CIRCULAR ECONOMY OF CONSTRUCTION WASTE: REMOVAL OF WASTE STATUS AND REUSE OF RECYCLED AGGREGATES IN CONSTRUCTION AND ROAD CONSTRUCTION

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Abstract: *Globalization and industrialization have significantly impacted the dynamics of waste generation, management, collection, and processing, resulting in increasing amounts of various types of waste and serious environmental challenges. This paper analyzes the treatment and recycling of construction waste through the legislative framework and presents key challenges in the implementation of green policies in the Republic of Croatia. The methodological framework is based on a qualitative analysis of normative acts at the national level. Through statistical analysis and a detailed review of the waste categorization process, including the origin, type, and properties of waste, as well as statistical data on the produced, collected, and utilized amounts of construction waste in 2022, an insight into the current state of the construction waste management sector is provided. The example of the company "Reciklaža Mišić" demonstrates how recovered construction waste can lose its waste status and be used as recycled aggregate if the assessment and verification of the constancy of performance are carried out according to the technical specification aligned with the legal regulations governing construction products. The research results indicate the need for further familiarization of the construction sector with the procedure for removing waste status so that recycled aggregates can become a construction product and ensure market placement of materials, thereby contributing to the circular economy and reducing environmental burden. In conclusion, the research shows that achieving sustainable construction waste management requires further strengthening of the economic sector, better integration of ecological principles, and active involvement of the local community in the waste management process.*
Keywords: *construction waste, recycled aggregate, green policies, waste status removal, Recycling Mišić study case.*

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1. INTRODUCTION

Urbanization in Europe, particularly in the Republic of Croatia, is generating increasing amounts of construction waste, which represents a priority waste stream with significant potential for reuse and recycling. In the Croatian language, the terms "građevinski" and "građevni" are not synonymous. The term "građevinski" refers to activities, processes, and operations related to the execution of construction works, including waste generated during those activities. On the other hand, "građevni" is used to denote materials, products, or elements applied in construction. According to the Waste Framework Directive (2008/98/EC), the EU's transition to a circular economy increases the waste recycling rate, reduces pressure on natural resources, and promotes sustainable growth and job creation (European Commission 2008; Lacy & Rutqvist 2016; Kirchgeorg et al. 2021). EU directives have been transposed into Croatian legislation through strategies, plans, laws, and regulations. In March 2020, the European Commission adopted the New Circular Economy Action Plan, a key component of the European Green Deal. This plan represents a new European agenda for reducing greenhouse gas emissions and transforming Europe into the first climate-neutral continent by 2050 (Official website of the European Union, Circular Economy Action Plan EU 2024; Official website of the European Union, Implementation of the European Green Deal 2024). The transition to a circular economy reduces pressure on natural resources, encourages sustainable growth, and creates new employment opportunities. According to the Waste Framework Directive, the waste prevention and management legislative and policy hierarchy is as follows:

a) prevention
b) preparation for reuse
c) recycling
d) other recovery operations, e.g., energy recovery, disposal (European Commission 2008) (**Figure 1**).

