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REGIONAL CONSTRUCTION WASTE MANAGEMENT

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Abstract

This paper deals with the problem of eco- logistic regional management of construction waste. In the introductory section, an overview was given of construction waste technologies and system management in the world and in our country. Furthermore, with the use of the methodology process of a questionnaire, morphological analysis and a multi-criteria method, analysis of the construction waste generators has been investigatedfor the areaof Niš. Finally, the structure of the functions and the selected structural solution for the system management of construction waste have been defined together with the proposed layout.

Keywords: *construction waste1, construction waste generators 2, multi-criteria method3*

1 INTRODUCTION

The promotion of environmental management and the mission of sustainable development have exerted the pressure demanding for the adoption of proper methods to protect the environment across all industries including construction. Construction, by nature, is not an environmentally-friendly activity.The hierarchy of disposal options categorizes environmental impacts in six levels, from low to high: reduce, reuse, recycle,compost, incinerate and landfill [1].

The three main waste minimization strategies of reuse, recycling and reduction, are collectively called the “3Rs”. Waste reduction is a process which avoids, eliminatesor reduces waste at its source or permits reuse/recycling ofthe waste for benign purposes[2][1]. The main stream of construction and demolition (C&D)waste generally results from the construction, renovation and demolition ofbuildings, roads, bridges and other structures.
According to its generation phase, C&D waste can be divided into three categories: construction waste (CW), renovation waste (RW) and demolition waste (DW). Typicalcomponents in C&D waste are inert materials (e.g., concrete, bricks, etc.), which are generally believed to causesmall damage to the environment [3].
For the last two decades, sustainable development and sustainable construction have been of increasing concern throughout the world. Sustainable construction is primarily regarded as ‘‘the creation and responsible management of a healthy-built environment based on resource efficient and ecologicalprinciples” [2].
Technological innovations, increasing population that is oriented to consumerism, increasing living comfort, uncontrolled area urbanization and a constant need for its expansion, result in the fact that people thinkmore about their personal needs than theycare about environmental pollution caused by the expansion ofliving and working space.
The use of secondary (recycled), instead of primary (virgin), materials helps easing landfill pressures and reducing demand of extraction. This is one way of getting the road construction industry on track towards sustainable construction practices. Current research and practice tend to concentrate on the use of waste materials in the lower courses of buildings and the roads (base, sub-base, etc.) as theyabsorb materials in larger quantities than the upper courses[4].
For establishing C&D waste management in Nišarea, it is necessary to launchamanagement systemprimarily in urban zones.
For the areaof Nis, which is the subject of discussion in this paper, it is almost impossible to find information about the companies, whether being public or private property, that deal with construction waste treatment [5].

2 CONSTRUCTION WASTE PROBLEM

The period after the industrial revolution implied the use of available natural resourceswhose processing and shaping ledtothe formation of final products available at the market. This type of organizing model is well known as the "linear model of economy" andits main paradigm is: take - make / use - dispose. Recycling and treatment of C&D waste constitute the first major step in changing the mindset of society and its cultural orientation. Linear economy (LE) has got its opposing concept which, instead of representing the movement of matter and energy in one direction, is represented by the circular motion of energy and matter, and therebyis known as circular economy (CE). CE economic model implies the circulation of material and its reuse, thus usingat the same timesignificantly less energy and water (in some cases over 90%). Comparative analysis of the movement of products and energy in the LE and CE can be seen in Figure 1 a and b. In the linear model of economy, for a longtimethe product has been disposed of in landfillsafter the end of its "life cycle", so thatalong with the increase in use of natural resources,thegeneration of waste was increased as well[8]. Waste is defined as any material by-product of human and industrial activity that has no residual value. In the world, 38% of the wastes are generated from C&D activities (Table 1), which is around 6408 tonnes per annum of wastes produced from any type of construction activities [1].
The process of CW management must have the basic steps like those shown in Fig. 2. For proper CW management, first it is necessary to make proper waste selection and classification, and then after loading wastein transport vehicles,it is necessary to take it toa designated transfer

station or a constructionlandfill. Then, it is important to follow the processes of recycling and manufacturing of new products. By means of these processes (Fig. 1) and CE, it is possible to obtain products with the same or similar purposes.

