Rehabilitation vs Demolition Methodology to Compare the Waste Generated in Alternative Scenarios of Building Elements in BIM During the Design Stage

Rocio Quiñones[1](✉), Carmen Llatas[2], Maria Victoria Montes[3], and Isidro Cortés[1]

[1] Department of Graphical Expression and Building Engineering, University of Seville, 41012 Seville, Spain
mquinones@us.es
[2] Department of Building Construction I, University of Seville, 41012 Seville, Spain
[3] Department of Building Construction II, University of Seville, 41012 Seville, Spain

Abstract. The construction sector is one of the highest waste generators in many countries. Several studies evidence the close relationship between the decisions taken during the design phase and the reduction of the construction and demolition wastes (CDW). Moreover, many studies show the advantages of Rehabilitation versus Demolition. However, a main barrier to apply waste minimization strategies in projects is the lack of information included in the design tools themselves. The present paper aims to describe a methodological framework based on Quantification and Reduction Models of Construction Wastes, used during design stages of buildings and integrated into a building's design methodology such as Building Information Modeling (BIM). The method is conceived to guide designers, contribute to measure and predict CDW. A case study is also provided. CDW of two alternative scenarios are obtained and compared: the demolition versus the refurbishment of a roof. It also contributes to develop a sustainability simulation of a building by obtaining the construction wastes from its BIM model.

Keywords: Sustainability · Construction and demolition waste · Building Information Modelling · Building design

1 Introduction

The construction industry is essential to realize the built environment and a key sector in the sustainable development of the world production model. In Europe, although construction currently generates 9% of Gross Domestic Product and provides 18 million jobs [1], it is also responsible for 50% of energy consumption, 50% of materials extracted, 33% of water consumption and 33% of the generated waste [2]. Due to the increase of the cost of construction projects and the environmental awareness [3], the construction industry is under an immense pressure to become a more efficient industry in the use

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of resources and in the minimisation of generated waste. Specifically, it is considered crucial to pay more attention to the end of the useful life of buildings because demolition activities represent more than 50% of the total waste production of the construction industry [4].

Directive 2008/98/EC establishes the principle "who pollutes pays" and the "expanded responsibility of the producer of pollution." It includes recycling and recovery targets that must be achieved by 2020: 50% of certain household waste and other similar waste, and 70% of waste from building construction and demolition (CDW). It also requires Member States to adopt waste management plans and prevention programs to achieve these objectives. In this way, the European Commission aims to help the construction industry to be more competitive, resource efficient and sustainable. Its approach to waste management is based on the "waste hierarchy" that indicates an order of priority when configuring waste policy and its management at an operational level: prevention (zero waste), reuse (once waste is generated), recycling, recovery and, as last and least desirable option, dumping in landfills and incineration without energy recovery [5].

The emergence of new technologies in the Architecture, Engineering and Construction (AEC), based on collaborative strategies, such as Building Information Modelling (BIM), is considered an opportunity to address the problem of construction and demolition wastes (CDW) from early design stages, to obtain more efficient results [6]. Several researchers [7, 8] point out that the use of the BIM platform can help minimise CDW. However, BIM remains a novel methodology that has not developed its full potential in the industry, both at the level of research and practitioners [9]. Therefore, there is a clear need to accelerate the development and standardisation of BIM tools for CDW and thus provide broad coverage in life cycle information flows of construction projects [10].

Hence, this work aims to establish a methodological framework based on two validated Quantification and Reduction of Construction and Demolition Waste Models [11, 12], to be used during building design stages and integrated into the BIM methodology. The proposed method is intended to help designers in the early prediction and measurement of CDW. At the same time, a case study is provided where the CDW of two alternative scenarios modelled in BIM are calculated and compared: demolition versus rehabilitation of a flat roof.

2 Reduction of Construction Waste

While CDW occur during construction execution activities, more and more voices agree that they are caused by decisions and activities throughout the whole building life cycle. There is a consensus in scientific literature that project design, material acquisition, construction, renovation and demolition contribute directly or indirectly to the generation of wastes [4, 9, 13, 14].

