Article

Construction waste audit in the framework of sustainable waste management in construction projects - case study

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Abstract: The issue of sustainability has long been the subject of interest of the architecture engineering and construction sector. All three aspects of sustainability - economic, environmental and social - can be affected through appropriate construction waste management. Construction and demolition waste (CDW) is one of the largest worldwide waste streams, therefore it is given great attention by all stakeholders (investors, contractors, authorities, etc.). Researches have shown that one of the main barriers to insufficiency CDW recovery is inadequate policies and legal frameworks to manage CDW. It is also one of the EU's environmental priorities. Aim of the article is to confirm the economic potential of construction and demolition waste audit processing through case study. A pre-demolition waste audit has been processed for unused building of shopping center in the town Snina in Slovakia. Subsequently, a comparison of economic parameters (waste disposal costs and transport costs) of recommended CDW management was performed. This comparison confirmed the economic benefits of environmentally friendly construction waste management methods according to the waste audit results, which will also increase the sustainability of construction projects. In addition, the cost parameters of selected waste disposal methods could be another dimension of building information modelling.

Keywords: construction and demolition waste; renovation, demolition; waste disposal; pre-renovation audit; waste audit; construction; comparison; costs

1. Introduction

Architecture engineering and construction (AEC) belongs to an important part of the EU economy. AEC activities contributes about 10% of GDP in European Union and create 20 million jobs [1]. At the same time, AEC is responsible for around half of all extracted material, half of the total energy consumption, third of waste generation and third of water consumption [2,3]. Construction and demolition activities creates the biggest worldwide waste stream: 36% solid waste produced in Europe [4,5], about 60% waste produced in the United States [6] and 30% - 40% waste in China [7]. Construction and demolition waste (CDW) arise from construction works, securing works, as well as the works performed during maintenance of constructions, modification of constructions or removals of constructions. CDW consists of many materials including masonry, concrete, metal, asphalt, wood, gypsum, glass, plastic and excavated soil [8]. Hazardous substances (asbestos, PCBs, etc.) are also part of CDW. Hazardous waste may generate an increased risk to the environment and the human health if not managed and disposed in a safe way. CDW is usually used as a substitute for natural material in road construction, for backfilling or landscaping, or for landfilling or incineration [2].

A significant amount of construction and demolition waste has a great potential for re-use and recycling [9]. This recovery performance of CDW is not fully used in all countries of the European Union. In 2018, recovery rate of construction and demolition waste in EU is 90% [10]. Recovery rate between EU member states differ significantly from one country to another (Figure 1). The recovery potential is fully applied (more than 90%) in countries the Netherlands, Ireland, Malta, Hungary, Lithuania, Italy, Luxembourg, Slovenia, Belgium, Denmark, Greece, Estonia, Germany, Portugal, the Czech Republic, Austria, United Kingdom. On the other side, member states as Bulgaria and Slovakia (24% and 51%) do not use the full recovery potential of CDW [10].

