Material flow management of construction waste: case study Jablanica district, Serbia

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The paper analyses the current situation and perspectives of construction waste management in the territory of Jablanica district, Serbia. Considering the importance of construction waste management for the ecosystem, the state and perspectives are assessed through the assessment of the possibilities of reuse and recycling. According to Rulebook on waste categories with catalogue in Serbia, construction waste found at the landfill Donja Jajina is classified and observed in this research. Based on a six-month daily monitoring of the material flow of construction waste at the landfill in Dona Jajina, the current estimated state of the amount of waste as well as further growth of waste at the landfill is presented. Using MATLAB simulation code, predictions for the next 15 years are obtained, and conclusions are made. At the moment, concrete, brick, asphalt, as well as other construction waste are being buried at the landfill in Donja Jajina, and no further waste treatment is being done. The landfill has a lot of material that could be further used and put into use. It is necessary to build a stationary recycling plant on the landfill itself that would produce recycled aggregates and thereby reduce the use of natural aggregates.

INTRODUCTION

The construction sector makes intensive use of natural resources and generates significant amounts of waste that, in recent times, the environment can no longer absorb. A significant amount of waste from the construction industry, whose growth is estimated at 4.2 % in the coming years, in the world (Pérez-Lombard et al., 2008), has created needs for the construction of landfills or recycling plants, which is difficult to achieve, and often entails deliberate disposal of waste in suburban areas which are not intended for that. Hazardous substances that require special treatment can also appear in construction waste. On the one hand, the necessary demand for stone aggregates has significantly affected the exploitation that has been planned and regulated with increasing difficulty in the last few decades. On the other hand, a significant amount of waste from the construction sector has created needs for the construction of landfills or recycling facilities, which is difficult to achieve, and often entails deliberate disposal of garbage in suburban areas in places not intended for this purpose (Ministry of Physical Planning and Environmental Protection Sarajevo, 2008). Integrated waste management includes a range of processes and programs such as resource reduction (prevention), recycling, transformation (e.g. incineration, composting) and final disposal, to meet multiple objectives, including public and environmental health, and a more sustainable and resource efficient society (Worrell, 2014).

Construction waste is generated daily during: construction, demolition and reconstruction of buildings; infrastructure construction and repairs; during the production of construction products; after natural disasters or catastrophes (e.g. earthquakes, floods, landslides, etc.). It can occur after complete or partial demolition of buildings and/or infrastructure facilities, as a result of construction of new buildings and/or infrastructure facilities (destroyed unused material, excess paint, sealants, half-empty gas cylinders, packaging, etc.). Construction waste also includes soil material, stone and plants that need to be removed during the preparation of the construction site, construction of the foundation pit and the foundation of buildings, as well as landscaping, but also as a consequence of ongoing traffic maintenance, most often roads (Luciano et al., 2021).

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Hazardous substances that require special treatment can appear in construction waste. In addition to various impurities that make construction waste hazardous, asbestos-based products that have long been used in construction as insulation and roofing material occupy a particularly important place. In addition to asbestos, aggressive and potentially aggressive construction waste include lead, tar, paints, protective coatings, adhesives, binders, some types of plastic, but also materials that become aggressive due to many years in aggressive environments (example: industrial facilities where materials are produced or used to produce chemicals). Hazardous waste also includes materials that are not aggressive if they have come into contact with aggressive impurities and have not been cleaned of and/or subsequently mixed with the same (a typical example of paint with lead impurities carelessly thrown on a pile of bricks or concrete elements) (Wahlström et al., 2019).

