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Review paper

DESIGN AND ENVIRONMENTAL IMPACT ASSESSMENT OF A RECYCLE CENTER FOR RECYCLE CONSTRUCTION AND DEMOLITION WASTE

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Abstract

Recycling of construction and demolition waste (C&DW) provides new raw materials, reducing the use of natural resources and the amount of waste for disposal. This work aims to increase the recycling rate of C&DW by building a recycling yard with a mobile plant, with minimal negative environmental impacts. Primary separation at source, including removing hazardous waste, is key to increasing the recycling rate. If this is impossible, the waste is transported to recycling yards for secondary separation. When selecting a location for recycling yards, environmental impact, energy requirements, transportation, distance from settlements, and natural factors are taken into account. Recycling yards have control points for measuring the mass of waste and storage. Construction waste is recycled using the best available technologies, and the resulting materials are reused in construction. Waste that is not suitable for recycling is disposed of in landfills, while the excavated soil is used for site rehabilitation. The impact of the recycling technological process on the environment was assessed using the Leopold matrix. Based on the assessed negative environmental impacts, measures were given for their elimination or reduction to an acceptable level, emission limits into the environment were determined, and environmental monitoring was carried out.

Key words: *Technology project, Recycling, Mobile plant, Environmental impact assessment.*

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1. INTRODUCTION

Urbanization encourages increased generation of construction and demolition waste (CDW), which requires effective management practices as it is one of the largest sources of waste globally, and has a major impact on environmental degradation [1, 2].

Construction waste and demolition waste make up about 40% of the total municipal waste generated as a result of large-scale construction activities [3, 4, 5].

According to the Law on Waste Management ("Official Gazette of RS", No. 36/2009, etc.), waste is any discarded substance or object and is divided into communal, commercial, and industrial, while according to its properties, it is classified as inert, non-hazardous, or hazardous. Construction and demolition waste (CDW) are generated during construction, demolition, reconstruction, maintenance, and excavation, and can be non-hazardous (eg, recyclable) or hazardous, and is subject to special regulations [6]. This waste can be defined as a mixture of different materials produced by the construction, maintenance, demolition, and deconstruction of buildings and construction works [7, 8].

Hazardous waste from construction materials used for insulation and roofing poses health risks during demolition or reconstruction [9]. Waste is classified by origin and composition in the Waste Catalog, aligned with the EU system. In Serbia, classification and handling rules are defined by the Rulebook on waste categories. Each waste type has a unique six-digit code; an asterisk indicates hazardous waste [10].

Developers are responsible for managing waste during demolition and reconstruction, and waste owners must arrange collection via authorized companies. Special regulations apply to this waste stream. Asbestos waste removal is overseen by labor inspectors under safety laws. Although banned in the EU since 2005, asbestos still appears in construction waste. It must be separated at source, properly packaged, and disposed of at authorized landfills. Its recycling or reuse is strictly prohibited [11, 12, 13].

Management according to the global hierarchy of waste management (rule 5R) can be proposed as a possibility to reduce landfilled CDW. Hierarchy of waste management (5R):

- Prevention of waste generation and reduction of resources,
- Product reuse,
- Recycling for the production of raw materials,
- Utilization for energy production i
- Environmentally responsible disposal.

Utilization procedures are marked with R and disposal procedures with D. Preferred options in the construction waste management hierarchy are waste utilization activities such as energy recovery (R1), metal recycling (R4), and recycling of other inorganic materials (R5). The disposal of construction waste is challenging because of hazardous materials such as asbestos, heavy metals, and volatile organic compounds that affect human health and the environment. The growing amount of construction waste globally has become an urgent environmental and economic problem, which requires effective waste management practices to mitigate its effects [14].

For proper waste management, it is necessary to accurately determine the index number based on the activity of origin, composition, and presence of hazardous substances. Documentation must follow the waste through the entire chain of handling to ensure safety and compliance with legal regulations [10].

Construction waste is classified in the Waste Catalog as group 17. Non-hazardous waste includes concrete, soil, brick, glass, metal, plastic, wood, and ceramics, while hazardous waste contains asbestos, PCBs, mercury, and other harmful substances. Effective recycling depends on waste separation at the source, as mixed waste complicates recycling and increases pollution [11]. Concrete is the main component of construction waste [15].

CDW is categorized by origin:

- waste from full or partial demolition,
- waste from new construction,
- waste from road construction and maintenance,
- removal of soil, stones, and vegetation during site preparation.