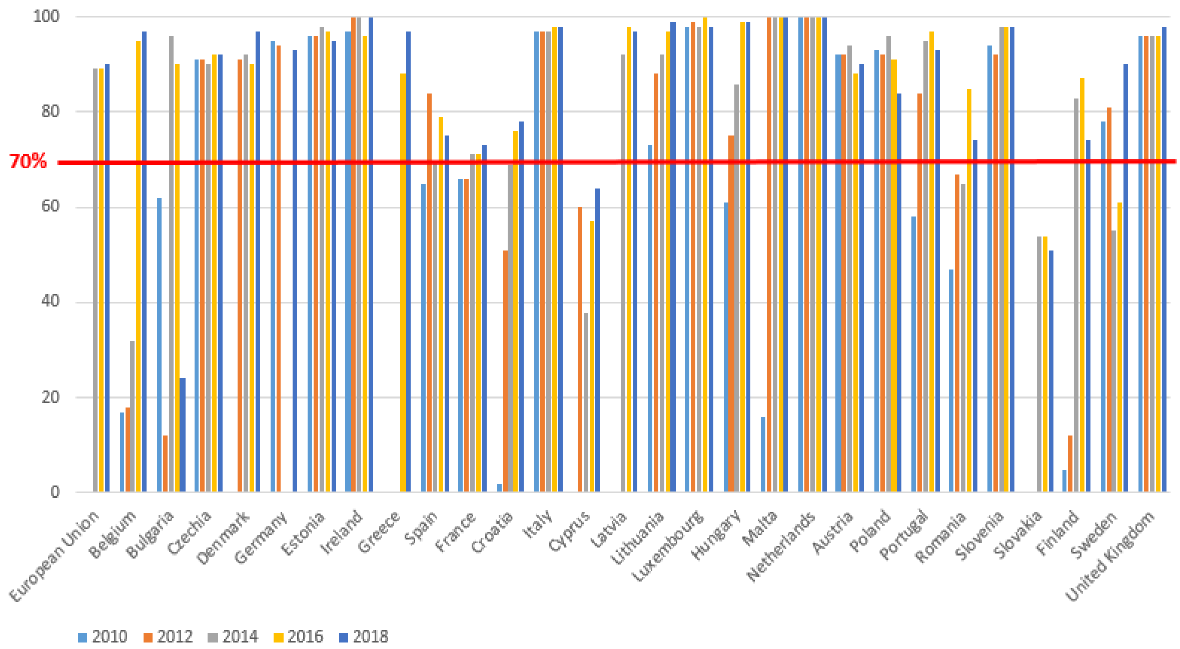

Figure 1. Recovery rate of construction and demolition waste in EU member states in period 2010 - 2018 [10].

Target of European Union according The Waste Framework Directive 2008/98/EC is to have 70% of CDW re-used, recycled and/or recovered by 2020 [11]. Most member states of EU have already met this target as early as 2018. In many states is still an opportunity to improve their approach to construction waste recovery. EU in 2016 processed document "EU Construction & Demolition Waste Management Protocol" [12] which contributed to reaching target of 70% of CDW to be recycled by 2020. This should to be achieved through: (i) improved waste identification, source separation and collection; (ii) improved waste logistics; (iii) improved waste processing; (iv) quality management; and (v) appropriate policy and framework conditions [12]. Unfortunately, there are still many barriers that prevent the recovery of construction and demolition waste from point of stakeholders' view.

2. Literature Review

2.1 Barriers to improving the environmental performance of construction waste management

Environmental performance of construction and demolition waste management is affect by many factors. Many studies have described these effects from many points of view. Author Mahphour [13] summarized the potential barriers to moving toward circular economy in CDW management; authors of study [14] had focused on description of barriers in terms of waste management strategy; study [15] has divided the barriers into six groups - financial/economic, institutional, environmental, technical, socio-cultural and legal/policy. The summary of barriers to increase CDW recycling and re-using has been processed based on its analysis [13-35]. The studied barriers are divided into four barriers group – environmental (Table 1), economic (Table 2), social (Table 3) and legal/policy (Table 4). Some barriers cannot be included in a particular group; they belong to several groups by their nature at the same time. The individual barriers mutual interact.

Table 1. Summary of environmental barriers to increase CDW recycling and re-using.

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Potential Barrier	Source
ineffective CDW dismantling, sorting, transporting, and recovering processes	[14,16,30]
not green designing of construction projects - waste reduction does not receive sufficient attention in building planning and design	[16,33]
using finitely recyclable construction materials	[16]
overemphasizing recycle and non-environment friendly methods during construction and demolition phases of construction projects	[17-20]
preferring off-site CDW sorting/landfilling over on-site sorting due to lack of incentives	[18,21,22]
lack of producer-based responsibility system in production of construction materials	[26,25]
inherent complexity of transforming to circular economy in CDW management	[26,19]
inadequate awareness, understanding, and insight into circular economy in CDW management	[14,18,26]
no benefits to sorting packaging materials	[14]
inherent complexity of transforming to circular economy in CDW management	[28,26]
lack of integration of sustainable CDW management	[26]
uncertain aftermaths of moving toward circular economy in CDW management	[23,26]
assumption that waste generation is inevitable and can't be reduced	[14]
design not using standard sized materials	[14]
lack of certainty about CDW condition	[14,30]

Table 2. Summary of economic barriers to increase CDW recycling and re-using.