In the current practice of construction waste management in Serbia, it has been noticed that there is no quality record of sources, quantities and flows of construction waste, although there is a legal framework for it that does not apply. Construction waste is disposed of uncontrolled, forming mixed waste with other types. For the purposes of waste management, the producers or the persons responsible for waste management, as well as all competent institutions, are obliged to classify waste according to the Waste Catalogue which is attached to Rulebook and forms an integral part thereof (Redžić et al., 2010). In Spain, in corporation with Serbia, there is no national law regulating the environmental assessment of recycled materials (Martín-Morales et al., 2011). The quantities of the construction waste from new construction and the demolition of buildings are extremely large. There are only two construction waste landfills in Serbia, which is not enough, so construction waste is disposed of uncontrolled in sanitary landfills. Separation of construction waste at the place of origin is not practiced. Apart from the fact that no selection is made, hazardous waste and waste contaminated with hazardous substances are not separated from construction waste. Encouraging the use of environmentally friendly and recyclable materials is not stimulated. In the design phase of buildings, the issue of construction waste is neglected, and is not sufficiently regulated by regulations and obligations of the designer. There is no established communication between all participants in the construction waste management process. Apart from the lack of a communication system, there is no system of incentives for the placement of recycled materials, there is no standardization of recycled materials. The success of disposal, recycling and reuse depends on the quality of the demolition of the building. Demolition of buildings is any procedure by which the structural parts of buildings or buildings as a whole are partially or completely demolished. The most important impact of the demolition of a building on the environment is reflected in the problem of depositing construction waste (construction debris) which is not further processed through the process of recycling and possible reuse. Deposition of usable construction waste in the form of construction debris to the city dump provokes multiple damages because instead of recycling and re-use for the new build and the same needs, natural materials from natural, mainly non-renewable sources are used.

Many European countries and regional governments have established regulations and procedures in an effort to encourage the reuse of these materials in construction applications (Van Gerve et al., 2005).

The aim of this research is to present the current estimated state of the amount of construction waste, as well as further growth of waste at the landfill in Serbia, and to indicate possible solutions to this significant environmental problem. To the best of our knowledge, there are no previous studies conducted regarding construction waste material flows in Serbia, which highlights the significance of the presented research.

MATERIALS AND METHODS

Description of the study area

Jablanica district is located in the south-eastern part of Serbia. According to the 2011 census report, there were 216,304 inhabitants. The area of the district is 2,770 km² and includes 336 settlements. The seat of the district is the town of Leskovac, the largest settlement in the south of Serbia. Donja Jajina is a populated place in the town of Leskovac in the Jablanica district, presented on the map in Figure 1. In Donja Jajina, there is a 15 year old solid waste landfill. According to the 2011 census, there were 1277 inhabitants. Depending on the time of year, different amounts of construction waste arrive at the landfill. Donja Jajina is also known for Jajina ponds. There are several bars. Fishermen still come to the two ponds because there are fish, but over time there has been less and less because it is no longer stocked. Two ponds are filled with construction waste. Otherwise, no valid data on the origin of these bars is completely reliable. According to some Turkish records Donja Jajina was first mentioned allegedly in the 15th century. According to recent and probably safer data, the company "Pobeda" from Leskovac dragged clay for the production of construction materials (RZS Serbia, 2011).

According to the Rulebook on waste categories with catalogue, the construction waste found at the landfill Donja Jajina is classified and observed in this



Figure 1. The map of Jablanica district

research. Table 1 shows the collected amounts of the construction waste monitored at the landfill in the observed 6 months' period.

MATLAB - for construction data processing

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to use environment where problems and solutions are expressed in familiar mathematical notation (The MathWorks, 2012). MATLAB is at the same time a generalpurpose programming language and a special-purpose one. It can easily do mathematically sophisticated computations such as control system analysis with MATLAB's built-in facilities or write program to do them (Hanselman, 1996). In this paper, MATLAB used a series of collected data. Based on the collected data, an interpolation of the curves was made. With MATLAB, and based on a six-month monitoring of the material flow of construction waste at the landfill in Dona Jajina, the current estimated state of the amount of waste, as well as further growth of waste at the landfill, will be presented.

RESULTS AND DISCUSSION

Depending on the time of year, different amounts of construction waste arrive at the landfill. About 40 % of the total waste is concrete itself.