***Fig. 1** The comparative model: a) LE and b) CE [8]*

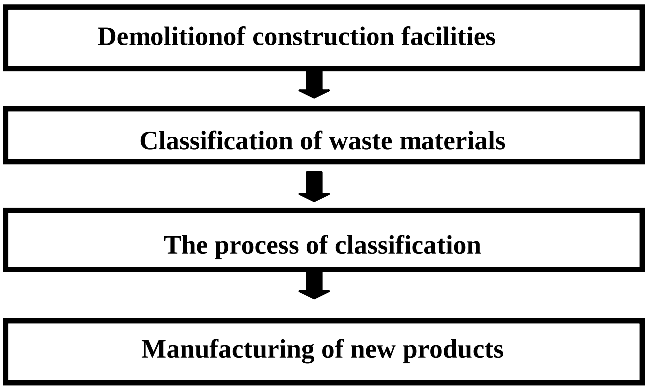


***Fig. 2**The method for collection and treatment of CW*

3 THE PROBLEMS OF CW IN THE AREAOF NIŠ

The main concept of waste collection in the area of Niš for the future is planned in such a way to have a central regional landfill with the facilities for separation andtreatment of different types of waste, where each municipality should have to develop a system forselective collection andtransfer of waste to the regional landfill.
Waste that is not further treatedafter collection is certainlyan unacceptable solution in terms of environmental protection and sustainable development.

Waste legislature inthe areaof Niš implies strategic plans for waste management for the period of 10 years. The existing regional waste management plan refers to the 10 –year-period (2010 – 2020) [6].

Table 1 The average quantities of solid waste disposed of at landfills [1]

Waste type	**Quantity**		
	Public	**Private**	**Total**
a) Domestic waste			
Waste from household, public cleansing	5822	1644	7466
Bulky waste	28	57	85
Sub-total	5850	1701	7551
b) Commercial waste			
Mixed waste from commercial activities	-	1120	1120
Bulky waste	-	68	68
Sub-total		1187	1187
c) Industrial waste			
Mixed waste from industrial activities	-	534	534
Bulky waste	-	28	28
Sub-total		562	562
d) Minicipal solid waste received at disposal facilities (a+b+c)	5850	3450	9300 (55%)
e) C&D waste (landfilled)	-	6408	6408 (38%)
f)Special waste (landfilled)	502	607	1109 (7%)
g) All waste received at landfills (d+e+f)	6352	10465	16817

The greatest part of waste in the areaof Niš is generated outsidethe households, andmost frequentlyithas differentcomposition from domestic waste (industrial, medical, construction, etc.). Depending on the type of a generator,it may contain some hazardous substances as well.
The data on thewaste generatorscan be obtained exclusively by voluntary self-reporting in accordancewiththe Regulations on the means of storage, packaging and labeling of dangerous waste [6]. A certain number of generators oftensendthe information onthe quantities of generated waste to the relevant environmental inspection, but the total number of generators and the amount of waste in the region isstill unknown.
The existing waste managament legislatureforthe area of Niš does notconsider CW in great detail. There arecertain initiatives to start solving this problem. The aforementioned waste should be selected first. Selecting the waste material should be carried out with the help ofpreviously well prepared,replaceablecontainers. This way, the selection can cover at least three planned groupsof waste materials: clay-basedwaste, concrete waste and wood waste.The excuse for covering just these types of waste materials is found in the absence of data in the regional strategy for managing construction waste in the studied period from2009 to 2019. The information that canbeobtainedis the envisaged amount of CW, expressed in thousands of tons per year, as well as the predicted increase in CWof 70% for the period until 2017. [7].