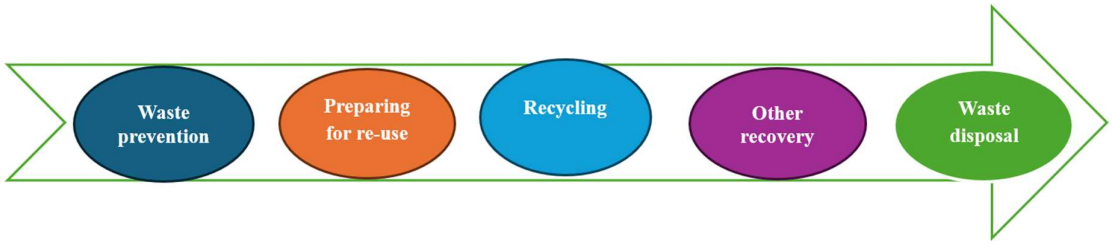

Figure 1. *Hierarchy of waste and energy recovery processes from waste*

In the Republic of Croatia, waste management is regulated by the Waste Management Act and its implementing regulations (Waste Management Act, Official Gazette, 84/21, 142/23). These regulations define the procedures and conditions for handling different types of waste by all stakeholders within the waste management system. The Act prescribes measures for the protection of the environment and human health through the prevention and reduction of waste, mitigation of negative waste impacts, and efficient waste management, with the aim of reducing the overall use of raw materials, improving resource efficiency, and increasing recycling and reuse of materials (Matošević et al. 2021). These measures are essential for the transition to a circular economy and for ensuring the long-term competitiveness of Croatia and the European Union. The Waste Management Plan of the Republic of Croatia for the period 2023–2028 sets ambitious targets for waste separation and recycling, and for reducing landfilling by the year 2035, in accordance with Directive 2008/98/EC. The goals include increasing the recycling rate to 65% and reducing landfill disposal to 10% (Waste Management Plan, Official Gazette, 1/22, 84/23). Although the legislative framework in Croatia aligns with EU directives and sets ambitious targets for increasing recycling and reducing landfill disposal, the practical implementation faces several challenges. One key issue is the insufficient coordination among different levels of government and involved stakeholders, which can lead to inconsistencies in applying specific regulations. Limited capacity for processing and recycling construction waste, along with a lack of sufficient incentives for local communities and citizens, further slow down the achievement of established goals. Another challenge is the absence of clear and consistent definitions and standards for "end-of-waste" procedures, which complicates the recycling process and reuse of construction materials. In some cases, different documents and regulations use terminology inconsistently, creating legal uncertainty and potentially discouraging investments in recycling technologies. Given these challenges, it is necessary to improve implementation mechanisms, enhance education and local community engagement, and harmonize legal provisions to increase the efficiency of construction waste management in Croatia.

The hypothesis of this research is based on the improvement of the construction waste collection and processing system through education and the encouragement of local community participation, which can significantly increase recycling rates and reduce the amount of waste being landfilled. The methodology used in the research includes analysis of existing legislative frameworks, examination of best practices in other countries, and the implementation of a systematic analysis of the end-of-waste procedure and reuse of aggregates in construction and road building.

In this context, the case of "Reciklaža Mišić" demonstrates how recovered construction waste can lose its waste status and be used effectively, thereby contributing to sustainable development and waste reduction. For the purpose of comprehensive environmental protection management, the Waste Management Information System (ISGO) has been established within the Environmental Protection Information System. ISGO serves as a foundation for the development and implementation of sustainable development and environmental protection documents, as well as for monitoring the implementation of related measures (Jurić et al. 2023). Key applications within ISGO include:

- e-ONTO (electronic waste tracking),
- the Environmental Pollution Register (ROO),
- ELOO, for recording locations of illegally dumped waste,
- an application for landfill operators,
- and portals and tools for waste prevention and reuse project tracking.

For the daily operations of legal and natural persons directly involved in waste management, the Waste Management Ordinance has been adopted (Waste Management Ordinance, Official Gazette, 106/22).

In practice, waste management services in the Republic of Croatia are mainly entrusted to public companies. However, in urban areas and municipalities, these services are also provided by private concessionaires authorized by local self-government units (Ivčić 2020; Džinić & Kovač 2022). The research findings should provide guidelines for the development of more efficient policies and practices in construction waste management, thereby contributing to sustainable development and the reduction of the environmental footprint of urbanization in Croatia.

2. ANALYSIS OF THE STATE OF CONSTRUCTION WASTE IN THE REPUBLIC OF CROATIA AND THE EU

In Croatian legislation, two synonyms are used for construction waste: “građevinski” and “građevni”, and this distinction needs to be clarified. The Ordinance on the Waste Catalogue defines the group of waste generated in construction activities as: “Construction and demolition waste (including excavated soil from contaminated sites)” (Ordinance on the Waste Catalogue, Official Gazette, 90/15). **Table 1** shows the waste subgroups: 17 06, 17 08, 17 09, in which the term “građevinski” is used.

Table 1. Excerpt from the Regulation on the Waste Catalogue

Waste Code	Waste Description	Classification
17 06	**Insulation materials and construction materials containing asbestos**	
17 06 01*[1]	Insulation materials containing asbestos	V122
17 06 03*	Other insulation materials consisting of or containing hazardous substances	V122
17 06 04	Insulation materials not specified under 17 06 01* and 17 06 03*	V122
17 06 05*	Construction materials containing asbestos	O49
17 08	**Construction material based on gypsum**	
17 08 01*	Construction materials based on gypsum contaminated with hazardous substances	V123
17 08 02	Construction materials based on gypsum not specified under 17 08 01*	V123
17 09	**Other construction waste and demolition waste**	

In the Ordinance on the Cessation of Waste Status (Article 2), which explains the meaning of terms, the term "građevni otpad" (construction waste) is used, and this term is consistently applied throughout the ordinance, except when:

- it defines the key number 17 09 04 (mixed construction and demolition waste, not otherwise specified under 17 09 01*, 17 09 02*, and 17 09 03* – includes only mineral-based materials),
- when the criterion for the cessation of waste status is recovery through the R5 process – Recycling/reclamation of other inorganic materials (which includes the recycling of inorganic construction materials and the recovery of soil) (Ordinance on the Cessation of Waste Status, Official Gazette, 55/23).

Construction waste management involves a series of key activities such as separate collection, recovery, and disposal, all carried out by authorized operators licensed under the Waste Management Act. Recycling yards play a vital role in this system, serving as controlled sites for the sorting, mechanical treatment, and temporary storage of construction waste. At these facilities, waste is sorted by material type, enabling more efficient reuse and recycling. Mechanical treatment, which includes processes such as crushing, grinding, and screening, prepares the waste for further use or recycling (Mišić 2024; Waste Management Strategy of the Republic of Croatia, Official Gazette, 130/05).