Other recent works [8, 9, 12, 13, 15–17] reveal the importance of reducing CDW in building planning and design stage as a first step to minimise waste by eliminating the root causes of its generation. In addition, it is claimed that inappropriate design decisions, lack of constructive details and unexpected design changes can lead to an increase of up to 33% in the volume of construction waste [18].

New production models such as "lean construction" [8, 19], "zero waste" [20] or the circular economy [21] also agree on the importance of reducing CDW at their source instead of recycling and recovering them, while they innovate through the involvement of people and the development of a more efficient work from the beginning of the design process. The influence that stakeholder's project engagement exerts on the reduction of CDW is considered crucial [8, 13], since CDW generated by late information, customer's last-minute requirements, bad distribution and slow revision of plans could be avoided by improving their coordination and communication during the design stage.

However, practitioners and policy makers are still far from implementing CDW minimization measures at the design stage and continue to consider them secondary about the traditional objectives of the project, that is, time, cost and quality [20]. Some authors [7] detect a lack of effective tools that allow accurate estimation of CDW. In conclusion, for the minimization of CDW, quantitative prediction methods and tools are considered essential by practitioners, since they can provide them with fundamental data to assess the actual volume, type, time and place of generation.

3 BIM Technology and Construction Waste

The great advances have forced the construction industry, considered one of the most resistant to change, to use new methods that allow it to survive. In recent years, new technologies are emerging in the international sector of Architecture, Engineering and Construction (AEC). This is the case of the BIM methodology. Since it first appeared in 1992 [22], the BIM concept is evolving from a 3D modelling technology to a comprehensive tool and project management process [3, 7, 23, 24], which allows a better exchange of information among the participants in construction projects, during the entire life cycle of the building, for precise decision making and a better delivery process for the final product.

The international ISO Standard 2010 defines BIM as "a shared digital representation of the physical and functional characteristics of any built object (…) that constitutes a reliable basis for decision making". Many authors estimate that BIM is a set of processes [25–27]. For Bazjanac [28], BIM is "the act of creating a construction information model". Eastman [24] defines BIM as "a modelling technology and the processes associated to produce, communicate and analyse construction models". The Building SMART International (BSI) association, which promotes the use of BIM worldwide, defines it as "a business process for the generation and use of construction data, to design, build and operate the building during its life cycle". Although most BIM processes are assisted by informatic tools, the scientific community agrees that it is a new working method that links new processes assisted by an important technological component [29].

Due to the strong commitment of the physical resources of construction projects and their unique and irreversible nature, it is too expensive, practically unfeasible, to try different design and construction schemes before a project is built without using new technologies. In this context, BIM has been revealed as a powerful technology and a versatile tool that helps predict and understand possible improvements and changes in a building before they are adopted on site [13, 30].

Therefore, BIM is considered a viable technology to address the performance problems of construction projects before having to make a large investment of time or money [31]. There is a consensus on the potential of BIM to minimise CDW during design scenarios. Many authors consider that BIM is a useful tool in the early stages of a project to identify, evaluate and effectively reduce the generation of CDW throughout building life cycle [3, 6, 7, 14, 17, 18, 32].

It is widely recognised that integrated building design based on BIM can improve the accuracy and quality of the design, thus reducing errors, repetitions, inefficiencies in communication and lack of coordination amongst the project participants and unexpected changes in design, which they are frequent causes of CDW generation [13, 32]. BIM mechanisms, such as alternative design simulations, design reviews, details, collision detection, digital prefabrication and construction activity planning can reduce the amount of construction waste by 4.3–15.2% [3, 6, 8, 13, 14, 18].

However, the most critical authors [3, 30, 33] warn that BIM is not a panacea. In any case, they consider that the implementation of BIM and the improvement of interoperability between different computer programmes are very necessary to effectively address waste minimisation, proposing a way forward rather than adding mere rhetoric. For this purpose, more research and implementation are required making this functionality a reality.