Potential Barrier	Source
lack of funding to implement circular economy in CDW management	[23]
tendency to manage cost and time rather than CDW	[21,23]
traditional construction methods	[14,31]
cost of recycling processes - construction price does not reflect the environmental cost	[30,15]
lack of time/time needed for material separation	[14,15]
limited budget/costs of material separation	[14]
lack of contractual requirement for reusing materials	[14]
reluctance to segregate for recycling and re-using materials with a low economic value or difficult to reuse	[32]
perception that waste reduction activities are not cost-effective,	[32]
financial benefits from waste reduction are inequitably distributed, providing little incentive for operatives	[32]

Table 3. Summary of social barriers to increase CDW recycling and re-using.

Potential Barrier	Source
lack of empirically based literature on the barriers	[26,18,25]
undeveloped individuals' engagement	[17,23]
constructor's attitude	[14]
user preference for new construction materials over reused/recycled ones	[18,23]
lack of commitment by top urban managers to move toward circular economy in CDW management	[17,23]
construction industry culture	[14]
first priority is financial profit and not environmental issues	[14,15]
ineffective CDW management	[30]
lack of a well-developed waste recycling market	[30,31]
the building users do not participate in the planning and design process	[35]

low demand by clients for sustainable buildings	[33]
difficulties in changing work practices of workforce	[31]
a belief that waste reduction efforts will never be sufficient to completely eliminate waste	[15]

Table 4. Summary of legacy/policy barriers to increase CDW recycling and re-using.

Potential Barrier	Source
inadequate policies and legal frameworks to manage CDW as well as lack of supervision on CDW management	[14,18 23-25,30,31,35]
lack of clearly defined national goals, targets, ad visions to move toward circular economy in CDW management	[17,23,27]
non-standardized CDW reduction reporting as well as lack of accessible data	[15,17]
lack of financial incentive	[14]
lack of coordination among divisions	[33]
inconsistencies between different governmental agencies	[33]
absence of industry norms or performance standards for managing waste	[32]
individual responsibilities for waste management are poorly defined, inadequately	[32]

2.2 Construction and demolition waste audit

The barriers to adoption of the construction waste recycling and re-using are different. Lack of clear and mandatory requirements for the CDW management have been identified as one of the most significant barriers to CDW recovery. In many cases, the stakeholders are interested in CDW management, but there are still some challenges to construction sector. For example, valuable materials are not always identified, collected separately, or adequately recovered [4]. Therefore, EU has decided to create EU waste audit guideline [36] for manage CDW which sets out the procedure for construction and demolition waste management, defines the stakeholders and their tasks, and provides the waste management recommendations. Document (called "waste audit" or "pre-demolition audit") is focused on assessment of CDW streams prior to renovation of demolition of constructions.

Table 5. Legislative obligation for construction and demolition waste audit [36,37,38].

Legislative obligation	Member state of EU
mandatory audit	Belgium, Bulgaria, Czech Republic, Finland, France, Italy, Luxembourg, Malta, Spain, Sweden, The Netherlands, United Kingdom
mandatory audit (only hazard CDW)	Hungary, Ireland, Poland, Slovenia
no legislative obligation	Austria, Croatia, Cyprus, Denmark Estonia, Germany, Greece, Latvia, Lithuania, Portugal, Romania, Slovakia

Audit of construction and demolition waste (CDWA) should be an integral part of each construction project, mainly demolition and renovation. The valid and proper CDWA has to be processed by qualified expert (authorized auditor). Authors of study [37] determined the mandatory pre-demolition and renovation audit as the most promising measures which impacts to environmental and socio-economic field of CDW management. This is also confirmed by best practices from many member states of EU [36,37,38]. CDWA is not specified by a common framework across the EU. Compliance with the document is not mandatory, but its adoption will significantly increase the rate of construction waste recovery. In many member states of EU is CDWA required due the key CDW policy and legislation for any type of construction waste or only for hazardous waste. On the other hand, in some states there is no legislative obligation of CDWA (Table 5).

Legislative requirements for CDWA are usually part of the permission for demolition or renovation of building.

The pre-demolition audit of CDW should be carried out before the renovation and demolition works. The demolition works supplier can identify and sort the demolition waste directly at the source bases on audits results. The contractor of demolition works can identify and separate the CDW directly on construction site. Pre-demolition audit of construction and demolition waste are an important driver to increase the recovery rate of construction and demolition waste according Waste Framework Directive 2008/98/EC [11].

3. Materials and Methods

Aim of the article is to confirm the economic potential of construction and demolition waste audit processing through case study.