3.1. Potential CW regional landfill locations

To place a CW regional landfill in the Niš region, two locations were suggested as potential. It should be noted thatboth locations are suggested by the Regional Waste

Management Plan as regional landfills of municipal waste. The construction of the municipal waste landfills must be completed in the near future so there is no need to take over new locations and reduce the options for vacant land. According to the Regional Plan these locations are "Kaleš" – the existing landfill - Location 1 and location "Lalinske Pojate" - Location 2.

Location 1 is about 7km from Niš downtow (City of Niš produces most of the CW in the region). A small distance from the city center means that operating costs and environmental pollution will be reduced. The unwillingness of the local population to accept the construction of new landfills indicates that it is much easier to expand the existing landfills, according to sanitary standards, than to open new landfills on new locations [7].

The regional landfill site„Keleš"is in the immediate vicinity of the existing landfill „ Bubanj". Itis located about 400m south of the existing landfill site. The land is privately owned and of low fertility. There is no infrastructurein this area, but there is a good possibility of connection. Along the site, the municipal road Niš-Malošište-Doljevac passes by, with the mark L-1.1, as a road of good caracteristics. It takes lead because of the acquired habits of the local population to the presence ofa municipal landfill.

Location 2 is situatedin the west-end of the city of Niš, west of the South Morava River, and north of the road Niš-Prokuplje between settlements Krušce, Lalinske Pojate, Mramor, Sečenica, Azbresnica and Mramorski potok, on the slopes of Mali Jastrebac. Distance from Niš downtown is about18 km. The land is owned by two agricultural cooperatives. It is necessary to redeem the land first[7].

3.2. The analysis of CW generators in Niš area

There are many methods that can be used in order to determine the quantity of CW. The main difference between the methods ismost frequently in the selection of a generator and the type of samples. The approach to sampling is usually the one based on a random selection method depending on the type of thegenerator.

As a methodological approach to data collection, asurvey was used.The survey was conducted in June 2015 and it refers to the construction work done in 2014.This way, an indicative amount of CW generated from reconstruction, renovation, demolition of old buildings and construction of new facilities in the area of the city of Niš was obtained.

The quantities have been collected for the groups and subgroups of waste that are given in the block diagram in Fig. 3.

The survey contains general information about CW generators, which encompasses the business name, place of head offices, name of building area and locations, type of building structures and the table that contains the groups and subgroups like those in Fig.3,types of generated CW, measurementunits, quantities of CW and comments. In general, the amount of CW in Niš area is very difficult to assess. The main reason is the lackof data on the quantitative CW analysis, preciserecordkeepingof quantities, determining the characteristics, especially the CW composition, as well as the implementation of waste categorization [9][10][11].

One of the important reasons was that the cooperation between examinersand the examinees was not that perfect. Some of the possible reasons may be the fear ofmoney fines and distrust to interviewers.

Some of the problems while collecting data are:

- a big number of unregistered construction sites, no matter if they are meant for recostruction, adaptation or new building construction,
- generators who are afraid to provide the accurate data about the morphological composition and quantity of CW,
- unconscientiousness of citizens,
- the system that allows companies not to provide information or to give incorrect information.

Itis possible to sort the survey resultsinto bigger and smaller generators, that is the CW that is generated during regular maintenance or during the construction of new buildings.

For the purpose of this paper, a survey was conducted among severalcivil engineering companies in the area of Niš in order to obtain the data on waste quantities, that are provided in Table 2 and 3. The tables consist of CW generator marks and thebasic values likethe amount of CW based on clay(g_{gi}), the amount ofconcrete CW (g_{bi}), the amount ofwood waste (g_{di}), number of similar construction sites (n_i) and other derived values that are calculated by the introducted equations.

