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Construction Waste Management in Croatia

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Abstract

This article discusses construction waste and its management in the territory of Croatia. In order to better understand the concept of waste, the first part of this paper discusses its origin, characteristics, and categorisation. In addition, it mentions special categories of waste defined within Croatian borders. All members of the European Union are encouraged to adopt a circular economy approach to manage these various types of waste. Furthermore, the article emphasises the necessity to construct legal landfills in addition to building management centres, recycling yards, and transfer stations, in order to reduce the formation of wild landfills, which result from irresponsible waste disposal. The second part of the article provides a detailed description of construction and demolition waste. In addition to the types of occurrences and the associated degree of hazard, a categorisation system is used. This system includes records and key numbers, and allows finding the appropriate species in the database with the corresponding key number. Modern technology has made it possible to recycle all types of waste, including construction waste, into secondary raw materials. Proper management is essential to achieve this goal. The first step involves prevention, diversion or conversion of waste into a resource. When these options are not possible, one of the recovery processes should be employed. Managing Construction Waste also provides a comprehensive explanation of recycling, which is given significant attention. The article concludes with an overview of the Republic of Croatia's system for managing construction waste, which lags behind more developed countries, as well as offers examples of best practices and possible improvements.

Keywords

Construction waste, waste management, landfills, waste in Croatia, recycling procedure

1 Introduction

Rapid population growth and rising living standards are driving the demand for natural resources worldwide. A significant proportion of natural resources are consumed by the construction industry, which, in turn generates substantial amounts of waste products.[1] Approximately 40 % of all materials consumed annually are used in the construction sector.[2] Solid waste constitutes a major portion of construction and demolition (C&D) waste.[3] In 2016, the European Union generated more than 2538 million tons of waste, with 36.4 % stemming from the construction sector.[4] Furthermore, about 29 % of landfill waste in the United States originates from the construction industry, with 40 % in Brazil, 44 % in Australia, 44 % in the United Kingdom,[5] 27 % in Canada,[6] and 23 % in Hong Kong.[7] Consequently, the construction industry both consumes natural resources and generates substantial amounts of greenhouse gases through raw material consumption and waste production.[8]

C&D waste comprises inert and non-inert materials resulting from construction activities, such as excavation, renovation, road construction, and demolition. The term "inert material" encompasses both soft materials such as soils, earth, and sludge, as well as hard materials like rocks and broken concrete. Wastes consisting of metals, wood, plastics, and packaging are not considered inert.[9] Much of the construction and demolition waste is dumped without environmental consideration, often leading to other kinds of illegal dumping. Therefore, it is clear that the construction industry contributes significantly to waste production.[10] To address the issue of increasing C&D waste, various challenges have arisen, including landfill space shortages and rising construction costs. This has led both government agencies and private companies to reduce waste generation. In developing countries, where C&D waste management is mostly conducted through uncontrolled landfills, the proper management of this waste is an important goal.[11] Several studies have been conducted to identify the factors contributing to the generation of construction waste.[12–14]

A significant amount of required C&D waste can have an adverse effect on the environment, as well as on social and economic systems. Environmental concerns are linked with the disposal of C&D waste, which is often contaminated with hazardous materials like asbestos, heavy metals, and volatile organic compounds (VOCs). These wastes no only pose risks to human health but also have a detrimental effect on the environment. Given that the construction sector is an integral part of all other sectors, C&D waste impacts the economic sustainability of countries.[15] A key environmental challenge in the construction industry is the effective management of construction and demolition waste. Prevention/reduction of C&D waste should be a top waste-management priority when considering the ecological and economic factors.[16] Both project-level and regional-level management systems should be established with the proper quantification of C&D waste.[17] Many countries have implemented various laws to address C&D waste,

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along with state policies that provide specifications and recommendations for C&D waste management.[18] However, in some countries there is still a need to develop integrated plans and comprehensive policies to address the problem of C&D waste. This entails filling information gaps regarding waste generation and diagnosing inappropriate waste management programmes. Therefore, this paper will discuss the issue of construction waste and its disposal in Croatia, drawing on examples from developed countries to explain how the system can be improved. The disposal of construction and other waste should align with the principles and waste hierarchy based on the circular economy, which is the foundation of waste management throughout the EU.[19] Primarily, waste should be avoided or diverted and converted into a resource. With today's technologies, it can be reused as a secondary raw material through one of the recovery processes, usually recycling.[20] Whenever possible, the release of waste into the environment should be prevented. To achieve this, appropriate facilities such as waste management centres, recycling yards, transfer stations, and legal landfills are essential. The goal is to reduce the creation of illegal landfills, which contribute to pollution and diseases.[21]

