BIM, GPP for CDW Management

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Information Modelling and Management (IMM) methods for Most Economically Advantageous Tender (MEAT) can promote the adoption of environmentally sustainable practices. Despite the wide regulatory framework and existing drivers, Construction and Demolition Waste (CDW) trend is still upward. The literature review regarding IMM and CDW management implementation during the design phases is mainly focused on studies and applications from the designer and contractor's points of view, although few studies focused on Green Public Procurement (GPP) and CDW management integration from the Public Client's point of view. This research aims at investigating the integration and efficiency of MEAT and IMM to promote the application of sustainable strategies focused on waste reduction and resource valorization. The study investigates the Public Client's role in promoting sustainable practices, introducing digital material inventory and BIM during the design phases, and including environmental award criteria in the call for tender documents. A Design Build (DB) procurement model is considered in the case study of a brownfield renovation and the construction of a new school in northern Italy. The methodology provided the Public Client with a replicable method to evaluate the environmental impact of the bids, allowing for proper selective demolition planning, CDW decrease, and organization while promoting their integration in companies' expertise and procedures.

building information modelling (BIM) | construction and demolition waste (CDW) | design build (DB) | environmental assessment | public client | waste minimization

1. Introduction

The construction sector is an industry with a high intensity of raw material consumption, corresponding to about a half of the Earth's raw materials [1]. In addition, over one half of annual material input returns as waste in the industrialized countries every year [2]. Construction and Demolition Waste (CDW) accounts for one third of the total amount of waste by volume in the EU, as reported by the EUROSTAT 2019 Waste Statistics [3]. Considering the high consumption of raw materials and the high level of discard production, the CDW management process must be reengineered to reduce waste and to take advantage of the high potential for reusing and recycling materials when construction waste is correctly identified and separated through selective demolition procedures [4]. Waste management in Architecture, Engineering, Construction, and Operations (AECO) industry requires adopting a 'cyclic' rather than a 'linear' approach [5]. The transition toward a circular economy approach in AECO sector is aligned with the global framework to avoid dangerous climate change effects set by the Paris Agreement [6].

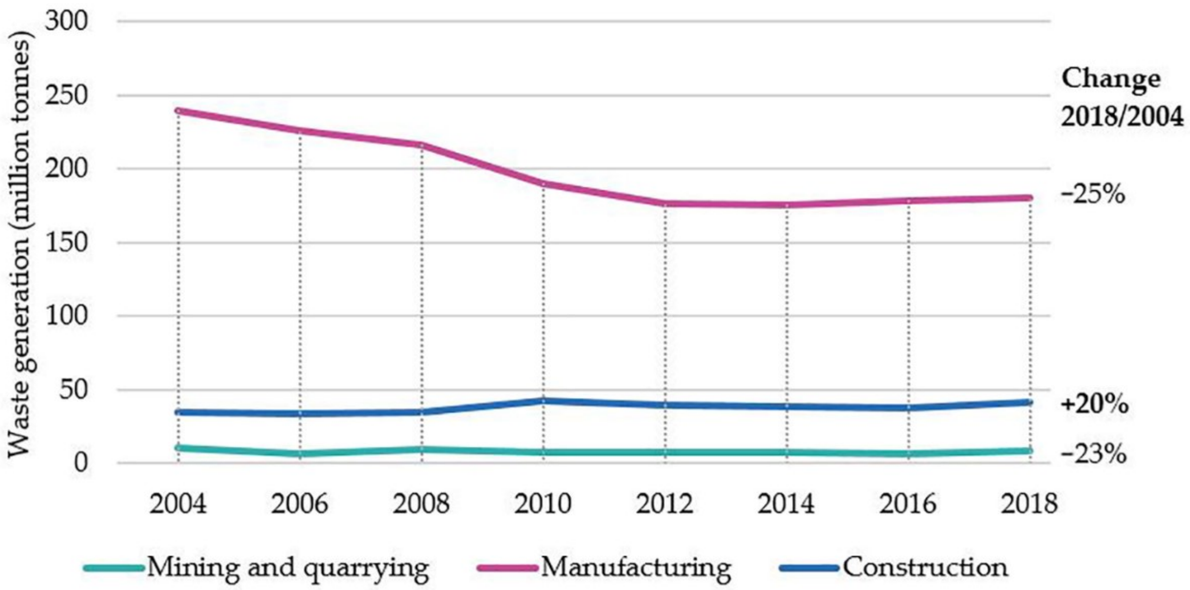

Figure 1. Comparison of current waste generate trends in the construction, mining and quarrying and manufacturing sectors, excluding major mineral wastes, EU-28, 2004-2018. Data source: EUROSTAT 2019 (env_wasgen).