Recent studies [14, 24, 31, 34], which have mapped the global research on BIM, reveal that CDW research is not a specific topic among BIM research areas. Main issues identified focused on the general environmental assessment of buildings, especially energy efficiency [35, 36]. Likewise, existing BIM and CDW studies have been developed mainly in the management of CDW during the execution of construction works, being considered as the stage in which wastes are generated [3].

Similarly, the actual implementation of BIM in the construction industry for the minimization of CDW is also relatively low, as emerged from latest studies [10, 13]. While stakeholders in the construction industry seem to be aware of the benefits of BIM to eliminate a large number of causes of waste from its beginning to its completion in a construction project, especially at the design stage, evidences show that the use of BIM to reduce them is not yet an extended practice.

Now, none of the world's leading BIM software products include waste minimization and prediction functionality. Nevertheless, it is evident from the reviewed literature that there is a promising demand for the use of BIM to reduce the generation of waste in construction.

4 Methods and Tools for Minimizing Construction Waste Integrated in BIM

Although they are still limited, some specific methods and tools assisted by BIM have been developed to minimize and manage the amount of waste from construction, renovation and demolition projects.

Won et al. [18] developed a method to quantify how many CDW would be avoided with the use of BIM through a design validation process on the Autodesk Revit platform and demonstrated through two case studies that it could be a possible solution to eliminate the main causes of CDW. Furthermore, considering the possibility of identifying errors without BIM, using the traditional approach based on drawings, the amount of CDW was analysed and compared with the CDW avoided through the use of BIM. In addition, they claimed that with the use of BIM they could minimize the construction waste generated not only during the design stage, but also during the building construction. For example, waste generated during the construction phase could also be minimized by maximizing the reuse rate by selecting appropriate cutting lengths, areas and volumes of materials based on the precise amount obtained by BIM. A limitation of their study is that the volume of construction waste generated by formworks and packaging materials was not considered. They justify these methodological aspects arguing that, in South Korea, formwork information is not commonly included in BIM models, and the percentage of packaging waste is very insignificant, representing only 0.02% of total construction waste.

Porwal and Hewage [37] proposed a BIM-based method to reduce steel waste in reinforced concrete structures by selecting appropriate bar lengths and considering available cutting lengths. BIM was used to simulate the architectural and structural design requirements and to compare the results in order to make the necessary changes in the design, to reduce and reuse the reinforcement bar waste. In addition, BIM was used as a database to communicate project information between various design teams (architectural, structural, mechanical, electrical and plumbing). The limitation of this method is derived from reducing only a specific type of construction waste, steel waste.

Mercader et al. [38] led an investigation on the quantification of CDW that was expected to be generated during the implementation of a building project through a BIM model. They determined the amount of waste generated during the execution of the structure, total volume of concrete waste and total weight in kg of steel waste, as well as the total amount of material resources consumed. Previously, Mercader et al. [39] had already demonstrated the possibility of automatically quantifying the waste generated in a model developed in BIM during earthworks and foundation process. They compared the results with the manual procedure, and these results varied in decimals of cubic meters; variations that were irrelevant to the magnitudes of the project considered.

Bilal et al. [8] defined an integrated descriptive database of construction materials as a first step of a construction waste simulation tool to be implemented in BIM. In addition, they coined the term BIM Waste Analysis (BWA) to capture the entire BIM process, to predict and design construction waste. The BWA consists of four key steps: (i) analysis of the construction model, (ii) waste prediction, (iii) waste visualization and (iv) waste minimization. Moreover, it is considered that, in a construction waste simulation tool, BWA must be integrated. First, the waste simulation tool would read BIM models and estimate the types and quantities of waste that arise from the different elements used in construction. Subsequently, the tool would visualize the production of waste from the construction elements and highlights those that produce massive amounts of waste. Finally, designers could further investigate these elements to be able to use different materials and strategies with lower waste production through the specification of smart materials.