Construction waste holds significant economic value, and existing technologies for its separation and recycling are well-established and widely accepted within the industry. Construction waste is defined as waste generated during construction, reconstruction, demolition, and maintenance of buildings, as well as excavated material that cannot be reused without prior recovery. This waste includes materials such as concrete, brick, metal, glass, plastic, and wood, all of which can have a substantial environmental impact if not properly managed (**Figure 2**).

There is a market for recycled aggregates used in construction, including road building, drainage works, and as a replacement for natural aggregate in concrete. Uncontaminated soil and other natural materials excavated during construction activities are not considered construction waste if reused on the same construction site. The problem is that approximately half of construction waste ends up in municipal landfills, increasing remediation costs and occupying valuable space (Waste Management Strategy of the Republic of Croatia, Official Gazette 130/05, Ordinance on Construction Waste and Waste Containing Asbestos Official Gazette 69/16, Srpak et al, 2024). Exceptionally, the landfilling of construction waste is permitted only when material and/or energy recovery and reuse are not possible in accordance with the provisions of the Ordinance. Landfills typically use this inert material to cover municipal waste. Construction waste must not be disposed of at the site of generation or in locations not designated for that purpose. Every holder of construction waste is required to bear all costs associated with its management, unless the responsibility has been legally transferred to another party (Srpak & Zeman 2017; Srpak et al. 2022). Construction waste is categorized based on its origin as follows:

[1] The asterisks (*) at the end of the waste codes indicate hazardous waste categories according to the European Waste Catalogue (EWC).

- Waste generated from complete or partial demolition of structures,
- Waste produced on-site during the construction of new buildings,
- Waste generated during the construction and maintenance of roads,
- Excavated soil that needs to be removed to prepare the site for construction (MINGOR 2024; European Commission 2020).

Figure 2. *Construction Waste – Key Number 0904 – Mixed Construction and Demolition Waste*

Construction waste varies depending on the type of structure and the nature of the work. In building construction (vertical structures), the dominant materials are concrete, brick, and gypsum-based products. Excavation work produces waste such as soil, sand, gravel, stone, loam, and clay (mineral materials). Civil engineering (horizontal structures) generates waste such as bitumen (asphalt), cement-bound materials, sand, gravel, and crushed stone. Mixed construction waste includes concrete, brick, wood, plastic, metal, cables, and rubble. Construction waste accounts for 95% of inert waste, including ceramics, brick, tiles, plaster, gypsum, concrete, iron, steel, wood, and plastic. Material from excavation makes up 75%, demolition and construction waste accounts for 15–25%, and asphalt, tar, and concrete for 5–10%. Asbestos-containing waste is disposed of in designated landfill cells, which are clearly marked to indicate the presence of such hazardous material. The waste categorization process determines the origin and location of waste generation, as well as its group, subgroup, type, and properties. It is crucial to assess whether the waste has hazardous characteristics (Ordinance on the Waste Catalogue Official Gazette, 90/15). The origin and type of waste must be identified according to the activity and location, its classification as municipal or industrial waste, and its phase (primary or secondary). The Waste Catalogue, as outlined in the Ordinance on Waste Management, provides guidelines for categorization, including groups, subgroups, and a list of waste types, systematized into 20 groups with over 800 waste types. Each waste type is assigned a six-digit code that identifies the waste, its name, and possible hazardous properties. The catalogue distinguishes between:

- Absolute entries (always hazardous or always non-hazardous)
- Mirror entries (potentially hazardous, requiring further analysis)

The Waste Catalogue is also used for maintaining the Waste Generation and Movement Register (ONTO). In managing construction waste, it is essential to follow the waste management hierarchy, which prioritizes prevention and reduction of waste generation, starting at the design stage. Waste should be sorted on-site to enable reuse. The reuse of recycled aggregates is made possible through the cessation of waste status or recognition as by-products, representing a significant opportunity for businesses in the construction sector. Construction waste accounts for nearly 40% of total waste in the European Union (EU), making it one of the key challenges in waste management. The Waste Framework Directive sets ambitious targets for reducing construction waste, but the lack of a common definition and uniform management approach has resulted in strategic discrepancies among Member States. Urbanization and the growth of urban populations have significantly increased the generation of construction waste, turning it into a global issue. In this context, Germany and France lead in waste generation, producing more than 60 million tonnes of construction waste annually. By contrast, the Netherlands boasts a 100% recycling rate, while Italy and Slovenia achieve rates above 97%. On the other hand, countries such as Ireland, Cyprus, Malta, Portugal, and Romania have recovery rates below 50%, highlighting the need for improved waste management practices (Dokonal 2024).