Common materials include concrete, brick, plaster, soil, gravel, asphalt, metals, wood, and plastic. Demolition waste is more voluminous, while construction waste is often more reusable. Excavated material used on-site is not considered waste but a mineral raw material.

The EU Construction and Demolition Waste Management Protocol aims to build trust in the CDW management process and the quality of recycled materials through better identification, separation, logistics, processing, quality management, and policies [16]. Sustainable construction and a circular economy rely on the continued reuse of construction materials, supported by both the public and international authorities [8, 16].Proper waste treatment and recycling play a key role in preserving the environment and promoting sustainable development. In order to increase the percentage of CDW recycling, it is necessary to build recycling centers with mobile facilities. Recycling centers specialized in CDW allow reducing the load on landfills, preserving natural resources, and reducing greenhouse gas emissions. However, the design process of these facilities requires careful analysis of potential environmental impacts [17].

This paper aims to present the key aspects of the design of a CDW recycling center and the environmental impact of the project (EIA).

2. METHODOLOGY

This study includes an analysis of literature and legal frameworks for the design of a CDW recycling center and the environmental impact of the project using Leopold's matrix. The Leopold matrix is named after the American environmentalist Aldo Leopold. It helps in identifying, quantifying, and evaluating the environmental effects of different project activities on different aspects of the environment.

2.1. Designing a recycling center

Recycling includes all reuse operations (R2–R10, R12) that process waste into products, materials, or substances, excluding energy recovery and conversion into fuel or landfill material [6]. It enables the recovery of useful materials and energy, reduces landfilled waste, lowers treatment costs, and prepares waste for storage. Recycling can also generate funds for further treatment phases, with main goals being waste reduction and conservation of mineral resources.

Construction waste recycling involves technical solutions ranging from mobile crushers to complex recycling centers. Technology selection depends on site-specific conditions, and off-site sorting facilities may also be used. Reliable data on waste origin, composition, and quantity is essential for selecting sustainable technologies and sizing facilities.

Designing a recycling center involves:

• Location (proximity to waste source, road access, minimal environmental impact);

• Infrastructure (reception area, storage, administration buildings, emission treatment systems);

• Technology (crushers, vibrating and magnetic separators, dust control systems).

Site selection must consider environmental impact, energy and utility needs, supply of construction and demolition waste, post-recycling material use, distance from residential areas, wind patterns, and flood risk. The center should include checkpoints for weighing incoming waste and designated storage areas. Recycling uses best available techniques, with products reused in construction and other markets. Non-recyclable mixed waste is sent to licensed landfills, while excavated soil can be used for site rehabilitation [1, 18].

The study by Ding et al. (2018) covered the design and construction phases to assess construction waste reduction. A two-level model was developed in Vensim software, covering waste generation, management, disposal, and environmental benefits assessment. The model supports measures such as prefabricated components, minor design changes, sorting, and reuse. It highlights the growing importance of waste prevention already in the design phase, in addition to construction [1].

2.1.1 CDW recycling procedures

The CDW recycling process at the recycling center consists of the following steps:

1. Reception of waste - visual inspection;
2. Selection - classification according to the waste catalog;
3. Crushing - use of primary and secondary crushers to reduce particle size;
4. Separation - metal parts are separated using magnets; light materials (plastic, wood) are separated by air separators;
5. Classification by granulation - sieve systems classify materials by grain size;
6. Storage - recycled materials are separated and stored according to type (concrete aggregate, metal, wood, etc.);
7. Resale or reuse - materials are used for new construction projects or sales [19].

At the location of the waste generator, the construction waste is selected - useful, useless, dangerous, and other materials are separated and are ready for treatment.

The waste generated from the demolition of the existing stadium is listed in Table 1, by the Rulebook on categories, testing, and classification of waste ("Official Gazette of RS," no. 56/2010, 93/2019, and 39/2021) [10].