Recently, Akinade [4] developed a BIM tool (BIM Waste) for construction waste analysis at the design stage, integrated into Autodesk Revit, based on hybrid models of Artificial Intelligence (AI), due to its ability to store and process large amounts of data. AI models were incorporated into Autodesk Revit as a complement to allow the prediction of construction waste from building designs. System performance was assessed by a test plan and two case studies. Results show that the tool works well and predicts construction waste according to the types of waste, types of elements and levels of construction. The study provides a clear direction on how construction waste (CW) management strategies could be integrated into a BIM platform to streamline CW analysis. Notwithstanding, the author recognizes as a limitation of the study that it was conducted in the context of the United Kingdom, so the findings have a bias in AI to conceive the environmental potential of BIM at the end of the construction life cycle.

Cheng and Ma [7] designed a BIM application programming interface (API) for the estimation and planning of demolition and reuse waste that provides alerts to contractors ahead of time in project planning. This API can extract material and volume information through BIM models in the Autodesk Revit platform and integrate it for detailed waste estimation and planning. This system can not only serve as an automated, fast and accurate tool for estimating waste before demolition or reuse, but also serves as a tool to calculate the waste disposal rate for different waste facilities and pick-up truck requirements. This estimation and planning system have been validated in a 47-story residential building in Hong Kong. Some of the limitations of this tool are that it focuses more on waste management than on minimizing the root causes that generate waste.

Therefore, it can be concluded from the literature review that there is a lack of tools and decision-making methods for minimizing CDW during the design phase of the building.

5 Methodology

Through a case study, the different scenarios of the methodology based on the integration in the BIM methodology of the Quantification and Reduction Models of Construction and Demolition Wastes [11, 12] are established. A native BIM program is used and the enrichment of BIM objects through attributes (see Fig. 1).

The case study chosen is that of a flat roof covering 25 m^2 under two different scenarios; in Stage 1, the demolition of the roof and its subsequent reconstruction are established, while in Stage 2 the rehabilitation of the flat roof is proposed.

5.1 Stage 1: Data Collection for the Quantification and Waste Reduction Model

It is essential to start from reliable and validated data on the quantification and reduction of waste generated in the construction processes. Therefore, the first step is to collect data on the production of waste generated in the following activities: demolition, construction and rehabilitation of a flat roof in the validated Quantification and Reduction of CDW Models [11, 12], (see Table 1 and 2). These models develop a systematic structure of the construction process, a waste classification system and factor-based analytical expressions.

5.2 Stage 2: Development of CDW Attribute Database in BIM

Then, in the BIM environment chosen to model and provide CDW attributes to the case study - the Allplan program -, the BIM database is created covering the types of wastes to be evaluated (see Fig. 2).

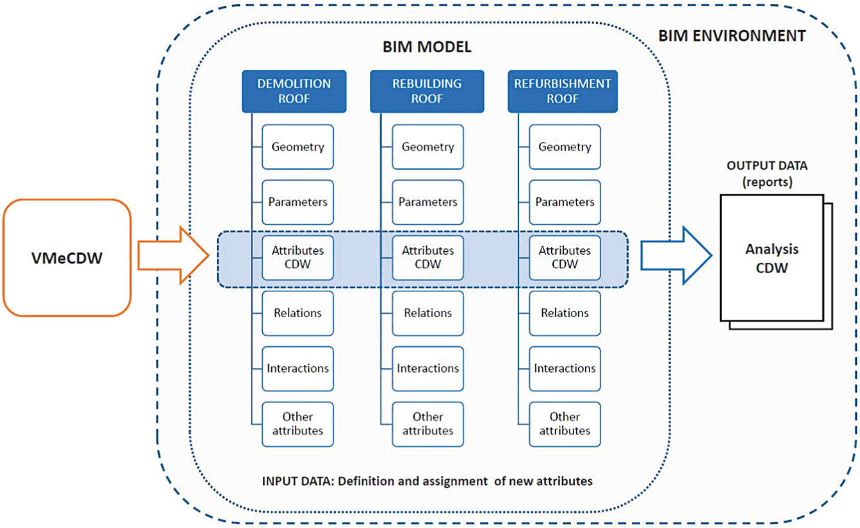

Fig. 1. Methodology scheme based on Quantification and Reduction Models of Construction Wastes [11, 12] integrated into Building Information Modeling.