2 Waste

According to the definition of waste, it encompasses an accumulation of chemicals, biological agents, and nuclear substances that result solely from human activities. It is important to note that waste is not always synonymous with garbage, and this distinction needs to be emphasised. Garbage is formed when waste is mishandled or mixed, making recycling very difficult, with only a very small percentage being recyclable at a high cost. Therefore, recycling and reusing garbage are not possible and have detrimental effects on the environment, whereas the reuse and recycling of waste are possible.[22]

A waste can be classified according to its place of origin and its characteristics, and there are specific categories of waste to be considered. Waste can be classified as municipal or technological waste, depending on its point of origin.[23] Municipal waste refers to waste collected by households, businesses and public institutions and disposed of as part of municipal activities. Technological waste, generated during production, differs in its properties and composition from municipal waste. There are special procedures for the monitoring and disposal of such waste that each manufacturer of technological waste must follow.[24] Hazardous and non-hazardous wastes are categorized based on their properties. As a result of chemical reactions or biodegradation, hazardous waste may release explosive, radioactive, harmful, toxic, carcinogenic, reactive, corrosive, ecotoxic, and teratogenic substances. Non-hazardous (inert) waste is waste that exhibits none of the aforementioned hazardous properties and therefore has no impact on human health or the environment.[25]

As stipulated in the Act on Sustainable Waste Management, Croatia defines 16 specific types of waste. Various regulations and legal provisions for waste disposal have been enacted regulate the handling of these wastes, and reduce their negative impact on the environment. The special types of waste include: packaging waste, tires, batteries and accumulators, oils, vehicles, waste electrical equipment and appliances, waste containing asbestos, bio-waste, waste textiles and footwear, medical and marine waste, construction waste, waste sludge from sewage treatment plants, waste from the production of titanium dioxide, waste polychlorinated biphenyls and polychlorinated terphenyls.[26]

2.1 Construction waste

Numerous industries are known for resource wastage, but the construction industry is one of the most wasteful. Approximately 40 % of the solid waste generated each year originates from construction and demolition activities.[27] As the construction industry grows, waste production increases exponentially. Annual construction waste is expected to reach 2.2 billion tons globally by 2025.[28] The European construction sector produces 820 million tonnes of C&D waste every year, which is around 46 % of the total waste generated, according to Eurostat.[29] Construction waste includes waste generated during construction, maintenance, reconstruction, demolition, and natural disasters.[30] Construction waste consists of 64–75 % excavated material including excavated earth, 15–25 % demolition and construction waste, and 5–10 % concrete, asphalt, and tar.[31] The percentage of waste generated during construction is lower (10–30 %) than during demolition, but it is more usable and recyclable.[32,33] For the effective management of C&D waste, it is essential to chemically characterise its composition. This is a challenging task due to the significant heterogeneity of C&D waste, as its composition is influenced by a number of factors, including the type of construction (ranging from road construction to metal-framed buildings), construction traditions (*e.g.*, wood versus reinforced concrete construction, precast construction, *etc.*), local resources, and national regulations.[34] Construction waste is typically inert, meaning it does not undergo physical, chemical, or biological changes. Examples of such inert construction wastes include gypsum, concrete, plaster, ceramics, iron, steel, wood, glass, and plastic.[35] It is important to note that the concrete materials discarded at the construction site are largely made of cement, which contains several hazardous compounds to enhance strength, durability, and proper setting time in various weather conditions. In the European Union, 27 different types of cement are produced for the construction industry, with Portland cement being the most commonly used. Concrete waste from construction can contain mercury, cadmium, and gypsum, as well as arsenic, cyanide, nickel, chromium, lead, sulphate, and zinc, which can leach into the environment if not properly managed.[36] While plastics are not as commonly used in the construction industry as concrete, wood, and glass, they find wide application in various tools, parts, and fittings, including windows, doors, pipes, building finishes, and packaging of building materials like plastic bottles and containers used for transportation. According to reports, the construction industry consumes approximately 10 million tonnes of plastic annually for various purposes, with around 50000 tonnes of plastics being discarded in the UK every year, most of which is polyvinyl chloride (PVC).[37] Wood waste constitutes a significant portion of the overall waste generated. Wood is often classified as an environmentally friendly material, certain construction wood undergoes a number of chemical treatments, such as the addition of copper compounds and the application of varnishes, paints or solvents to protect the surface layer.[38] On the other hand, hazardous construction debris must be identified and managed appropriately. Improper handling of this type of waste can pose hazards not only to those working with it, but to the general public. Many hazardous wastes are generated in the construction industry, including lead, asbestos, paint thinner, paint stripper, fluorescent tubes, and aerosol cans. Managing hazardous materials in C&D waste is vital in order to avoid fines and environmental liabilities.[39,40]