Table 1: List of generated waste and total amount after demolition [10]

Index number	CDW
17 01	Concrete, bricks, tiles, and ceramics
17 01 01	Concrete
17 01 02	Brick
17 01 03	Ceramics, tiles
17 02	Wood, glass, and plastic
17 02 01	Wood
17 02 02	Glass
17 02 03	Plastic
17 03	Bituminous mixtures, tar, and tar products
17 03 02	Bituminous mixtures other than those specified in 17 03 01

Index number	**CDW**
17 04	Metals (including their alloys) 17 04
17 04 02	Aluminum
17 04 05	Iron and steel
17 05	Earth (including earth excavated from contaminated sites), rock, and excavation
17 05 04	Earth and stone other than those mentioned in 17 05 03
17 06	Insulation materials and building materials containing asbestos
17 06 04	Insulating materials other than those mentioned in 17 06 01 and 17 06 03
17 08	Construction material based on gypsum
17 08 02	Gypsum-based building materials other than those specified in 17 08 01
17 09	Other construction and demolition waste

After the final selection, the waste was placed in bags or containers, which prevented spillage. As the owner of the waste, the producer sorted it according to regulations. The waste was stored until it was handed over to authorized collectors, transporters, or storage facilities with a contract and a valid permit from the Ministry of Environmental Protection. There is supporting documentation for waste transport, but it was unavailable when writing [20].

Bricks, roof tiles, ceramic materials, asphalt, concrete, and reinforced concrete elements, bulky waste, stone, and the like are crushed and classified on the mobile plant. Treatment of construction waste includes mechanical crushing and screening. Crushing is done with a mobile crusher, and sieving and classification with a mobile sieve. The material is loaded with an excavator into the infill vibro-basket of the crusher, from which it falls by gravity into the jaw crusher. The tailings ("soil") are separated on the vibro-grid (first sieve). The crushed material then falls on the conveyor, which, via the magnetic separator, transports it to the mobile sieve, where it is sifted and classified into three fractions: 0–15 mm, 15–45 mm, and 45–160 mm. All fractions are temporarily stored at the waste generator location. The obtained aggregates are recyclable and are used as raw material in construction. Metal waste (iron and steel) is separated on the magnetic separator, which is also stored on site and can be sold as secondary raw material. The main equipment of the mobile plant for the treatment of non-hazardous construction waste is a mobile crusher and a mobile sieve. The crusher crushes all types of stone and solid materials, including crushed concrete, old asphalt, and brick. The auxiliary belt separates small impurities (eg, soil, clay) to obtain clean recycled material.

The plant moves independently as needed. The maximum diameter of the input material is 550 mm, and the crushed material is obtained in fractions of 0–15 mm and 15–45 mm, depending on the need. The capacity of the crusher depends on the type and granulation of the input material, as well as the required size of the output aggregate, and includes the amount of separated material on the magnetic separator. The amount of waste depends on the amount generated amounts of the specific waste generator. Since the already selected material is treated, except for tailings from the vibro-grid, no additional residues are produced [19].

The following figure shows a block diagram of the treatment of non-hazardous construction and demolition waste.

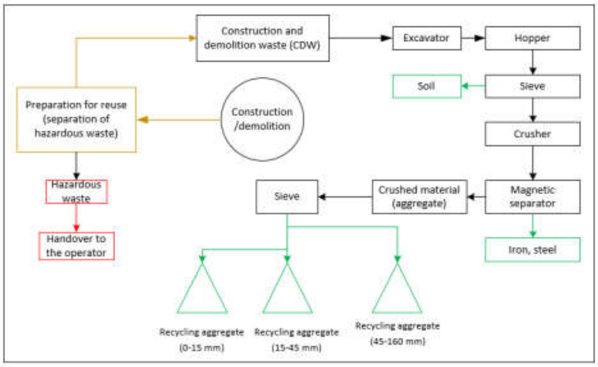

Figure 1. Block scheme for the treatment of non-hazardous construction and demolition waste

Recycled aggregates from construction waste can be classified as concrete, masonry, mixed, and those originating from mixed construction waste with a higher degree of contamination. Their composition depends on the origin and method of processing, which affects the physical properties and quality. The presence of materials such as asphalt, plaster, plastic, or wood can negatively affect the strength of concrete. The research analyzed the properties of recycled aggregates and proposed a classification based on performance. The importance of selective demolition, examination of composition and physical properties before use, as well as proper processing and categorization to ensure reliability in construction application, was emphasized [21].

A large part of the generated construction waste is not returned to the supply chain but is still disposed of in landfills [2]. The problem of construction waste has reached a critical point in many countries. The following negative impacts caused by construction waste can be explained by the following: land occupation, energy consumption, raw material consumption, environmental pollution, and greenhouse gas emissions, all of which threaten ecological sustainability [8].

2.2 Environmental Impact Assessment (EIA)

Urban development requires a project, and all projects aimed at increasing the well-being of urban settlements are associated with numerous environmental and social effects, resulting in positive and negative effects [22].