The total number of building sites N_g can be calculated according to the equation (1):

$$N_g = \sum_{i=1}^{n} n_i \quad (1)$$

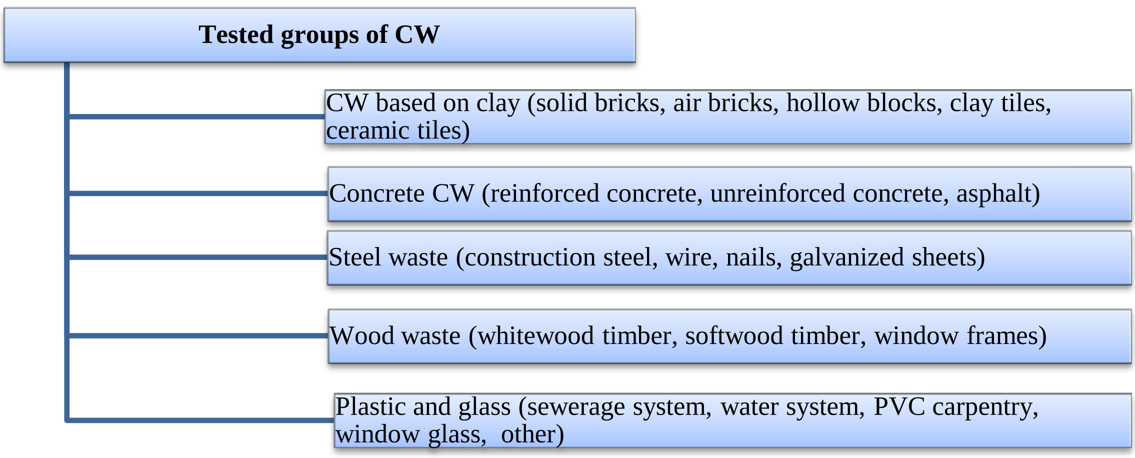


Fig. 3 *Block diagram of tested CW groups and subgroups*

The total amount of CW generated in 2014 (V_i) can be calculated according to the equation (2):

$$V_i = g_i \cdot n_i \tag{2}$$

The value*S*is equal to the sum of the total amount of CW and it is calculated according to the equation (3):

$$S = \sum_{i=1}^{n} V_i \tag{3}$$

The average value of the CW per aconstruction site p is equal to the quotient of the total amount of CW*S* and the total number of sites N_g (4):

$$p = \frac{S}{N_g} \tag{4}$$

To obtain the average value of the final C&D waste in a loose state *P*, it is necessary to introduce the coefficient k_i (for the purposes of this study the adopted loosenesscoefficient is 1.30).*P*value can be calculated according to the following equation (5):

$$P = p \cdot k_i \tag{5}$$

Table 2CW according to generators of commercial and residential buildings

Gerenator marks	$g_{g2}(m^3)$	$g_{b2}(m^3)$	g_{d2} (m^3)	n_i*(pieces)*
G 1	21,68	8,00	7,00	2
G 2	92,60	22,00	14,00	4
G3	2000,00	4,00	1,00	3
G 4	200,27	6,50	3,00	3
G 5	100	65,00	20,00	1
N_g				**13**

Table 3 Total amount of CW

Gerenator marks	$V_{g2}(m^3)$	V_{b2} (m^3)	V_{d2} (m^3)
G 1	43,36	16,00	14,00
G2	370,40	88,00	56,00
G3	6000,00	12,00	3,00
G 4	600,81	19,50	9,00
G 5	100,00	65,00	20,00
S(m³)	7114,57	200,50	102,00
p_2(m³)	547,27	15,42	7,85
P_2**(m³)**	**711,45**	**20,05**	**10,21**

3.3. Versions of the CW system management in the areaof Niš

To define CW system management, it is necessary to implement a morphological analysis.

The totalfunctionof the morphological matrix is decomposedto the following elemental functions: selection, collecting, storing, treatment, serving and scheduling.

For these elementary functions, several alternative solutions were given. Further analysis is carried out in order to obtain possible combinationsand to select theone that provides the best solution.By barainstorming (BS)- combining variant solutions of partial functions, a setof three different variantsolutions (E1, E2 and E3) of the total function ofwaste collection is singled outand is shown in Table 4.