3.1. Research Material

An object of the case study is the unused building of shopping center in the town of Snina in northeastern Slovakia (Figure 2). The owner of the building decided to carry out the renovation works. The purpose of the construction has been changed. Building will be used for administrative purposes.

(a) (b) (c)

Figure 2. Building of shopping center in Snina: (**a**) Southern view; (**b**) Eastern view; (**c**) Northern view.

The load bearing system of the construction is a reinforced concrete frame skeleton in modular coordination 6x6m. Slabs are made of prefabricated reinforced concrete Spiroll panels, the vertical communication system is secured by existing reinforced concrete stairs, lift shaft is not used, the roof construction is hipped with timber roof truss.

Demolition works will be carried out due to the unsatisfactory technical and static condition of the structure. They are part of the reconstruction of the building. Demolition works are focused on:

- Complete demolition of the non-load-bearing exterior cladding
- Complete demolition of the internal non-load-bearing partition walls
- Complete demolition of internal stairs and lift shafts
- Increasing the depth of the foundation slab because of the installation of new lift shafts and escalators
- Demolition of a part of the roof because of the construction of a new roof structure
- Reduction of the wooden roof truss overlap around the perimeter of the building
- Drilling holes in Spiroll slabs because of new communication system

Demolition works will be carried out downwards, from the roof structure to the foundations.

3.1. Research Methods

3.1.1. Construction and demolition waste audit

Pre-demolition audit of construction and demolition waste has to be carried out before renovation or demolition works begins. The methodology (Figure 3) of its processing is recommended according to "Guidelines for the waste audits before demolition and renovation works of buildings" [36]. The document sets out the content of the individual steps.

The result of the CDWA is a report identifying the construction and demolition waste stream originated during the renovation or demolition works; and disposal options considering to the building location. Desk study is focused on studying all available information about a specific building which are found in the project documentation of the renovated or demolished building: information about load bearing system of the construction, information about construction elements and materials, information about dangerous substances, information about originated CDW amount, information about renovation history. Information are given mainly in the technical report of the construction project by the designer. CDW data are often determined only by expert estimate, may not be accurate. Desk study of available recycling facilities and landfields in the building location has been added beyond the recommended procedure of the CDWA because of future economic analysis of waste management. This obtained information represents input to proper CDWA. Another step of CDWA is field survey which involves a visit of construction site and particular building. All rooms of building are visually inspected during this visits. Detailed inventory of construction material for each room and construction elements (slabs, roof, columns, etc.) is processed. The aim of this step is measurements or confirm the data obtained during the desk study. If necessary, samples are taken for analysis. All obtained information should be complemented with photographs and confirmed by interviews.