Environmental impact assessment is the process of identifying and evaluating the possible consequences of projects, plans, or laws on the natural and social aspects of the environment. Its main purpose is to enable decision-making that respects environmental aspects and promotes sustainable development. It includes analyzing impacts, proposing measures to reduce them, and considering alternative solutions. This procedure was introduced in response to the bad consequences of earlier projects that did not take environmental factors into account. Although it has met with resistance in some quarters, especially in developing countries, it helps in better planning and environmental protection. The process includes several stages, including identification of relevant issues, impact analysis, proposing mitigation measures, and involving the public in decision-making [23].

Impact assessment is part of a systemic process that predicts and evaluates the Project's impacts on the physical, biological, socio-economic, and cultural environment, with the identification of measures to avoid, reduce, and mitigate negative impacts and increase positive impacts. EIA includes the following stages:

• Identification of potential impacts: air emissions, noise, water and soil pollution, impact on biodiversity.

• Analysis and assessment: Using standard procedures and models to predict pollution levels.

• Proposal of mitigation measures: technical, technological, and organizational measures to minimize negative effects [24].

Environmental impact assessment is a systematic process that assesses how human activities affect the ecosystem. It includes data collection, prediction of pollution levels, and analysis of project sustainability. Based on that information, a decision is made whether the project is acceptable from an environmental point of view [23].

The environmental impact assessment study includes data on the project holder and location, a description of the project and its alternatives, the state of the environment, possible impacts (including adverse situations), protective measures, a monitoring plan, a summary for the public, and information on possible technical limitations [25].

2.2.1 Identification of potential impacts

To identify the impact, a modified Leopold matrix is used, which links project activities with the impact on society and the environment. It consists of a two-dimensional table in which the rows represent project activities and the columns represent environmental aspects. At the intersection of each activity and aspect, it is assessed whether there is an impact, and if there is, its importance and intensity are assessed. A modified version of the matrix may include additional factors, such as time duration, reversibility, or likelihood of impact, as well as specific local conditions. Based on the characteristics of the location, project documentation, and identification of sensitive receptors, possible significant impacts during the construction, operation, and closure of the Project are analyzed (Table 1).

Table 1: Possible significant impacts of the project on the environment

Receptor	**Activities**				
	Project Construction	Project Operation	Waste Management	Emergency/Accident Project	Closure
Air quality	√	√		√	√
Surface water				√	
Underground water				√	
Land	√	√	√	√	√
Flora and fauna	√	√	√	√	√
Noise and vibration	√	√			√
Population		√		√	

Gas emissions are caused by the combustion of diesel fuel in engines and are present only during the duration of the work. The technological process does not use water, so there is no wastewater or risk of pollution. Working fluids are stored in tanks, and any leaks are taken care of in metal barrels and handed over to authorized operators. Since the process is dry and without the use of water, no wastewater treatment system is required. During plant operation and material transportation, there may be a temporary increase in noise (90–100 dB(A)). Greater vibrations are not expected.

2.2.2 Impact analysis and assessment

A sensitivity and strength assessment are used to define the significance of the impact, which ranges from negligible to large (Table 2).

Table 2: Significance of the project's impact on the environment

		Sensitivity		
Influence		Low	Medium	High
	0 No significant impact	Negligible	Negligible	Negligible
	1 Weak	Negligible	Small	Moderate
	2 Moderate	Mali	Moderate	Large
	3 Strong	Moderate	Large	Large

An impact is negligible if any of the receptors (including humans) will essentially not be affected in any way by the particular activity, or the predicted effect is considered "invisible" or indistinguishable from natural variation.

The impact is low if there is a noticeable effect on the resource/receptor, but the magnitude of the impact is small enough, and/or the resource/receptor is of low sensitivity/vulnerability/importance. In any case, the size should be according to the applicable standards.

The impact is moderate if the magnitude of the impact is within the applicable standards, but is in the range from the threshold below which the impact is smaller, to the level where legal limit values may be exceeded. The emphasis on moderate impacts is therefore on demonstrating that the impact is reduced to as low as reasonably practicable.

The impact is significant when a limit value or standard may be exceeded, or large effects occur on highly valued / sensitive resources/receptors. The impact assessment aims to arrive at a position where the project has no significant residual impacts, especially not those that will last in the long term or extend over a large area.

2.2.3 Assessment procedure

The operation of any process plant, regardless of all the technical and technological characteristics of the process itself and the equipment used, can, in certain situations, represent a source of environmental pollution. The impacts that occur during the arrangement of the location itself and which are by nature temporary in nature are the result of the presence of people and machines, as well as the technology and organization of the preparatory works for the construction of the building.