Most EU Member States still rely on backfilling as the primary method of construction waste recovery, although this cannot be considered true recovery. For instance, Malta reports a 100% recovery rate by including backfilling; however, without this method, the actual rate drops to 24%. Many countries, including Poland, the Czech Republic, France, Estonia, Romania, Croatia, Ireland, and Portugal, did not meet the 70% recovery target by 2020 without including backfilling. Sweden, Slovakia, and Cyprus failed to meet the target even with backfilling included (Dokonal 2024). Around 300 companies hold permits for the treatment (pre-treatment, recovery, or

disposal) of construction waste, but only a few conduct energy recovery operations. From 2004 to 2020, the amount of waste recovered through backfilling and energy recovery increased by 29.4%, from 870 to 1,164 million tonnes. Over half of the waste (59.1%) was treated through recycling (39.9%), backfilling (12.7%), and energy recovery (6.5%). Although all EU Member States have implemented the Waste Framework Directive, only Portugal, Slovenia, Spain, and France have developed specific national regulations for construction waste. The construction sector in the EU contributes to 37.5% of total waste, while in Croatia, this share stands at 23.8%. In 2022, the total amount of construction waste in Croatia was estimated at 1,735,581 tonnes, a 6.2% increase compared to 2021. Unregistered waste is often disposed of at illegal dumping sites or managed without proper permits.

The largest share of construction waste consists of soil, stones, and dredging materials (47.5%), followed by metals (17.2%), and concrete, bricks, tiles, and ceramics (12.4%). In 2022, 154 operators carried out construction waste treatment at 210 locations, with the highest concentration of operators in Zagreb, Split-Dalmatia, Zagreb County, and Varaždin County. A total of 1,510,125.9 tonnes of construction waste was treated in 2022, representing a 3.9% increase compared to the previous year (**Table 2**) (MINGOR 2024).

Table 2. Quantity of Generated and Treated Construction Waste from 2015 to 2022

YEAR	Estimated and Reported Processed Construction Waste in Croatia (2015–2022)		
	Estimated Generated Construction Waste (t)	Reported Processed Construction Waste (t)	Processed Waste (%)
2015	1,189,316.0	881,554.7	74
2016	1,226,072.9	879,000.0	72
2017	1,225,263.0	994,644.5	81
2018	1,243,642.3	911,442.5	73
2019	1,365,066.0	1,076,662.0	79
2020	1,399,192.7	1,144,214.2	82
2021	1,634,257.1	1,453,916.8	89
2022	1,735,581.0	1,510,125.9	87

The amount of construction waste in Croatia has been steadily increasing, with a growth of 45.9% between 2015 and 2022. The EU target for construction waste recovery was set at 70% by 2020, while Croatia's recovery rate in 2022 was 66.5%, marking an increase of 3 percentage points compared to 63.5% in 2021. The highest amount of waste collected and processed in 2022 was in Zadar County, with 501,161.3 tonnes of waste collected and 500,977 tonnes processed, representing a processing share of 33.2%. **Table 3** provides a detailed overview of the quantities of waste collected, stored, and processed in 2022 by county.

3. METHODS AND MATERIALS FOR THE ANALYSIS OF RECYCLED AGGREGATES: A CASE STUDY OF RECIKLAŽA MIŠIĆ D.O.O.

Construction waste can be recovered at the place of generation as well as in facilities for material and/or energy recovery of waste. In material recovery facilities, construction products are produced that can be reused for construction purposes, provided they comply with specific regulations and standards.

Reciklaža Mišić d.o.o., based in Ivanovec in Međimurje County, operates a construction waste recycling yard at the same location. The Reciklaža Mišić d.o.o. facility was selected for the case study based on several key criteria that ensure its representativeness and relevance for the research. As one of the leading construction waste recycling facilities in Croatia, Reciklaža Mišić employs modern crushing technologies that enable the production of high-quality recycled aggregates in accordance with applicable regulations and standards. Furthermore, the facility holds valid permits for the revocation of waste status, which allows transparent monitoring and analysis of the practical implementation of the legislative framework. The availability of detailed data on processes and operations has further facilitated the conduction of a systematic and methodologically sound analysis. Additionally, the facility's significant contribution to the local community and economy represents an added value and justification for its selection. This approach ensures that the research achieves high relevance and provides convincing findings that can serve as a basis for improving policies and practices in construction waste management. The company processes non-hazardous mineral waste by ensuring its recovery through crushing using impact crushers. This process produces recycled aggregates of various types and fractions (recovery operation R5), for which the waste status is revoked in accordance with specific regulations, namely the Regulation on the Revocation of Waste Status:

a) Recycled aggregate (crushed asphalt) 0/45 mm (**Figure 3**) – produced by pre-crushing construction waste with the waste code: 17 03 02 – Bituminous mixtures not otherwise specified under 17 03 01*.
b) Recycled aggregate (crushed concrete) 0/45 mm (**Figure 4**) – produced by pre-crushing construction waste with the waste code: 17 01 01 – Concrete.
c) Recycled aggregate (crushed mixed) 0/45 mm (**Figure 5**) – produced by pre-crushing construction waste with the waste codes: 17 01 02 – Bri□ks; 17 01 03 – Tiles/□erami□s; 17 01 07 – Mixtures of □on□rete, bri□ks, tiles/□erami□s not otherwise spe□ified under 17 01 06*; 17 09 04 – Mixed construction and demolition waste not specified under 17 09 01*, 17 09 02*, and 17 09 03* (Mišić 2024).