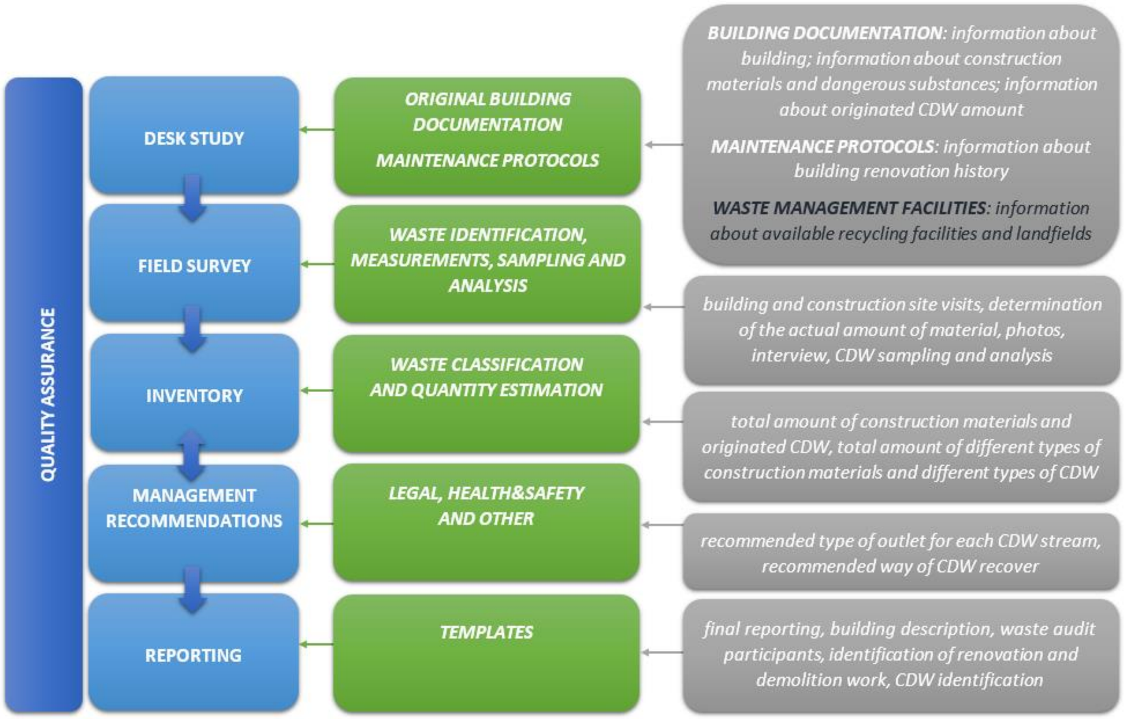

Figure 3. Scheme of the construction and demolition waste audit steps

Previous steps have focused on buildings and construction materials. The inventory of materials and elements determined the amount and type of construction waste that will be originated during renovation or demolition work. Inventory of materials and originated CDW should be developed for each room separately, minimum required set of data for the whole building. Quantified and qualified data on generated waste have an impact on waste management recommendation; and is necessary for decision making process of the appropriate CDW recovery method in terms of technical and economic aspect. Final report involved an essential, mandatory and optional information. Final report must contain essential information about construction project, location, stakeholders, total amount of CDW, summary of hazardous waste, description of the waste treatment methodology. The mandatory information of report involves construction materials inventory. This data could be: (i) basic (hazardous/non- hazardous CDW), (ii) intermediate (hazardous/non-hazardous CDW (non-inert)/ non-hazardous CDW (inert)), (iii) type of material + waste code (according European List of Waste [39]). Construction elements inventory is not mandatory. Last point of CDWA is waste management recommendations that presents an optional result.

3.1.2. Economic analysis of construction and demolition waste disposal

The economic potential of a sustainable approach to CDW management will be demonstrated through the calculation of costs for waste treatment and costs of waste transport for two variants:

- Variant "A" will present a waste management according to CDWA recommendation
- Variant "B" will present the least environmentally friendly way of waste management, namely landfilling of the whole amount volume of waste

The economic comparison of the proposed variants focuses on the analysis costs for waste disposal and transport costs. Waste disposal costs are expressed using the following equation:

$$C_{wd} = \sum_{i=1}^{n} Q_i * FD_{ij} \qquad [€] \tag{1}$$

where C_{wd} - costs for waste disposal [€]
Q_i - volume of i-th waste type [t]
FD_{ij} - fee for j-th waste disposal method of i-th waste type [€/t]
i - waste type
j - waste disposal method

Transport costs depend on number of transport kilometers and transport fee. They are expressed by the following equation:

$$C_t = \sum_{i=1}^{n} n_{ij} * FT_{ij} \qquad [€] \tag{2}$$

where C_t - transport costs [€]
n_{ij} - the number of kilometers for the transport of the total amount of i-th waste to the j-th waste disposal site [km]
FT_{ij} - fee for transport i-th waste type to j-th waste disposal site [€/km]
i - waste type
j - waste disposal method

Number of transport kilometers relates with distance of waste generation site to waste disposal site and number of rides between these two sites through equation:

$$n_{ij} = \sum_{i=1}^{n} D_{ij} * nr_{ij} * 2 \qquad [km] \tag{3}$$

where n_{ij} - the number of kilometers for the transport of the total amount of i-th waste to the j-th waste disposal site [km]
D_j - distance of the waste generation site for i-th waste type to the j-th waste disposal site [km]
nr_{ij} – number of rides from i-th waste type to the j-th waste disposal site waste type [pcs]
i - waste type
j - waste disposal method
2 - return distance coefficient

Number of rides related to truck transport volume which is used for waste transport i-th waste type to the j-th waste disposal site waste type. The number of rides is determined by rounding up from 0,3 by equation:

$$nr_{ij} = \sum_{i=1}^{n} \frac{Q_i}{Q_v} \quad [\text{pcs}] \tag{4}$$

where nr_{ij} – number of rides from j-th waste disposal site to the waste generation site for i-th waste type [pcs]
Q_i - volume of i-th waste type [m³]
Q_v - volume of truck [m³]
i - waste type
j - waste disposal method