On average, about 10 trucks arrive daily at the landfill in Donja Jajina, which is owned by the public utility company "Komunalac" from Leskovac, which would amount to 50 m³ of construction waste. Of that, 40 % is concrete on average, which would amount to 20 m³ of concrete. Collected data for 6 months is represented in the effective 105 days of construction waste disposal on the landfill. Thus, simulation was performed on a sample of 105 days. Figure 2 shows the amount of the actual construction waste that is transported in one day, for the observed period.

By summarizing daily collected amounts of construction waste for the period of 105 days, there is 11666.5 m³ of total construction waste at the landfill. Data on the quantities of waste projected into the future were obtained by simulation code, as presented in Figure 3.

Based on this trend, for the next 15 years we can expect: $15 \cdot 12 \cdot \frac{11\,666.5}{3.5} = 599\,991.4286 \approx 600\,000\,m^3$ of construction waste, as shown in Figure 4.

Month	Total construction waste [m³]	Concrete [m ³]	Asphalt [m³]	Brick [m³]	Other [m³]
March	1233.25	491.3	251.65	342.91	147.39
April	1313.25	524.3	266.65	365.11	157.19
May	2830	1132	576	785.9	338.6
Jun	2390	956	478	669.2	286.8
July	2730	1092	546	764.4	327.6
August	1170	468	234	327.6	140.4

Table 1. Collected amounts of construction waste in the observed time period



Figure 2. The amount of construction waste arrived at the landfill in one day, for a period of 105 days

1 - clear all 2 - clc	
2 - clc	
3 - otpad=xlsread('podaci.xlsx', 'N2:N106	;('
4 - beton=xlsread('podaci.xlsx','E2:E532	:');
5 - asfalt=xlsread('podaci.xlsx','F2:F53	2');
6 - opeka=xlsread('podaci.xlsx','G2:G532	');
7 - ostalo=xlsread('podaci.xlsx','H2:H53	2');
8 - size(otpad)	
9- 🕞 for i=1:105	
10 - t(i)=i	
11 - end	
12 - plot(t,otpad)	

Figure 3. Simulation code

It can be concluded that at the annual level, there would be 3650 trucks with 50 m³ of construction waste, 18250 m³ of construction waste where the concrete itself would be 9327.2 m³. The amount of asphalt is estimated to be in total of 4690.6 m³, while the amount of brick would be 6510.24 m³. Therefore, there is a wider interest in recycling all usable construction waste generated by demolition of buildings and thus reducing the need for raw materials from natural sources.

In recycled aggregate concrete, cement acts as a bonding phase. The disadvantage of using a recycled concrete aggregate is the lower quality of that material (Pontikes & Snellings, 2014). Because the recycled aggregate undergoes various treatments, it has a higher porosity than natural materials, so more water is needed to fully saturate the aggregate and this may require more intensive compaction. Also, there is a weaker surface connection between recycled agglomerates and cement, so they are most suitable for such low levels of application as a base material for the construction of roads, foundations, sewers and



Figure 4. The amount of construction waste reached at the landfill in a period of 15 years

as an aggregate for concrete and asphalt (Bassani et al., 2017). Concrete is one of the most common types of construction and demolition waste. The use of concrete waste as a recycled aggregate is limited to low quality applications, including substrate and pavement (Tam, 2014).

Asphalt is also represented as waste that is mostly dumped at the landfill. The application of recycled bitumen is for the production of new asphalt, which can contain 10-15 % of recycled asphalt added as a new raw material. Another application option could be to replace old asphalt. For this application, asphalt waste is crushed for recycling as an asphalt aggregate and then mixed with binder sand. Two different alternatives to binders can be used: one is the use of cement and the other is the use of a liquid in the form of a bituminous emulsion. A combination is also sometimes used. Also, the asphalt aggregate can be stabilized with blast furnace slag or fine slag (Arm, 2017).

The problem of brick recycling can occur if it is contaminated with cement and gypsum, and will most likely be mixed with other materials such as wood and concrete. Brick recycling processes are separation, sorting and cleaning, which is generally difficult with these processes. Brick is used as a filling material, crushed brick as an aggregate in recycled concrete. By adding 30 % of brick waste material in production, at 900 °C a new product is obtained, which can be used in the protection of agricultural land (Poon, 2002).