Most of existing studies adopted Building Information Modelling (BIM) approaches to introduce environmentally sustainable practices, specifically to AECO industry, in the building design phase from the designer and contractor's points of view [7]. Few studies have analyzed the integration of BIM and Green Public Procurement (GPP) in construction procurement to evaluate the environmental impact of the bids [8]. However, a comprehensive application of Information Modelling and Management (IMM) methods and GPP from the Public Client's point of view, aiming to evaluate and reduce the environmental impact of a building related to resource and waste management during design and call for tenders phases, represents a gap in the literature. This can be critical considering the high purchasing power of public organizations and institutions [9] and the poor competences in the Italian context in drafting calls for tender documents including environmentally sustainable criteria [10].

The goal of the presented research is to fill this gap by defining a replicable model that adopts IMM and GPP for a sustainable use of resources and CDW minimization and management in AECO sector. The methodology covers the design phases and the call for tenders phase of a public construction process.

2. Background

2.1 Digital Techniques for Field Surveys

One of the critical steps when dealing with existing buildings is collecting real-world data about the to-be-demolished structures. There are two main different approaches for digital field surveys: photogrammetry is a well-established digital image-based survey technique that extracts data from 2D pictures, and places them in 3D spaces [11], providing 3D measurements and producing points clouds for several engineering fields [12]; enabling safe [13], low-cost [14] field surveys but lacking automatic BIM object modelling capabilities; on the other hand, laser scanning can enable the automatic conversion from points clouds to BIM models, but it is more expensive and is still a developing technique [15].

2.2 Waste Management and BIM Methods adoption

Fundamental objectives to achieve a sustainable development, which are set at international and European level, are the efficient use of natural resources, the 3Rs approach, i.e., reduce, reuse, and recycle, for waste minimization and management [16], and the concept of waste as a resource [17]. In addition, in 2018 the EU Commission released guidelines for the definition of waste audits: they have a central role to ensure the proper identification and separation of demolition materials, thus facilitating the application of selective demolition and reusing and recycling practices [4]. Concerning the Italian regulatory framework, Legislative Decree 50/2016 introduced the requirement for Public Clients to purchase products and services that are compliant with the national document called the Minimum Environmental Criteria (CAM—Criteri Ambientali Minimi), which requires the reuse, recovery, or recycling rate of about 70% by weight of non-hazardous waste in cases of renovation, maintenance, and demolition [18].

IMM methods play a double role of managerial and technological drivers [5], supporting the implementation of sustainable strategies and waste management practices during all stages of the construction and demolition processes [19], since better data and information flow means improved decision-making processes and enhanced capacity to manage and decrease CDW streams. Digital methods and techniques are demonstrated to guarantee the consistency of the information flow during the entire construction and demolition process [20][21][22][23]. Regarding the integration of BIM and CDW minimization and management, most of the existing studies focused on CDW reduction and management [24][25][26][27][28][29], highlighting the extensive implementation of BIM methodologies to support CDW management during the design phases through the parametric modeling, visualization, and simulation capabilities of BIM, and showing promising results, with possible waste reduction of 4–15% [30]. However, the application of BIM methodologies for CDW minimization and to manage the demolition or reconstruction of existing buildings that had not been designed following deconstructability principles is a less investigated topic [7].

2.3 Green Public Procurement and IMM Methods adoption

Green Public Procurement integrates requirements and criteria in order to achieve value for money in the whole lifecycle of a project while supporting resource protection [31] and reducing environmental impacts [32]. Since public organizations and institutions wield a purchasing power of 15 to 30% of the national gross domestic product [9], GPP is supported and promoted at the international, European and national level as a means of driving the market towards innovative and sustainable practices [33][34]. Concerning the Italian regulatory framework, the Legislative Decree 50/2016 was a turning point for national procurement regulations, making GPP mandatory in public tenders and introducing the Most Economically Advantageous Tender (MEAT) approach, which aims to achieve value for money on a basis of the lifecycle of a construction project [18]. However, only around 20% of the Italian Provinces have adopted GPP including sustainability criteria so far, while around 50% of municipalities have very poor knowledge of GPP, caused by a lack of staff training and competence regarding GPP and how to draft tender documents that include sustainability criteria [10].

Despite the importance of introducing GPP and green purchasing criteria, the majority of purchasers still tend to favor past practices [35]. Two main factors have been identified as facilitators for the adoption of green design approaches in the construction process: the proactive role of the Public Client in pushing green procurement adoption, and the application of IMM approaches [8][36]. However, little investigation has been conducted on the integration of IMM approaches and GPP, while it could be critical to define a method for the Public Client considering the high purchasing power of Public Administrations [9] and the poor competence in the Italian context in GPP adoption [10].