5.3 Modelling Architectural Elements in BIM and Attribute Assignment

The roofs are modelled, for the different scenarios of the case study, with the specific tool "Roof", thus obtaining quantifiable BIM objects. Then, with the order "Assignment of attributes to any element", and using the previously created database, the types of wastes corresponding to each case are assigned and the corresponding values of each type of waste are entered by a manual and systematized procedure (Fig. 3). This Allplan tool allows to define any property or attribute, provide it with value and link it to any object so that data can be analysed and evaluated later through other tools.

5.4 Analysis and Discussion of Results

To analyse and evaluate the CDW of each of the proposed scenarios, a report that identifies the different constructive elements and the stages to which they are subjected is designed. This report allows the comparative study of results (Fig. 4 and Table 3). From this analysis it is concluded that Rehabilitating/refurbishing the roof (Stage 2) would reduce up to 99% of the CDW waste generated in the case that the roof was demolished and rebuilt (Stage 1).

Table 1. CDW expected in building/site work elements in Stage 1 (Source: data obtained from Llatas, 2011; and Llatas and Osmani, 2016)

INPUT DATA				OUTPUT DATA		
STEP	Quantity	Unit	BUILDING ELEMENT/ SITE WORK	EWL CODE	Type of waste	Volume (m3)
1	1	m2	Demolition of floor (Thick: 25 cm) and flat roof	17 09 04	Mixed CDW	0.520000
					TOTAL	**0.520000**
2	1	m2	Rebuilding of concrete floor (Thick: 25 cm, ceramic small vault)	15 01 02	Plastic	0.000554
				15 01 03	Wood packaging	0.004619
				15 01 06	Mixed packaging	0.000052
				17 01 01	Concrete	0.001901
				17 01 03	Ceramics	0.005960
				17 02 01	Wood	0.000170
				17 04 05	Iron	0.000022
				17 09 04	Mixed CDW	0.000080
					TOTAL	**0.013358**
	1	m2	Rebuilding of flat floor	15 01 01	Cardboard	0.000244
				15 01 02	Plastic	0.004627
				15 01 03	Wood packaging	0.038560
				15 01 04	Metallic	0.017330
				15 01 06	Mixed packaging	0.000608
				10 13 99	Lime	0.000032
				17 01 01	Concrete	0.003148
				17 01 02	Bricks	0.000595
				17 01 03	Ceramics	0.004967
				17 03 01	Bituminous	0.000096
				17 06 04	Insulation	0.000440
				17 09 04	Mixed CDW	0.000088
				17 05 04	Soil and stones	0.000793
					TOTAL	**0.071528**

Table 2. CDW expected in building/site work elements in Scenario 2 (Source: data obtained from Llatas, 2011; and Llatas and Osmani, 2016)

INPUT DATA				OUTPUT DATA		
STEP	Quantity	Unit	BUILDING ELEMENT/ SITE WORK	EWL CODE	Type of waste	Volume (m3)
1	1	m2	Refurbishment of a flat roof (waterproofing, thermal insulation thick:40 mm, non-adhered pavement)	15 01 02	Plastic	0.000497
				15 01 03	Wood packaging	0.001954
				15 01 06	Mixed packaging	0.000026
				17 01 01	Concrete	0.001009
				17 03 01	Bituminous	0.000020
				17 06 04	Insulation	0.000440
				17 09 04	Mixed CDW	0.000004
					TOTAL	**0.003950**