4. Results and Discussion

Construction and demolition waste audit before demolition and renovation works was implemented for the building of shopping center in Snina town. Considering that the object of CDWA is also the object of a case study, more detailed information about this building and renovations and demolition work is given in the Research Material section. An initial step of CDWA is the desk study (Figure 4). An original building documentation, maintenance protocols and documentation of construction changes were not available. The only relevant document was the project documentation of designed building renovation and actual state. Project provides the information about currently building materials types (non-hazardous/hazardous) and estimated amount and type of CDW (Table 6). These requirements are usually linked to the renovation or demolition permit [40].

Figure 4. Steps of desk study for construction and demolition waste audit

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Table 6. Estimated amount of construction and demolition waste according project documentation.

Waste code	Type	Amount (t)	Category
17 01 03	tiles and ceramics	1,5	non-hazardous
17 01 07	mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06	45,0	non-hazardous
17 02 01	wood	1,0	non-hazardous
17 02 02	glass	2,0	non-hazardous
17 04 05	iron and steel	1,2	non-hazardous
17 04 11	cables other than those mentioned in 17 04 10	0,05	non-hazardous
17 05 04	soil and stones other than those mentioned in 17 05 03	40,0	non-hazardous
17 09 04	mixed construction and demolition wastes other than those mentioned in 17 09 01, 17 09 02 and 17 09 03	1,0	non-hazardous

Nature of demolition works affects the type of waste generated. Renovation works involved the complete demolition of the internal non-load-bearing partition walls and complete demolition of internal stairs and lift shafts. Therefore, mixtures of concrete, bricks, tiles and ceramics and soil and stones represents the largest estimated share of generated waste for the solved construction.

Table 7. Waste management facilities in Snina's region.

Facility	Distance (km)	Code of treated CDW	Type of waste treatment	Treatment fee (€/t)
A	40	17 01 03	recycling	5,00
		17 01 07		10,00
		17 02 01		20,00
		17 05 04		5,00
B	98	17 01 07	recycling	20,00
		17 05 04		15,00
		17 09 04		15,00
C	110	17 01 07	recycling	10,00
		17 05 04		10,00
D	82	17 01 07	recycling	10,00
		17 02 01		15,00
		17 05 04		5,00
		17 09 04		10,00
E	28	17 01 03	landfilling	46,80
		17 01 07		46,80
		17 02 01		30,00
		17 02 02		48,00
		17 04 05		30,00
		17 04 11		100,00
		17 05 04		12,00
		17 09 04		109,00
F	73	17 01 07	landfilling	49,00
		17 02 01		96,00
		17 05 04		16,60
		17 09 04		84,00
G	5	17 02 02	collection yard	0,00
		17 04 05		0,00
		17 04 11		0,00

For the purpose of the economic analysis of CDW recovery were detect its facilities in Sinan's region (Table 7) as a part of desk study. Four recycling facilities (distance 40-110 km) and two landfills (28-73 km) of CDW are nearby the place of CDW generation. The selected waste management facilities disposal only a specific type of CDW. The treatment fees vary depending on the type of CDW, the waste treatment method and treatment facility. The selected types of wastes (glass 17 02 02, iron and steel 17 04 05 and cables 17 04 11) can be placed in the collection yard 5 km away from the construction site. There is no fee for their disposal.

The results of multiple visits of building and site (Figure 5) were the visual inspections and comparisons of construction conditions with desk study's findings. During the building visits, photo documentation (Figure 6) was taken and measurements of the building were processed. As hazardous materials are not expected to be present, sampling and analysis of hazardous substance in materials have been irrelevant [36].