2.1.1 Construction waste management

Much of the waste generated by the construction industry is inert and non-degradable. Furthermore, construction waste is heavy and dense, necessitating more storage space, and it cannot be managed according to the typical principles of waste management, namely, "reduce, reuse, recycle", *i.e.*, which apply in management in the construction industry as in any other sector.[41,42]

Construction waste management encompasses activities and measures, such as separate collection, reduction of waste volumes and its harmful effects on the environment, and recovery and/or disposal of waste.[15] Construction waste management influences the final cost, quality, timing, and environmental impact of a project, and human health. When managed properly, construction waste is minimised in landfills, preserving valuable landfill space, and recycled construction waste is transformed into a high-value secondary raw material that can serve other construction purposes.[43,44] For instance, the replacement of coarse natural aggregates with coarse recycled aggregates from C&D waste in the production of concrete is one such practice that reduces the consumption of natural mineral resources, and provides an opportunity for recycling construction and demolition waste into raw material. Nevertheless, industry representatives in most countries are hesitant to use recycled aggregates in concrete. This is due to the perception that natural aggregates may be cheaper than recycled ones, customer scepticism regarding the reliability of recycled aggregates, and the lack of a market for recycled aggregates suitable for concrete production in C&D waste processing plants.[45] It is prohibited to dispose of construction waste at the origin point or any location other than the designated site. Whenever possible, construction waste should be collected and recycled separately, and permanent disposal in the environment should be avoided. The processing, recycling, and disposal of construction waste are largely determined by its composition.[46,47]

2.1.2 Construction waste disposal procedures

Proper management of construction waste is vital for safeguarding the environment, wildlife, and human health. In line with the principles of sustainable construction, a waste hierarchy has been introduced to provide guidance for construction managers.

The hierarchy of construction waste management is as follows:

1) Waste Prevention - The most effective approach is to avoid waste generation by reducing its source. This can be achieved, for example, by preserving existing buildings rather than building new ones, using fewer materials in design and production, adopting construction methods that enable deconstruction and reuse of materials, and using materials that are less harmful to the environment.
2) Preparation for reuse – Construction and demolition waste can be diverted and converted into a resource. This involves inspection, cleaning, repair, or replacement of entire products or consumables. Valuable construction materials that are no longer needed can be reused to generate savings and conserve natural resources, such as gravel, concrete.
3) Recycling – Converting waste into a new product, including composting, when quality protocols are met. For example, recycled wood can be used to manufacture wood-based products such as furniture, while recycling metals such as steel, copper, and brass is also desirable.
4) Other Recovery Processes – Additional recovery processes include anaerobic digestion, incineration with energy recovery, gasification, and pyrolysis for energy generation (electricity, heat, and fuel), as well as material reclamation from waste, and some landfilling.
5) Disposal – This is the lease preferred option involving either disposal or incineration without energy recovery.

In the hierarchy of construction waste management, the prevention of waste generation takes top priority. However, due to the nature of construction materials, it is not always feasible to implement this point for construction waste. Preventing the generation of construction waste would essentially require a building that depreciates over time to be constructed, demolished, or renovated every day. The least desirable option is the disposal of waste in landfills, as it poses significant environmental and health concerns. In most Croatian counties, suitable sites for the disposal of construction waste are still lacking, resulting in its improper disposal in municipal landfills and illegal dumps. This not only pollutes the environment, but also mars its aesthetic appearance.[48]