Aspects of the environment that may be affected by the Project, as required by regulations, namely:

The project may have local and temporary environmental impacts, primarily on air quality due to emissions of exhaust gases and dust during construction and, later, from transportation and mechanical waste treatment during operation. There is no impact on surface water quality, as wastewater and rainwater are treated through separators. Shortterm effects on soil and groundwater may occur from material storage and potential spills, but proper waste handling prevents long-term contamination. Noise levels from machinery reach 70–85 dB(A) but are limited to the construction site. There is no expected negative impact on public health due to the project's distance from populated areas and controlled emissions. The project does not affect protected natural or cultural assets, and a green buffer zone offers additional protection. There is no influence on population dynamics or residential zones. Communal infrastructure is unaffected since no water is used in the technological process. Visual impact on the landscape during construction is temporary and will be mitigated with vegetation and architectural solutions. Land use is in accordance with spatial plans, and areas will be restored to their original or improved condition after project completion.

A simplified example of Leopold's matrix was used to assess the impact of the construction and operation of a recycling center for construction waste.

The table shows key project activities (rows) and environmental components (columns), with an impact assessment:

0 = No significant impact; 1 = Weak; 2 = Moderate; 3 = Strong.

Table 3: Leopold's matrix for environmental impact assessment

Activity/ Aspect	Air quality	Noise	Soil	Surface and groundwater	Population	Flora and fauna	Use of resources
1. Reception of waste	1	1	0	0	1	0	1
2. Crushing	3	3	2	0	2	1	2
3. Separation	1	1	1	0	1	1	0
4. Storage	0	0	1	0	0	0	1

Table 4. Type and characteristics of impacts during construction, operation, and closure of the Project

Environmental factor	Significance of impact
Construction and closure of the project	
Air	Moderate
Surface water and municipal infrastructure	Small
Soil and groundwater	Small
Noise and vibration	Moderate
Public health	Small
Flora and fauna	Small
Resource use	Small
Project work	
Air	Moderate
Surface water and municipal infrastructure	Small
Soil and groundwater	Small
Noise and vibration	Moderate
Public health	Small
Flora and fauna	Small
Resource use	Small

3. RESULTS

The key results based on the assessment of the project's impact on the environment, using the Leopold matrix methodology, are:

• The greatest negative impacts are expected in the crushing phase (on air, noise, and population);

• Overall impacts are mostly local in nature and temporary in duration;

• There are positive impacts in terms of employment and the re-use of resources.

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4. DISCUSSION

The obtained results show that the design of the recycling center according to the principles of sustainable development has multiple benefits, including the protection of natural resources, reduction of pollution, and economic benefits through the sale of recycled materials. The application of Leopold's matrix enabled the systematic analysis of all relevant impacts and the prioritization of mitigation measures.

Environmental protection measures can be classified into the following categories:

• Legally prescribed measures and standards;

• Protection measures in the event of an accident;

• Technical and planning solutions for protection;

• Measures during the cessation of work or removal of the facility;

• Other relevant measures.

When designing, you should choose a location that is at least 500 m away from residential areas and watercourses in order to minimize the impact of noise and water pollution.

It is necessary to comply with regulations on air protection, use technical solutions to prevent emissions, regularly maintain equipment, and carry out monitoring with reporting to competent authorities. The application of a water spraying system and closed crushers reduces dust emissions.

It is forbidden to dispose of dangerous substances that threaten the soil. Waste must be managed according to the law - it must be properly classified, stored, handed over to authorized persons, and the flow of waste must be monitored.

It is necessary to comply with regulations on noise, apply technical measures to reduce it, perform measurements, and react if the permitted values are exceeded. The installation of sound barriers can reduce the noise level by 15-20 dB.

It is necessary to apply safety procedures, train employees, use protective equipment, and regularly control safety at work.

5. CONCLUSION

Designing a recycling center for construction waste, with an adequate environmental impact assessment, contributes to sustainable waste management. The Leopold matrix is an effective tool for impact assessment and helps in the design of environmentally friendly plants. The main challenges are dust and noise emissions, which require measures such as sprinkler systems and sound barriers. Mitigation of these impacts is key to the acceptance of the plant by the local community.

Success depends on the correct choice of location, modern technologies, legal regulations, investor motivation, and citizens' awareness. Further activities should be directed towards education and encouragement of the private sector.

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