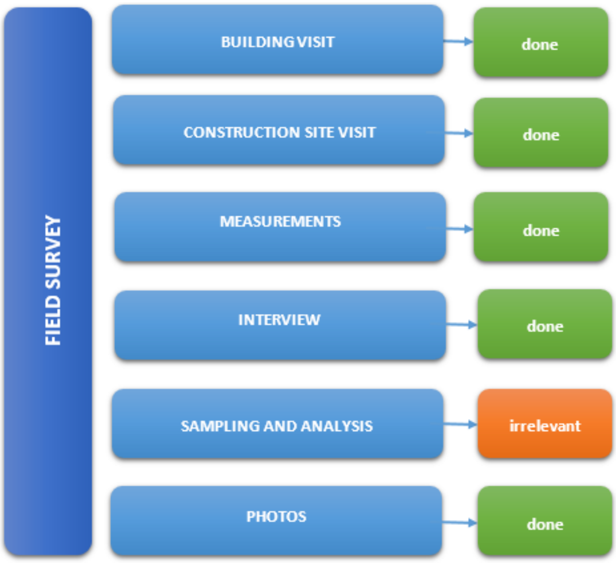

Figure 5. Steps of field survey for construction and demolition waste audit

Figure 6. Photo documentation of the construction during the site visit

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Inventory of materials is the most significant step of CDWA that determines the exact list of building materials and elements, their hazards and nature. The removed building material generates the construction waste. Thus, the properties of building materials predetermine the properties of CDW. The inventory of construction and demolition waste is summarized for the whole building of shopping center (Table 8). Inventory of materials may differ from the estimated amount of CDW in the desk study. The accuracy of the estimate depends on the professional competence and skills of the person who proposed the estimate (designer of construction project). The amount of CDW originated, which is determined on the basis of material inventory, is accurate. Actual amount of CDW was different compared to the estimated amount for soil and stones (less by 2,5t), mixtures of concrete, bricks, tiles and ceramics (more by 10t) and mixed construction and demolition wastes (more by 0,5t). The comparison proved to be significant of field survey when building is inventoried on many occasions in a destructive manner.

Table 8. Inventory of construction and demolition waste.

Type of material	Type	Waste code	Amount (t)
inert waste	tiles and ceramics	17 01 03	1,5
inert waste	mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06	17 01 07	50,0
inert waste	wood	17 02 01	1,0
inert waste	glass	17 02 02	2,0
inert waste	iron and steel	17 04 05	1,2
inert waste	cables other than those mentioned in 17 04 10	17 04 11	0,05
inert waste	soil and stones other than those mentioned in 17 05 03	17 05 04	37,5
inert waste	mixed construction and demolition wastes other than those mentioned in 17 09 01, 17 09 02 and 17 09 03	17 09 04	1,5

All analyzed items were a non-hazardous inert waste material. A suitable way of this CDW management is the recycling. The report of construction and demolition waste audit describes and determines the possible outlets for particular CDW type and recommended outlets (Table 9).

Table 9. Waste management recommendations.

Type of material	Waste code	Amount (t)	Possible outlets	Recommended outlets
inert waste	17 01 03	1,5	A - recycling E - landfilling	E - landfilling
inert waste	17 01 07	50	A - recycling E - landfilling	A - recycling
inert waste	17 02 01	1,0	A - recycling E – landfilling	A - recycling
inert waste	17 02 02	2,0	E - landfilling G – collection yard	G – collection yard
inert waste	17 04 05	1,2	E - landfilling G – collection yard	G – collection yard
inert waste	17 04 11	0,05	E - landfilling G – collection yard	G – collection yard
inert waste	17 05 04	37,5	A - recycling E - landfilling	A - recycling
inert waste	17 09 04	1,5	A - recycling E - landfilling	A - recycling

For many investors and contractors (as CDW holders or producers), the environmental benefits of waste recovering alone is not sufficient. The way of CDW treatment must have an economic effect. In order to confirm the economic benefits of CDW recovery, an economic analysis of possible ways of waste management also performed. Variants A (waste management according to CDWA recommendation) and variant B (all types of CDW are landfilled) of waste management for all types of construction waste were compared.

Economic potential proving of CDWA processing was realized using equations (1-4). The calculation of costs for individual variants of waste disposal confirmed significant economic effect of a sustainable way (recommended by CDWA) of disposal CDW. The cost of recovering CDW according to waste audit recommendations was 878,50 € (Table 10). Fees for a sustainable way of waste treatment are up to 72,5% lower than if we landfill the generated waste for the reconstruction of the shopping center in Snina only in a construction waste landfill (3190,70 €) (Table 11).

Table 10. Economic analysis of waste management according CDW recommendation - variant A.

