed that the introduction of certain forms of favouring the usage of recycled material will promote further growth of the waste reuse segment. The political context can help to raise awareness of the economic benefits of reusing recycled material.

4.5. Vocational training
Since the introduction of tools used for planning and control of waste impact management, construction companies have been aware of the need to develop vocational training in this field. Therefore, many construction companies invest in training their employees in these fields.

5. Waste use possibilities
Waste management strategies can help the construction industry in many ways in terms of cost savings and environmental impact. Construction demolition waste management is gaining prominence as major environmental issue in the world. This analysis proposes procedures improving the current situation. The analysis shows that the government and other stakeholders should continue to improve the conditions for minimizing waste production. The introduction of certain forms of benefits will significantly support entities that reduce the amount of waste deposited in landfills and support the use of recycled material.

New waste treatment technology helps reduce the amount of construction waste ending up in landfills. More efficient use of building materials would mean a significant reduction in the construction impacts on the environment, including a reduction in the demand for landfills and the depletion of limited natural resources [13]. It is possible to minimize the amount of waste generated during the designing phase of the building without increasing costs, however, by increasing the usability of building materials.

Lessons learned can promote that best practices are used to minimize waste from the initial designing phase of a project. Cost savings and environmental responsibility apply to building owners throughout the life cycle of a building. The benefit of cost savings through waste minimization procedures gives many entities a better position in the construction market.

6. Conclusion
The process of waste minimization is still topical in the Czech Republic, especially from the point of view of construction site management. It follows that the economic and environmental impact of waste reuse needs to be monitored and evaluated. The most common reasons for waste generation are an excessive waste of building materials, inefficient construction management, lack of knowledge about waste minimization strategies, but also a lack of administrative capacity at all levels of state administration which intensively deals with the topic.

The economic viability of construction demolition waste management on a construction site can be justified by the potential for cost savings. The benefits shall outweigh the costs of waste management by following the right waste management procedures. The research described in the paper examined the issue of construction waste awareness, current procedures and practices in the construction industry in the Czech Republic and the viability of applying the 3R principle to the construction and demolition waste in terms of cost savings.

The analysis found out that the benefits of reusing and recycling waste can lead to significant savings from the overall project budget. It is possible to minimize the costs of waste flow in the construction industry in the Czech Republic by introducing the 3R principle.

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