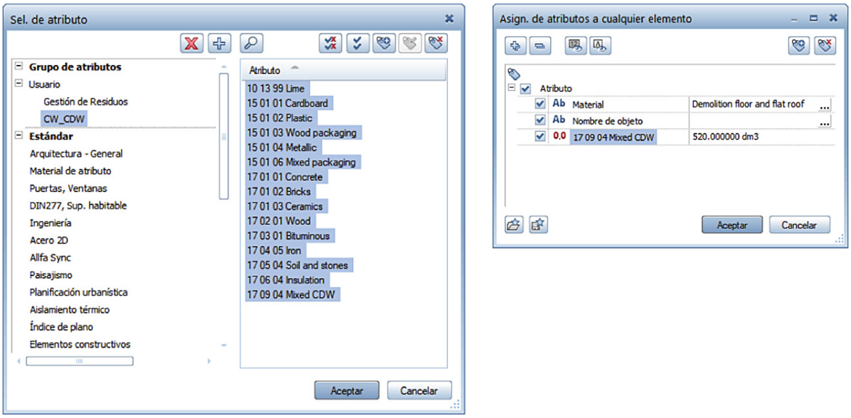

Fig. 2. CDW database: definition of CDW attributes.

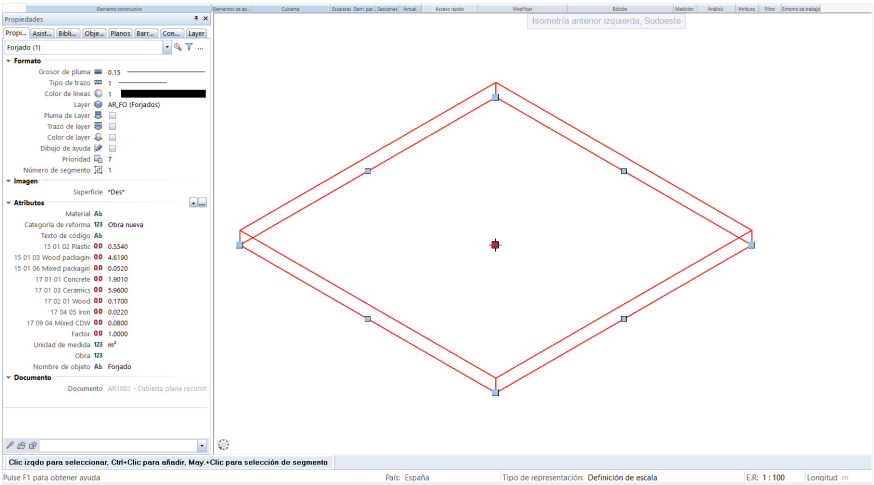

Fig. 3. CDW database created in Allplan: assignment of CDW attributes.

In addition, another advantage of Stage 2 is that it facilitates the selective separation of wastes and its subsequent removal, promoting their recovery. While in stage 1 most of the waste is made up of a fraction of mixed materials, making it difficult to recover (Table 3 and Fig. 5).

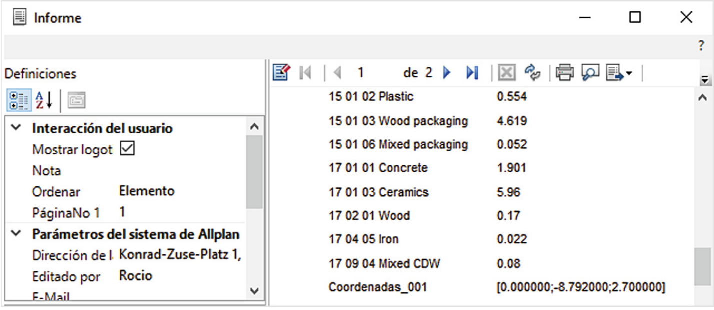

Fig. 4. Analysis of results. Custom reports in Allplan.

Table 3. CDW. Comparative study of results.