Waste code	Recommended outlets	Amount (t)	Treatment fee (€/t)	Total treatment fee (€)
17 01 03	A - recycling	1,5	5	7,50
17 01 07	A - recycling	50	10	500
17 02 01	A - recycling	1,0	20	20
17 02 02	G – collection yard	2,0	0	0
17 04 05	G – collection yard	1,2	0	0
17 04 11	G – collection yard	0,05	0	0
17 05 04	A - recycling	37,5	5	187,50
17 09 04	E - landfilling	1,5	109,00	163,50
			TOTAL	***878,50 €***

Table 11. Economic analysis of waste management by landfilling - variant B.

Waste code	Recommended outlets	Amount (t)	Treatment fee (€/t)	Total treatment fee (€)
17 01 03	E - landfilling	1,5	46,80	70,20
17 01 07	E - landfilling	50	46,80	2340
17 02 01	E - landfilling	1,0	30	30
17 02 02	E - landfilling	2,0	48	96
17 04 05	E - landfilling	1,2	30	36
17 04 11	E - landfilling	0,05	100	5
17 05 04	E - landfilling	37,5	12	450
17 09 04	E - landfilling	1,5	109,00	163,50
			TOTAL	***3190,70 €***

Of course, it is also necessary to assess the transport costs of individual variants using equations (2-4). Transport costs of variant A was 1343,75 € and variant B 1190,00 €. The amount of transport costs depends mainly on the distance of waste disposal site from the waste generation site. Higher transport distance between recycling center A and the waste generation site in Snina also affected the higher transport costs of variant A.

Costs for waste recovery of individual variants have changed after taking into account transport costs in the calculation. The total costs (disposal and transport) of waste recovery for the recommended way (variant A) are 2222,25 €, and for variant B 4380,70 €. Considering that, even after taking into account transport costs, environmentally suitable solution is 49,5% more cost-effective than landfilling despite the fact that the landfill was closer than the recycling facility.

Finally, it should be noted that a similar environmental and economic comparison can be made through buildings information modeling (BIM) [45]. Another dimension of information in BIM could relate to the cost parameters of selected waste disposal methods which may be the subject of further research. Building information modelling, parametric modeling or visualization could improve the efficiency of CDW management planning in many aspects. Correctly implemented CDWA will significantly contribute to the sustainability of construction, total quality management systems and reducing the impact of construction sectors to the environment [46-49]. Moreover, audit has an unquestionable place in the sustainable design of construction because it affects all three dimensions (economic, social and environment) of sustainable construction projects and is accordance with the newest trends of EU.

5. Conclusions

Construction sector has a huge potential for reducing waste. Most construction and demolition waste is not hazardous and is therefore suitable for recovery. The undeniable fact is that there are currently many barriers to the proper management of CDW. Also, different approaches to the management of CDW are also noticeable between EU member states. Recovery rate between EU member states differ significantly from one country to another. Therefore, the European Union has taken a number of measures, including "Guidelines for waste audits before demolition and renovation works of buildings" [36]. Document is focused on assessment of CDW streams prior to renovation of demolition of constructions. Slovakia does not belong to leaders in construction and demolition of waste recovery. On the contrary, Slovakia is one of the few countries not meeting the EU target of 70% of CDW re-used, recycled and/or recovered by 2020 [11].

The presented case study provides the processing of a construction and demolition waste audit before the realization of renovation works on the building of a shopping center in Snina, a town in northeastern Slovakia. The report of CDWA describes and determines the possible outlets for particular CDW type and recommended outlets. The recommended outlets prefer mainly a CDW recycling. A very common practice in Slovakia is that most of the originated construction waste is landfilled. The second part of the paper provides an economic analysis of two variants of waste disposal. Variant A presents a waste management according to the CDWA recommendation; and Variant B presents the least environmentally friendly way of waste management, namely landfilling of the whole amount volume of waste. The comparison of costs for waste recovery and transport costs of both variants confirmed the economic benefit of waste recovery according to recommended outlets in CDWA. Environmentally suitable recommended solution was 49,5% more cost-effective than landfilling despite the fact that the landfill was closer than the recycling facility. Of course, such economic efficiency is expressed only for the present case study. The result cannot be generalized. On the other hand, the methodology of solving a case study represents a procedure that can also be implemented in building information modeling. Another dimension of information in BIM could relate to the cost parameters of selected waste disposal methods which may be the subject of further research.

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