In addition to concrete, asphalt and brick, wood-plastic composites, Medium Density Fibreboards, rubber, plastic, non-coating metal and coating metal can be found at the landfill as construction waste, but also as potential raw materials for recycling.

CONCLUSION

Recycling construction waste provides significant opportunities. The problem of disposing of construction waste is not related to its quality, but to the quantities in question.

At the moment, concrete, brick, asphalt, as well as other construction waste, are being buried at the landfill in Donja Jajina, and no further waste treatment is being done. The landfill has a lot of material that could be further used and put into use. It is necessary to build a stationary recycling plant on the landfill itself that would produce recycled aggregates and thereby reduce the use of natural aggregates. This would prevent a negative impact on the environment and reduce the amount of waste at the landfill. The construction of the plant at the landfill would prevent waste disposal. It would find its new application. Processed materials are widely used in bulk for road and railway foundation works or for environmental restoration. They can also be used for low-strength concrete mixes. The choice of aggregate for a particular application should depend solely on the characteristics of the material, and not on its origin. To improve the market for recycled aggregate, its price must be at least 20 % lower than the price of natural aggregate, in order to overcome the "cultural resistance to buying worn-out goods" in the market.

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Tok materijala građevinskog otpada: studija slučaja jablanički okrug, Srbija

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Keywords: građevinski otpad, agregati, MATLAB, perspektiva.

Građevinski sektor intenzivno koristi prirodne resurse i stvara značajne količine otpada koje, u novije vrieme, okolina više ne može apsorbovati. Značajna količina otpada koja proizlazi iz građevinske industrije, čiji se rast procenjuje na 4,2 % u narednim godinama, stvorila je potrebe za izgradnju deponija ili reciklažnih postrojenja što je teško ostvarivo, pa često za sobom povlači namerno odlaganje smeća u prigradskim područjima na mestima koja nisu za to predviđena. Pred državom se postavlja zahtev da razvije program prevencije otpada usredsređujući se na ključne uticaje na okolinu i uzimajući u obzir celi životni ciklus proizvoda i materijala. Neophodno je uspostaviti hijerarhiju u pet faza kao niz prioriteta u zakonodavstvu i politici prevencije i upravljanja otpadom: a) prevencija, b) priprema za ponovno korišćenje, c) recikliranje, d) dalje obnavljanje, i odlaganje na deponije kao poslednji izbor. U građevinskom otpadu mogu se pojaviti i opasne supstance koje zahtevaju poseban tretman. U radu će biti analizirano aktuelno stanje i perspektive upravljanja građevinskim otpadom na teritoriji Jablaničkog okruga. Trenutno se na deponiji ne radi nikakav dalji tretman otpada, pa se beton kao i ostali građevinski otpad, trajno odlaže pokopavanjem. Imajući u obzir odloženu količinu otpada na deponiji i procenu količine permenentnog dotoka novog otpada, može se proceniti da bi ponovna upotreba i reciklaža betona, opeke i asfalta u građevinske agregate bila isplativa investicija. Otpad se evidentira zapreminski, a dalja obrada podataka vrši se pomoću kataloga građevinskog otpada, indeksnih brojeva i pripadajućih konverzionih faktora. Za izabrani vremenski period prikazani su podaci o ukupnoj kumulativnoj količini otpada, kao i parcijalne kumulativne količine betona, opeke i asfalta, koje se mogu ponovo upotrebiti ili reciklirati. Reciklirani agregati su sve prisutniji na tržištu, jer su prirodni agregati (šljunak, pesak i tehničko-građevinski kamen) neobnovljivi resursi koji se koristite u građevini i postaće limitirajući faktor. Imajući u obzir značaj upravljanja građevinskim otpadom za ekosistem biće procenjeno stanje i perspektive. Uz pomoć MATLAB-a, a na osnovu šestomesečnog praćenja materijalnog toka građevinskog otpada na deponiji u Donjoj Jajni, biće prikazano trenutno procenjeno stanje količine otpada kao i dalji rast otpada na pomenutoj deponiji.