The variant E1: for the CW collection, the following is planned:a container of 4m³in volume (V12), a container transport vehicle –a Renaultbrand skip loader (V22) andthe existing landfill Location 1 for disposal of waste(V31). For treatment,the crusher Innocrush 30 with the capacity of 30 t/h (V42) isenvisaged, while two workers are usedas manpower(V52). The period of CW collection is assumed to be15 days(V62).

The variant E2: for the CW collection , the following is planned:a container of 5m³in volume (V13), a container transport vehicle - a Scania brand Model P230 telescopic skip loader (V23), and the planned landfill for disposal- Location 2 (V32). For treatment,the crusherInnocrush 30 with the capacityof 30 t/h (V42) is envisaged,while serving consists ofmanpowerof three individuals(V53). The period of CW collection is assumed to be 30 days (V63).

The variant E3: for the CW collection , the following is planned:a container of 9m³in volume (V14), a container transport vehicle - a Renaultbrand skip loader (V22), and the planned location for disposal- Location 2 (V32). For treatment,the crusher Innocrush 30 with the capacity of 30 t/h (V42) is envisaged,while serving depends on the manpower of three workers (V53).The period of CW collection is assumed to be2 months (V64).

To select the optimal solution, a multicriteria method was used(MCmethod). This method is most useful for the optimization of complex systems since theoptimization criteria encompasses various system parametres.

3.4. MC decision method

MCmetod can be implemented when it is necessary to find a solution tosome complexproblems that encompass quantitative and/or qualitativeaspects to the problem while making a decision. MCgives a structure that makes decisions according to the criteria. MCmethod does not have toreplace the decision maker, but should rather give supportwhen making decisions. The quality of the optimal system solution depends on the criteriaand the goals that are setat each stage of its development. For the assessment of the alternative solutions of collected CW, a set of different criteria based on the 5e criteriais defined.

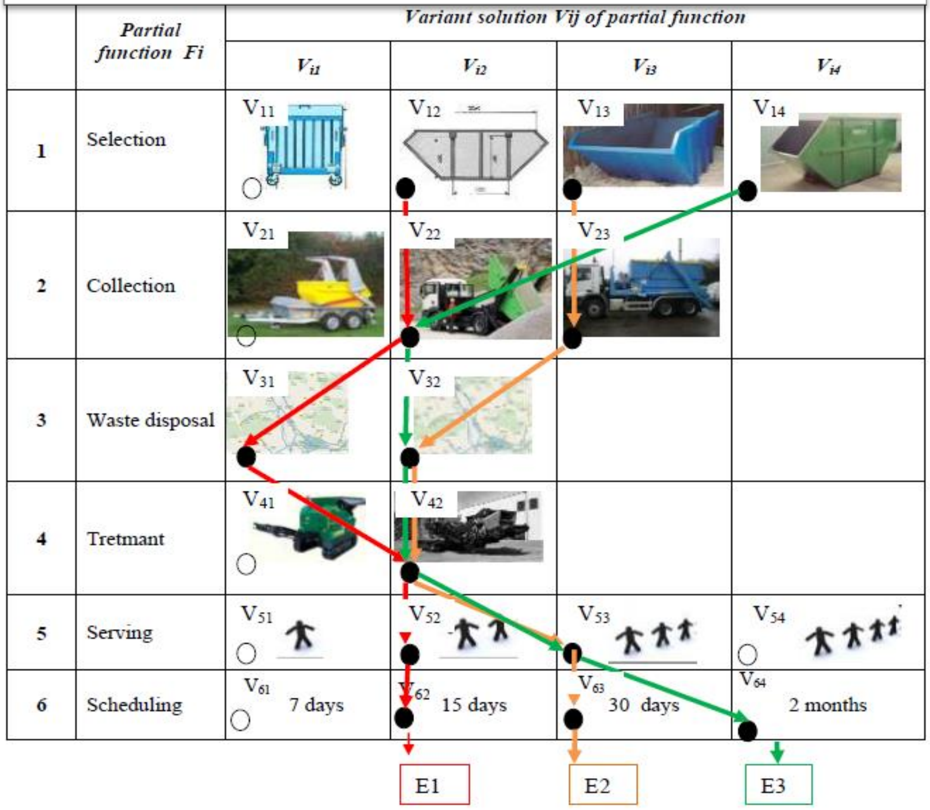
Efficiency criteria - system solution's efficiency is related to the completion of tasks in a given time-frame with the given parameters. Efficiency depends on the current field conditions, route length, the time that the vehicle spends loading, etc.