Table 3. Quantities of Received, Stored, and Treated Waste in 2022 by County (Ministry of Economy and Sustainable Development 2022)

County of Processing Location	Number of Location	Collected from Croatia (t)	Collected from import (t)	Processor's warehouse 1 Jan (t)	Processor's warehouse 31 Dec (t)	Processed (t)	Share (%)
Zagrebačka	18	28,709.2	151.3	32,317.0	27,323.6	33,853.9	2,2
Krapinsko-zagorska	11	42,976.1	0.0	20,538.9	22,234.9	42,384.3	2.8
Sisačko-moslavačka	11	26,798.0	73,742.1	12,265.1	14,218.1	98,587.4	6.5
Karlovačka	9	15,347.3	0.0	69.9	7,125.2	8,349.9	0.6
Varaždinska	16	109,865.1	0.0	73,288.6	123,835.3	59,325.3	3.9
Koprivničko-križevačka	5	10,218.9	0.0	0.0	0.0	10,218.9	0.7
Bjelovarsko-bilogorska	10	7,319.9	2,425.7	140.0	300.0	9,585.5	0.6
Primorsko-goranska	7	60,475.1	0.0	17,486.7	22,336.4	55,625.9	3.7
Ličko-senjska	2	14,699.4	0.0	60.0	7,480.0	7,279.4	0.5
Virovitičko-podravska	3	9,020.1	0.0	183.9	203.6	9,361.6	0.6
Požeško-slavonska	3	1,853.6	614.0	0.0	10.1	2,457.5	0.2
Brodsko-posavska	6	7,154.5	0.0	19,115.2	16,079.5	10,191.0	0.7
Zadarska	7	501,161.3	0.0	4,525.1	4,709.3	500,977.0	33.2
Osječko-baranjska	14	81,903.2	16.5	1,072.8	794.5	82,198.1	5.4
Šibensko-kninska	10	28,069.7	0.0	16,239.4	13,583.8	31,111.6	2.1
Vukovarsko-srijemska	6	11,021.0	0.0	30,700.0	23,700.0	18,063.6	1.2
Splitsko-dalmatinska	22	142,783.5	2,933.7	4,400.4	21,277.7	134,906.9	8.9
Istarska	13	140,461.1	15.1	6,930.4	9,613.8	138,663.7	9.2
Dubrovačko-neretvanska	4	1,997.7	0.0	753.7	273.7	2,477.8	0.2
Međimurska	7	35,986.7	1,898.8	4,161.7	2,822.6	39,224.5	2.6
Grad Zagreb	26	180,247.0	1,354.1	64,456.0	30,831.7	215,282.1	14.3
Ukupno	210	1,458,068.2	83,151.1	308,704.8	348,753.6	1,510,125.9	100.0

The recovery process R5, which recycles inorganic material by crushing, produces recycled aggregates: crushed asphalt, crushed concrete, and their mixture, ready for reuse. Such mechanical processing does not change the category of the individual waste fraction, and the goal is to achieve the highest possible quality, i.e., purity of the output aggregate. The entire mechanical processing starts with sorting the input material, during which other types of waste are manually removed. Therefore, the quality of the final product depends on the quality of the pretreatment by sorting and the mechanical processing, which begins with crushing. The crushing process involves a pneumatic hammer or other forms of comminution, such as hydraulic shears, as shown in **Figure 6**.

Figure 3. *Recycled Aggregate (crushed asphalt) 0/45 mm*

Figure 4. *Recycled Aggregate (crushed concrete) 0/45 mm*

Figure 5. *Re□y□led Aggregate(□rushed mixed) 0/45*

Figure 6. *Hydrauli□Shears*

The crushed material passes through crushers shown in **Figure 7**. Crushing is performed using gyratory crushers, impact crushers, and jaw crushers that crush the material.