	Type of waste (European Waste List code)	Scenario 1 (Stages 1&2)	Scenario 2
CDW in building: Flat Roof 25 m²	10 13 99 Lime	0,000800	0
	15 01 01 Cardboard	0,006100	0
	15 01 02 Plastic	0,129525	0,012425
	15 01 03 Wood packaging	1,079475	0,048850
	15 01 04 Metallic	0,433250	0
	15 01 06 Mixed packaging	0,016500	0,000650
	17 01 01 Concrete	0,126225	0,025225
	17 01 02 Bricks	0,014875	0
	17 01 03 Ceramics	0,273175	0
	17 02 01 Wood	0,004250	0
	17 03 01 Bituminous	0,002400	0,000500
	17 04 05 Iron	0,000550	0
	17 05 04 Soil and stones	0,019825	0
	17 06 04 Insulation	0,011000	0,011000
	17 09 04 Mixed CDW	13,004200	0,000100
	CDW (m³)	**15,122150**	**0,098750**

One of the difficulties we have encountered, from an operational point of view, is that BIM programs developed for architectural modelling, consider a maximum of 4 decimal; this fact has conditioned the units we have worked with. In the reference quantification model the values are expressed in m^3. This problem has been overcome with the use of the dm^3 unit in the early stages of the methodology. Finally, in the reports the results are expressed in m^3.

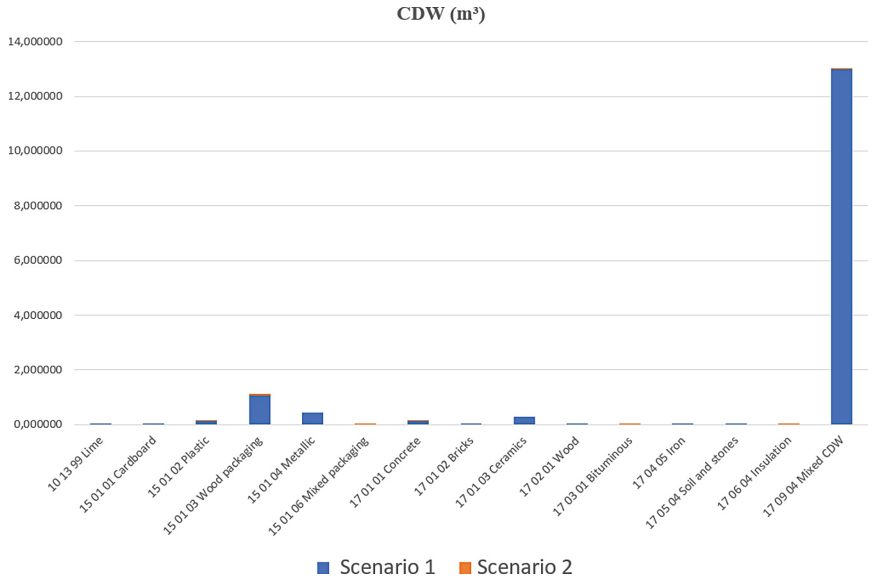

Fig. 5. Comparative analysis between Scenario 1 & Scenario 2.

6 Conclusions

The results reveal that the Waste Quantification and Reduction Model can be implemented in BIM environments. The proposed methodology and the information flows generated, through the indexed database, allow us to know the waste produced by the construction systems defined in the early scenarios of the design, helping in decision making. However, the following limitations must be considered:

– The attributes related to the quantification of wastes do not exist by default in the database of BIM modellers.
– The use of more than four decimals imposes the need for the use of units that are expressed with fewer decimals.

The digitalization of the design process using BIM objects with attributes allows a real response to the growing need to include environmental considerations in the projects, such as the production of wastes at the beginning of the design process. For example, the case study demonstrates with quantitative values how a Rehabilitation Stage reduces the wastes of a Demolition and Reconstruction Stage up to 99%.

The study forms a basis for future research on the optimization of the integration of CDW in BIM. The proposed methodology presents a high potential since all data can be centralized in a single database and customize the information that you want to evaluate.

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