Ecological criteria - takes into consideration vehicle's evnironmental impact for the duration of its engagement. Mobile machinery's impact is most frequently assessed by their pollutant emissions, surface pressure while in motion, noise emissions, dust, energy consumption, etc.

Ergonomical criteria - observes the system: man - machine - environment. This means safe, logical and visible handling of themachinery without errors, noise, and workers' fatigue. Ergonomical criteria adhere to norms and standards.

Economic criteria is used for evaluating variant solutions and is closelyrelated to the criteria of efficiency.The indicator of economy is the time needed to do operations like collecting waste on a planned route, which is further related to the route length, manpower, number and type of containers and other.

Table 4 *Morphological analysis of construction waste management*



Aesthetic criteria takes into account the compatibility of the ambiente, equipment and container design, clothes of the workers who collect waste and other [12].
By analysing the current conditions of waste collecting, the attention was directed to the waste type and composition, size of conatainers, typesof transport vehiclesand other. A possible variant solutionis analyzed by using the BS method.
At the first, somemorphological analysis were conducted.

This helped to determine partial$F_i$functions (Table 4) and some characteristics that system solutions must contain.Partial and elementary functions are given in the first column of the morphological matrix. Then, in other columns partial solutions were given(Vij) for all the elementary functions.By linking partial functions, possible variant solutions E1, E2 and E3were obtained [12].
For forming a morphological matrix of possible variant solutions, the basic function was splitinto the following partial functions (Table 5):

1) Selection at the source (F1),
2) Collection (F2),
3) Waste disposal (F3),
4) Treatment (F4),
5) Serving – number of people (F5),
6) Scheduling (F6).

Table 5 Isolated variant solution of some functions

Variant solutions	*Partial solutions*
E1	V_{1-2}-V_{2-2}-V_{3-1}-V_{4-2}-V_{5-2}-V_{6-2}
E2	V_{1-3}-V_{2-3}-V_{3-2}-V_{4-2}-V_{5-3}-V_{6-3}
E3	V_{1-4}-V_{2-2}-V_{3-2}-V_{4-2}-V_{5-3}-V_{6-4}

In the Table 6,an assessment and selection of the solutionswere given. In the left subcolumns E1, E2 and E3 some criteria indicators were given, that is the assessments, while the right subcolumns were obtained as a product of importance factor indicatorsof the $K_i$criteria and the criteria indicators from the left subcolumns. The application of this method led us to the conclusion that the variant marked as E1was assessed as the best combination of the CW managament functions.

Table 6 Evaluation and selection of the solutions

Optimization criteria Ki	*Factor of importanc e k_{oi}*	*Possible variant solutions*					
		E1		*E2*		*E3*	
		k_{rli}	$k_{oi}k_{rli}$	k_{rli}	$k_{oi}k_{rli}$	k_{rli}	$k_{oi}k_{rli}$
K1 Number of container	0,05	0.50	0.025	0.60	0.03	1.00	0.05
K2 Loading time	0,10	1.00	0.1	0.89	0.089	0.80	0.08
K3 Container accessibility	0,05	0.40	0.020	0.30	0.015	0.30	0.015
K4 Surface preassure while in motion	0,20	0.30	0.06	0.20	0.04	0.20	0.04
K5 Energy consumption	0,15	0.60	0.09	0.40	0.06	0.30	0.045
K6 Noise emissions	0,10	0.50	0.05	0.30	0.03	0.30	0.03
K7 Ergonomy	0,10	0.60	0.06	0.40	0.04	0.30	0.03
K8 Economy	0,20	0.60	0.12	0.50	0.1	0.50	0.1
K9 Aesthetic	0,05	0.50	0.025	0.50	0.025	0.50	0.025
	$\sum k_{oi}=1$	u_{1-2}=0.55		u_{2-2}=0.429		u_{3-2}=0.415	