Figure 7. *Impact Crusher*

Crushed mineral waste has a granular consistency and passes through screens with different openings, producing fractions for which the waste status is revoked in accordance with the Regulation on the Revocation of Waste Status (Ordinance on the Revocation of Waste Status, Official Gazette, 55/23). The findings from the Reciklaža Mišić d.o.o. case study clearly demonstrate how the application of modern technologies and adherence to legal frameworks can significantly contribute to increasing the recycling rate of construction waste in Croatia. The facility successfully produces high-quality recycled aggregates that meet prescribed standards, aligning with the national targets set out in the Waste Management Plan of the Republic of Croatia (2023–2028) and EU directives, such as Directive 2008/98/EC on waste. These results reflect positive progress towards a circular economy, which is a key priority at both the national and EU levels. However, the analysis also highlights challenges faced by Croatia, such as the lack of clear and consistent definitions for waste status revocation procedures and limited coordination among various stakeholders. In this context, the success of Reciklaža Mišić d.o.o. as a best practice example provides valuable guidance for improving policies and construction waste management systems across the country. Linking to national trends, the study's results confirm the need for additional incentives and education of local communities to raise awareness and participation in construction waste recycling. Moreover, the facility's experience can serve as a model for developing more efficient procedures and standards that would facilitate the implementation of "end-of-waste" rules and reduce legal uncertainty, thereby encouraging greater investments in recycling technologies.Overall, this analysis shows that integrating practical examples like Reciklaža Mišić d.o.o. and aligning them with national and EU policies are essential for achieving sustainable waste management, reducing landfill burden, and fulfilling circular economy goals in Croatia.

4. REVOCATION OF WASTE STATUS

The Regulation on the Revocation of Waste Status defines recycled aggregate as a product resulting from the recovery of construction waste, prescribes quality criteria after the recovery process, and the intended uses of such materials. In order for recycled aggregate, as recovered waste, to have its waste status revoked, inspections and assessments must be conducted in accordance with Croatian or specific technical specifications that demonstrate compliance with special regulations. The inspection must prove that the use of recycled aggregate will not cause a greater risk in terms of hazardous properties than the risk associated with the use of aggregate produced from mineral deposits (Ordinance on the Revocation of Waste Status, Official Gazette, 55/23). The recycled aggregate must demonstrate through a test report carried out in accordance with the special regulation of the competent construction authority that it meets the requirements of the project or technically recognized professional rules. The aforementioned recycled aggregates are used for the production of unbound layers in construction and road building, subgrade filling, as well as stabilization layers and embankments, in accordance with the standard HRN EN 13242:2008 – Aggregates for unbound and hydraulically bound materials for use in construction and road building (EN 13242:2002+A1:2007) (Declaration of Properties of Recycled Aggregate 2024).

This standard defines the properties of aggregates obtained by processing natural, manufactured, or recycled materials for civil engineering and road construction, enabling product conformity assessment. Sampling and testing of recycled aggregate properties are carried out by accredited laboratories. If the aggregate meets the HRN EN 13242:2008 standard, a Declaration of Performance of the recycled aggregate and the "CE" marking are issued, confirming that these products meet essential requirements for safety, health, and environmental protection according to EU guidelines. The tested physical properties of recycled aggregates are shown in **Table 4**. Samples are taken in bags separately by processed waste type and granulation for each batch, where a batch denotes each individual waste recovery process.

Table 4. Physical Properties Tested in Recycled Aggregate from the Company Reciklaža Mišić d.o.o.

KEY FEATURES A2:B26B2A2:A19	Details / Parameters (according to HRN EN 13242:2002 + A1:2008)
Granulometric Composition, Fine Particles Content, Grain Shape	Aggregate fraction d/D, mm Granulometric composition Shape index Fine particles content
Quality of Fine Particles	Equivalent sand
Density and Water Absorption	Grain density, Mg/m³ Water absorption, %
Content	Total sulfur content Water-soluble sulfates Humus content
Resistance to Crushing and Abrasion	Resistance to crushing (Los Angeles test) Resistance to abrasion (Micro-Deval test)
Durability	Resistance to freezing and thawing Magnesium sulfate test
Content of Components in Coarse Recycled Aggregate	Concrete, mortar (Rc) Concrete, unbound aggregate, natural stone, bound aggregate with hydraulic binder, glass (Rc+Ru+Rg) Bituminous mixtures – asphalt (Ra) Brick, roof tile, calcium silicate boards, aerated concrete (Rb) Glass (Rg) Others (clay, soil, non-floating wood, plastic) (X) Floating particles (FL)

The obtained eluate values of the recycled aggregate must not deviate from the values prescribed in Annex I, paragraph 3 of the Regulation on the Revocation of Waste Status. However, the eluate must also meet additional limit values prescribed in Annex I of the Regulation on the Revocation of Waste Status (**Table 5**).