2.2 Recycling procedure in the Republic of Croatia

The enormous amount of construction waste accounts for up to one-third of the total waste generated in the EU.[15] In 2020, approximately 1.4 million tons of construction waste were generated in Croatia, of which only 7 % was recycled or disposed of in an acceptable manner, while 11 % was separated as secondary raw materials. Compared to more developed European countries, such as Denmark, the Netherlands and Belgium, which recycle up to 80 % of their building materials, Croatia lags far behind.[49] This is primarily due to the fact that the waste management economic system is not yet fully developed. Proper waste management practices as seen in some developed European countries, can significantly improve the quality of life. To instil trust in recycled materials, the European Commission has established a protocol. This protocol, drafted by a team of experts from various fields of waste management, emphasizes the importance of good construction planning and appropriate on-site waste management practices to achieve higher recycling rates and better quality recycled products. Recycling can occur on site or at an off-site recycling facility, depending on the protocol.[50]

Understanding the current situation in the territory of the Republic of Croatia is essential for developing a strategy and finding better solutions. According to the available information, Table 1 shows the amount of characterised construction waste in Croatia for the year 2020.

The percentage of total waste accounted for by each type of material is shown in Fig. 1. It is estimated that soil, stone, and dredge waste account for 38 % of the total waste generated during the construction of roads, tunnels, building foundations, and other excavations. This type of waste is generally not recycled but used for other purposes, such as backfilling. The total amount of construction waste generated in Croatia in 2020 was estimated at 1,399,194 tonnes, of which a total of 1,144,214 tonnes were processed. The rest of the waste, on the other hand, was disposed of in landfills or temporarily stored.

Waste generation in 2020 increased by 2.5 % compared to the previous year (2019), but the amount of waste processed increased by 6.3 %. As shown in Table 2, the largest share of construction waste was generated by the City of Zagreb (23.9 %), Split-Dalmatia County (8.5 %), Istria County (8.5 %), Zagreb County (7.7 %), and Primorje-Gorski Kotar County (7.5 %).

Table 1 – Amount of generated construction and demolition waste for 2020 in Croatia[36]

Tablica 1 – Količina nastalog građevinskog otpada u 2020. godini u Republici Hrvatskoj[36]

Key number Ključni broj	Waste Otpad	Amount/tons Količina/tone
17 01	Concrete, bricks, tiles and ceramics	243,306
17 02	Wood, glass and plastic	21,966
17 03	Bitumen mixtures, coal tar and products containing tar	129,287
17 04	Metals (including their alloys)	222,248
17 05	Soil, stones and dredging waste	528,123
17 06	Insulation materials and building materials containing asbestos	5,764
17 07	Gypsum-based building materials	1,384
17 08	Other construction waste and waste from demolition	247,116
	Total: Ukupno:	1,399,194

Zagreb and Sisak-Moslavina Counties also generated substantial amounts of waste as a result of the devastating earthquakes in 2020, inflicting great damage to the cities of Zagreb, Petrinja, and Sisak. Following the first earthquake in Zagreb in March 2020, around 50,000 tons of construction waste were generated. Precise data on the earthquake in Sisak-Moslavina County in December 2020, is not yet available, but much greater damage is anticipated. In the first six months after the earthquake, 80,000 m^3 of demo-

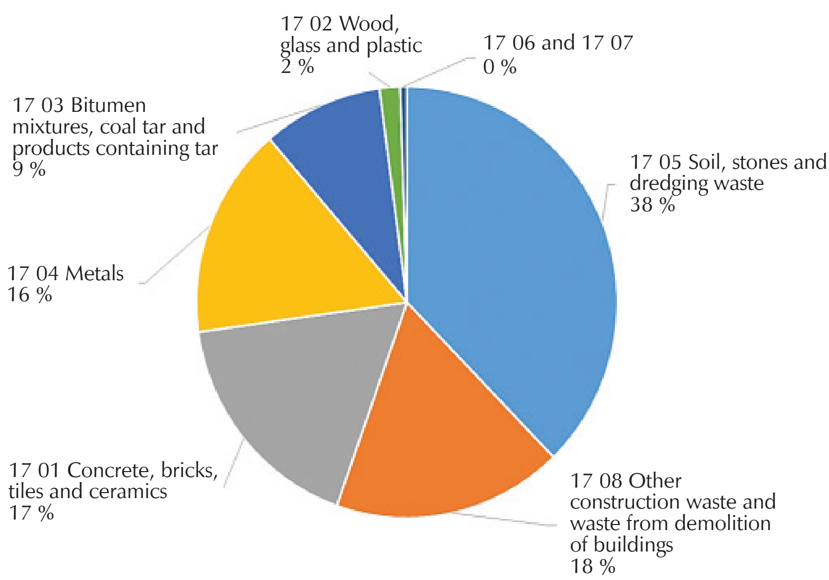

Fig. 1 – Share of individual materials in the total amount of construction waste generated[36]