3.5. Layout of a recycling yard

CW managment problem also takes into account defining of the concept of recycling, which implies that the recycling yard must exist. The purpose of the recycling yard is to relieve the landfill. Landfill relieve means that only the unrecyclable waste can be permanently disposed ofin the landfill. The recycling yard can be arranged in a few ways. The Figure 4 shows an example of a recycling yard layout. In the yardmeasuring 1200 m^2, CW drop offs from collection sites are envisaged. The yard also provides for treatment of CW. This recycling yard is planned as part of a regional landfill. After signing up at the reception, a vehicle that transportsreplaceablecontainers of CW performs emptyingof containers. After treatment, CW waste is transported in dozersto replaceable containers, which are further transported to purchasers and factories for processing of construction waste.

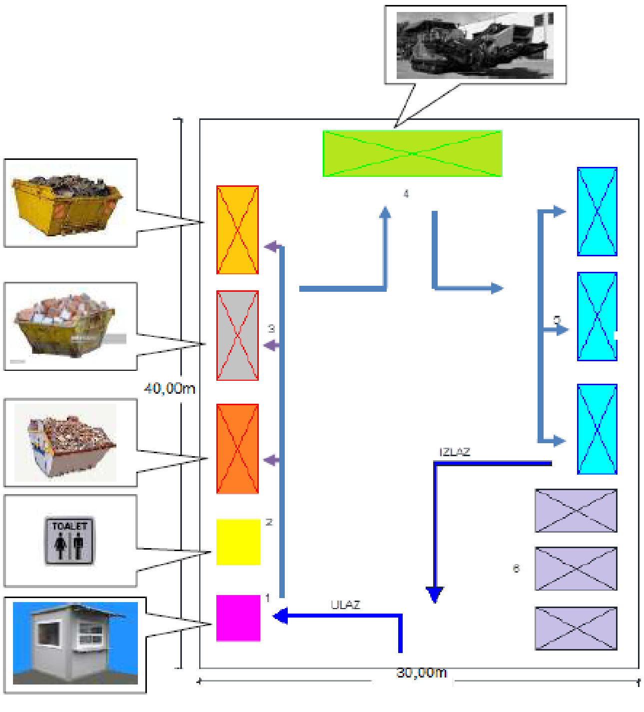


***Fig. 4** Layout of a recycling yard*

4 CONCLUSION

Construction waste management in the area of Niš (and the Republic of Serbia also) is an important issue that needs an effective response. We all know that a large amount of waste isstored in inappropriate places, due to the fact that appropriate places do not actualy exist.

Construction waste disposal in ilegal, municipal and other types of landfills is not just an environmental problem, but also an economical one,since a significant amount of waste that could be reused inconstruction or other type of industry is lost, although it could otherwisebe used to prevent the creation of new cycles of construction waste.

Construction waste is the type of waste that could be returned to the market with good organization, professional implementation and support of the Ministry of Construction and other governmental organizations.

In this study, the current situation was analyzed and a construction waste management system was proposed. The proposed solution of the construction waste system management is designed to complement the existing regional waste management plan for the regionof Niš.

For the final solution of the proposed construction waste in the areaof Niš, it is necessary to conduct additional analysis, measure the real quantities of waste, observe the formation of construction waste over a longer period of time (during the construction season which lasts from March to November), but also include a greater number of construction wastegenerators.

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