Table 5. Additional Limit Values

PARAMETER	VALUE (mg/kg)
BTEX (benzene, toluene, ethylbenzene, and xylenes)	6
PCBs (polychlorinated biphenyls, 7 related compounds)	1
Mineral oil (C10 to C40)	500
PAHs (polycyclic aromatic hydrocarbons)	10

Recycled aggregates must meet the conditions prescribed for inert waste landfills in order for their waste status to be revoked and for them to be used as recycled construction aggregates. The goal is to eliminate any potentially harmful effects of recycled aggregates on the environment and human health, so that they can be safely used as materials in road construction and building construction, as well as for embankment filling (Declaration of Properties of Recycled Aggregate 2024). According to tests, the recycled aggregates described in this study meet the conditions for inert waste landfills according to relevant regulations. If these conditions are met, the waste status can be revoked, and they can be used as construction materials (Ordinance on Methods and Conditions for Waste Disposal, Categories and Operating Conditions for Waste Landfills, Official Gazette, 114/15, 103/18, 56/19). The procedure for revoking the waste status includes the preparation of necessary documentation and submitting an application to the competent Ministry of Environment and Green Transition. The Waste Management Act stipulates that a substance produced by waste recovery can be entered into the Waste Status Revocation Register (hereinafter: the Register) if it meets certain criteria, including, among others, that there is a market and demand for that item or product, and that its use will not lead to overall harmful effects on the environment or human health.

When entering into the Register, it is necessary to fulfill the criteria based on Article 3 of the Waste Status Revocation Regulation:

- Implementation of a quality management system (HR EN ISO 9001) in the waste recovery process, which includes inspections and record-keeping in written or electronic form for each individual received waste shipment and batch (visual inspection of the waste shipment and the data provided in the accompanying documentation);
- Records of the inspection of incoming waste shipments and accompanying documentation, including

the date, accompanying document number, and the name of the person who performed the inspection;
- Records of the recovery verification, linking each Recovery Document (Pl-O) with the corresponding waste batch number, the date of batch formation, and the dates of related measurement and handling procedures for the batch;
- Compliance with prescribed standards and the results of testing/certification.

The type of waste registered in the Register is assigned a Waste Status Cancellation number (WSC number): the recovered waste from which the recycled aggregate is produced loses its waste status at the moment of sale to another person or at the moment it is used by the person who produced it, by one of the methods shown in **Table 6**.

Table 6. Use of Recycled Aggregates and Methods of Proving Non-Harmfulness

RECYLED AGGREGATE			
Intended Use	Properties and Essential Characteristics	Proof of Non-Hazardous Impact on the Environment and Human Health	Document Proving the Properties of the Recycled Aggregate
1.			
Aggregate for bituminous mixtures	According to harmonised technical specifications*[2] or Croatian technical specifications	Proof that the use of recycled aggregate does not pose a greater risk in terms of hazardous properties than the use of aggregate from natural mineral sources, and that the tested parameter values are less than or equal to the limit values shown in **Table 3.5**.	Declaration of Performance in accordance with specific regulations governing construction products and accompanying reports confirming that the sample of construction material produced from waste (key waste codes from Tables 3.1 and/or 3.2) meets the requirements of the relevant standard for the intended use + Declaration of Conformity using the form from Annex II of this Regulation
Aggregate for unbound and hydraulically bound materials for use in construction and road building			
Aggregates for concrete			
Aggregates for mortar			
Aggregates for railway ballast			
Rock armour			
Recycled asphalt aggregates			
Lightweight aggregates for concrete, mortar, and grouting mortar			
Lightweight aggregates for bituminous mixtures and surface treatments, and for use in unbound and bound mixtures			
Other aggregates intended for use in roads and other civil engineering structures			
2.			
For use in accordance with the building project	According to the requirements of the building project	Proof that the use of recycled aggregate does not pose a greater risk in terms of hazardous properties than the use of aggregate from natural mineral sources.	Test report in accordance with a special regulation by the competent authority for construction

5. RESULTS AND DISCUSSION – TEST REPORTS OF RECYCLED AGGREGATES

The findings from the case study of Reciklaža Mišić d.o.o. highlight the importance of implementing modern technologies and adhering to the legal framework in increasing construction waste recycling rates in Croatia. The facility successfully produces high-quality recycled aggregates, in line with the national objectives set out in the Waste Management Plan of the Republic of Croatia (2023–2028) and the goals of EU Directive 2008/98/EC. However, to further strengthen the argument, it is important to compare the case study findings with best practices from other EU countries:

- The Netherlands achieves a high level of circularity through advanced on-site selective separation systems and systematic financial incentives, including subsidies and strict recycling obligations.

[2] Harmonised technical specifications are technical standards adopted by the European Union to ensure uniformity and compliance across all member states, facilitating market integration and product safety

- Belgium uses a certification system for secondary materials and platforms for their redistribution, which increases market confidence and facilitates wider implementation..
- Sweden achieves a recycling rate of nearly 100% for household and industrial waste, positioning it at the forefront of circularity in the EU.
- The Stockholm Royal Seaport is an example of integrating circular principles into urban development, including systems for local excavation processing, a high degree of reuse, and reduced material transport.
- Germany, as one of the leading examples, combines advanced legal measures with innovations such as robotic demolition, recycled 3D-printed components, and digital tools for material tracking.