Slika 1 – Udjel pojedinog materijala u ukupnoj količini nastalog građevinskog otpada[36]

Table 2 – Amount of construction waste generated in Croatia in 2020 presented by county[51]
Tablica 2 – Količina nastalog građevinskog otpada u Republici Hrvatskoj u 2020. po županijama[51]

No. Br.	County Županija	Amount/tons Količina/tone
1.	Zagreb	107,589
2.	Krapina-Zagorje	22,534
3.	Sisak-Moslavina	38,786
4.	Karlovac	23,558
5.	Varaždin	63,402
6.	Koprivnica-Križevac	18,365
7.	Bjelovar-Bilogora	18,661
8.	Primorje-Gorski Kotar	105,341
9.	Lika-Senj	13,055
10.	Virovitica-Podravka	15,376
11.	Požega-Slavonia	12,907
12.	Brod-Posavina	32,400
13.	Zadar	85,461
14.	Osijek-Baranja	70,531
15.	Šibenik-Knin	29,628
16.	Vukovar-Srijem	50,833
17.	Split-Dalmatia	119,413
18.	Istra	118,680
19.	Dubrovnik-Neretva	79,127
20.	Međimurje	38,908
21.	City of Zagreb	334,639
	In total: Ukupno:	1,399,194

lition material was deposited in landfills in Sisak-Moslavina County.

In 2020, 60.2 % of the total construction waste processed in Croatia (1,144,214 t) was recycled (excluding backfilling), 24.7 % was disposed of, 15.0 % was used for backfilling, and 0.1 % was processed in other ways. According to the Waste Directive, 70 % of the construction waste should have been recycled by January 1, 2020. In contrast to 2019, when 67.3 % of construction waste was recycled, the calculated recycling rate for 2020 is 60.2 %, representing a 7 % decrease. The main reason for this decline is the waste generated by the devastating earthquakes. The management of construction waste in Croatia was already challenging before the earthquakes. The extensive damage made it impossible to properly dispose of this waste. The existing recycling system in Croatia could not effectively handle the post-earthquake waste, resulting in a significant amount being deposited in landfills. This was mainly because the system sorts materials in advance, which is a challenging task in the event of an earthquake. The Covid-19 pandemic also impacted recycling facilities, leading to a decrease in the export of construction waste and an increase in its storage. Improved data reporting can also be seen as positive, raising awareness among citizens and responsible companies.[51]

2.3 Possibilities to improve recycling in the Republic of Croatia

Croatia should currently utilise construction waste to create new raw materials, following the principles of circular economy, for the reconstruction of buildings in areas affected by destruction. This can also improve construction waste recycling efforts. In the wake of the earthquake, Sisak-Moslavina County and the City of Zagreb generated substantial amounts of construction waste that required proper sorting. The sorting was done manually, which, aside from being costly and time-consuming, posed significant challenges, including potential health risks for the workers involved. Workers in such facilities must undergo high-level training, have access to protective equipment, and receive guidance on workplace safety. Automating the sorting process with modern technology can prevent such issues in the future. Modern waste sorting methods include the use of optical sensors in the sorting process.[52] This method allows the desired fractions to be separated from the waste quickly and cost-effectively. A sensor is a device that converts physical phenomena into electrical signals. Consequently, sensors act as interfaces between physical parts and electronic parts, such as computer parts.[53]

Optical sorting setups are mostly based on NIR or VIS sensors:[54]

1. *Infrared sensors* (Near-Infra Red sensors) use infrared radiation, a region of the electromagnetic spectrum between 700 and 2500 nm. Based on their chemical composition, they detect various materials, such as waste glass, paper and cardboard, polymers, electronic waste, and construction waste. When the infrared beams illuminate the objects on the conveyor belt, they are reflected into systems that process the data and identify the type of waste. A jet of compressed air is used to convey the defined material into a specific container. Fig. 2 illustrates the operating principle of the NIR sensor.