These examples of best practices from the EU can serve as guidelines for improving construction waste recycling in Croatia, promoting the adoption of modern technologies, legislative measures, and circular economy principles in the construction industry.

Based on the Waste Management Act, certain waste can have its waste status revoked if it is registered in the Waste Status Revocation Register. An application for registration in this register is submitted to the Ministry of Environment and Green Transition. The conditions are:

- Use of the substance or object for a specific purpose,
- Existence of a market and demand for such substance or object,
- Compliance with technical requirements and regulations for products,
- Absence of harmful effects on the environment or human health.

Applications for the removal of waste status are submitted through the ReDGO-OGO application, with registration and entry of basic data about the applicant, organizational unit, and attached permits and test results of recycled aggregates. According to the Regulation on the Removal of Waste Status, the criteria and methods for implementing EU regulations are defined, as well as the reports and declarations of conformity from the producer (Ordinance on Methods and Conditions for Waste Disposal, Categories and Operating Conditions for Waste Landfills, Official Gazette, 114/15, 103/18, 56/19). The basic criteria include evidence of market demand and minimal harmful effects on the environment, inspections and assessments by authorized companies in accordance with Croatian or special technical specifications proving compliance with special regulations. Certificates according to the international standard HRN EN ISO 9001 and appropriate permits for the recovery process are also required. Recycled waste no longer classifies as waste at the moment of sale or use in the producer's own production process and may be used for the purposes prescribed by the Regulation. Recycled aggregates and materials for filling obtained through the removal of waste status have certain permitted uses (Khan & Kumar 2019).

After registration and obtaining a decision from the Ministry of Environment and Green Transition, the producer must issue a Declaration of Conformity with every shipment. This declaration confirms compliance with prescribed requirements and technical specifications, as well as the implementation of quality and environmental management systems. The producer is also obliged to submit an annual Report on the Removal of Waste Status to the Ministry by March 1st, containing information about the person removing the waste status, the substance or object, the quantity of waste, and the recovery process. The presented data are obtained from the waste management information system (reporting obligation) and the Croatian Bureau of Statistics, although part of the construction waste is not recorded, mainly mineral waste. Most waste is recovered by process R5 (processing of mineral waste using crushers), primarily in the City of Zagreb, Istria, and Sisak-Moslavina counties, although there is a demand for such processing in other parts of Croatia as well. Based on a public call in 2020, MINGOR (Ministry of Environment and Energy) signed 30 contracts through projects under the Operational Programme Competitiveness and Cohesion.

These projects involved the procurement of crushers for processing mineral construction and/or bulky waste, which led to the issuance of numerous new permits by 2022. According to the 2022 Report on Construction Waste Management (MINGOR), four landfill operators reported the capability to process waste on-site using crushers (R5) in 2022, with processed material being used on-site at three locations. Twenty-seven landfills reported disposal of construction waste, and filling operations were carried out at 17 locations, mostly within landfill areas and to a lesser extent for filling inert roads. At the same time, based on issued permits, 39 entities operated 44 crushers recovering waste through process R5.

6. CONCLUSION

The analysis of construction waste management in Croatia and the EU clearly demonstrates the need to improve recycling and reuse of these materials. The case study of Reciklaža Mišić d.o.o. shows that the successful application of the R5 process – processing mineral construction waste using crushers – is a feasible and effective practice in Croatia. The recycled aggregates produced through this process not only comply with applicable technical standards but also achieve high-quality parameters suitable for various construction applications. This example clearly illustrates how the implementation of modern technologies, combined with adherence to the legal framework and standards, can significantly increase construction waste recycling rates at the national level. Local government units can play a crucial role in planning and developing recycling yards, further stimulating entrepreneurial activities and providing the necessary infrastructure for processing and reusing materials. Recycled aggregates represent a valuable resource that can substantially reduce the demand for natural

raw materials and mitigate the environmental impacts of their extraction. Their use in construction projects brings multiple benefits, including environmental protection, job creation, and the promotion of sustainable economic development. Systematic research into the technical characteristics and functional suitability of recycled aggregates, along with compliance with relevant standards, is essential for their full integration into construction practice.

Promoting successful projects using recycled materials, supported by education and systematic incentives, can significantly influence the perception of citizens and key stakeholders in the construction sector, strengthening the culture of sustainable waste management. Incorporating the specific findings from the case study further highlights the practical relevance of the research and demonstrates how the implementation of modern technologies and regulatory measures supports theoretical and policy frameworks. These measures are crucial for achieving long-term sustainability, reducing waste quantities, and improving environmental quality. By adopting these approaches, Croatia and other EU member states can achieve higher recycling rates, reduce harmful environmental impacts, and establish a solid foundation for a sustainable and circular economy.

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