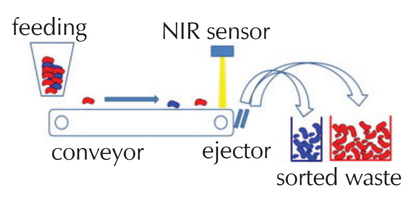

Fig. 2 – Principle of NIR sensor operation
Slika 2 – Princip rada NIR senzora

2. *VIS sensor* – Visible light sensor is used to sort waste by colour. NIR sensors and cameras are most commonly utilised in conjunction with this sensor. This sensor works by interacting with the sample with electromagnetic radiation of the visible spectrum (400–780 nm).

The sensor sends wavelengths of different colours to the waste, and based on the received rays, the system determines the colour and type of waste.[55] Today, in addition to optical sensors, robots are increasingly used for sorting construction waste, as well other waste.

To identify and sort waste, the plant employs a variety of sensors and artificial intelligence. This system offers numerous advantages, including cost reduction, increased profits from high-quality recycled materials, high speed and accuracy, high purity of fractions, 24/7 operation, minimal downtime and maintenance, tireless work, and improved work safety. The introduction of an automated sorting mechanism would significantly expedite and improve the construction waste disposal process in the earthquake-affected areas, as well as improve overall construction waste management.[56]

3 Conclusion

Construction waste constitutes a significant portion of the total waste generated, including concrete, brick, tile, and metal that can be recycled and reused. Separate collection of waste, ideally at the point of generation, is critical to a quality recycling process. Proper construction waste management not only reduces environmental impact, but also conserves recycled materials and lowers waste disposal costs, offering several benefits. However, Croatia still disposes of most of its construction waste in landfills, highlighting the underdeveloped waste management system despite the European Union requirements. Besides financial constraints, since the facilities and equipment that Croatia requires for its waste management programme are extremely expensive, the lack of awareness among citizens and construction companies also contributes to improper waste handling. Investing in the construction of more management centres, recycling yards, transfer stations, and official landfills for construction and demolition waste is crucial to creating a better and safer future for Croatia. Educating people about the value of proper waste management is essential.. To enhance work safety and promote more efficient and cost-effective waste management, these facilities should be equipped with automated and robotic systems discussed in this paper.

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SAŽETAK

Gospodarenje građevinskim otpadom u Hrvatskoj

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U ovom radu daju se osnovne informacije o građevinskom otpadu i gospodarenju građevinskim otpadom na području Hrvatske. S ciljem boljeg razumijevanja pojma otpada, u prvom dijelu rada govori se o njegovu podrijetlu, karakteristikama i podjeli. Navedene su i posebne kategorije otpada definirane na području Republike Hrvatske. Sve članice Europske unije trebale bi usvojiti pristup kružnog gospodarstva za upravljanje svim tim vrstama otpada. Osim izgradnje centara za gospodarenje, reciklažnih dvorišta i pretovarnih stanica, naglašeno je i da je potrebno izgraditi legalna odlagališta da bi se smanjilo stvaranje divljih odlagališta koja su rezultat neodgovornog ljudskog postupanja s otpadom. U drugom dijelu detaljno je opisan građevinski otpad i otpad od rušenja. Osim vrsta i stupnja opasnosti, primjenjuje se sustav kategorizacije koji uključuje ključne brojeve te omogućuje pronalaženje odgovarajuće vrste u bazi podataka. Zahvaljujući suvremenoj tehnologiji, sve vrste otpada, pa tako i građevinski otpad, danas se mogu jednostavno reciklirati kao sekundarne sirovine. Da bi se to postiglo, njime se mora pravilno upravljati. Prevencija i pretvaranje u resurs je prvi korak; ako to nije moguće, treba primjenjivati jedan od procesa recikliranja. Gospodarenje građevinskim otpadom uključuje i iscrpno objašnjenje reciklaže, kojoj se posvećuje velika pozornost. Rad završava pregledom sustava gospodarenja građevinskim otpadom u Republici Hrvatskoj, koji zaostaje za razvijenijim zemljama, te primjerima najbolje prakse i mogućim poboljšanjima.

Ključne riječi
Građevinski otpad, gospodarenje otpadom, odlagališta, otpad u Hrvatskoj, procedura recikliranja

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