3. Methodology

3.1 Preliminary Design Phase: Waste Management and Selective Demolition Planning within a IMM Approach

During the preliminary design phase, the methodology proposes the creation of a digital material inventory, i.e. a digital database, for waste audits to plan and manage CDW streams and the selective demolition activities of existing facilities. In order to collect the information needed to define the digital material inventory, close-range photogrammetry was considered. This technology enables 3D measurements and the remote analysis of the images to identify materials and elements. Data collected through field surveys are the basis for the definition of the digital material inventory, i.e. the output of the waste audit, which includes:

- Basic information, including material estimation and description;
- Detailed information, including material types and European Waste Codes (EWC);
- Three levels of reporting: (a) hazardous, (b) non-hazardous and recyclable, and (c) non-hazardous and reusable on site;
- The identification of recyclable materials and authorized recycling plants in the proximity of the project site to minimize the carbon emissions for waste transportation.

The digital material inventory is then used to define proper selective demolition activities and plans, and their related costs, which can be included in the total budget for the subsequent design and call for tenders phases.

The evaluation of the methodology applied to the case study was performed by comparing the selective demolition costs calculated through the digital material inventory with the costs of the parametric non-selective demolition of the same buildings.

3.2 Design Phase: Waste Minimization and Sustainable Resource Use within a BIM Approach

During the design phase, the BIM approach was proposed for waste minimization and management and to foster the sustainable use of resources. The BIM model for the design phase was generated by linking all construction materials to similar information as the ones collected for the demolition materials in the digital material inventory. Material quantities, types, related quantities of construction waste, and EWC codes are linked to each construction material. The BIM model is used to: (i) store all graphic and non-graphic information, drawings, and documents of all the disciplines of the design phase; (ii) perform design reviews, clash detection, quantity take-off, phase planning, and site utilization, thus supporting and facilitating the proper management and minimization of construction waste; (iii) identify materials producing the highest quantities of construction waste. The quantities of construction materials from the BIM-based quantity take-off and from the digital material inventory can be compared in order to identify possible reuse strategies on site. It is possible to select the construction materials that can be replaced by demolition waste materials as secondary raw materials, allowing for a reduced use of raw materials.

The effectiveness of the methodology applied to the case study is validated by analyzing the advantages enabled by the use of the BIM model, in particular, regarding the sustainable use of resources through the on-site reuse of demolition waste materials.

3.3 Call for Tenders Phase: Environmental Award Criteria within IMM and BIM Approaches

During the call for tenders phase, GPP is adopted to a Most Economically Advantageous Tender (MEAT) procedure by introducing award criteria to evaluate the bids in terms of their environmental impact and integration of sustainable practices. All of the data and information from the design stages performed via IMM approaches support the definition of the tender documents and award criteria. The BIM model allows the management of waste and the related recycled and reused quantities for construction site planning. The adopted tender process type is the Design Build (DB) model, in which a single operator is selected to conduct the final design and construction, enabling a more efficient information transfer with the Public Client and a more collaborative process [37], representing a valuable framework for the application of IMM approaches [38].

The evaluation of the bids is based on objective alpha-numerical criteria, which are aligned with LEED certification criteria [39]. The assessment of the quality of the bids is based on the rankings on the defined criteria, thus promoting the automation of the evaluation process [40]. Throughout the entire process, waste minimization paired with the definition of safe and efficient selective demolition procedures is promoted with the highest rankings. Respecting the environmental criteria when presenting the bids would have provided additional points to the ranking of the companies, covering more than 25% of total points, thus increasing their possibility of winning the call for tenders, and, at the same time, promoting the application of sustainable practices among the participants. The main sub-criterion to evaluate the CDW management strategies of the bids is sub-criterion D.2.2. The scoring of sub-criterion D.2.2 depends on the quantities of reused, recycled and landfilled non-hazardous waste materials, and of landfilled hazardous waste materials as proposed by the bids.

Table. Scheme of criteria and sub-criteria for the bid evaluation process.

Category	Criterion	Evaluation Sub-Criterion	Sub-Criterion Value
A—Passive element requirements	A.1—Material production site distance	A.1.1—Distance of the production site of materials	3
	A.3—Environmental requirements	A.3.1—Contractor certification according to UNI EN ISO 14001	1
		A.3.2—Producer certification according to UNI EN ISO 14001	3
		A.3.3—Recyclability of materials at end-of-life	2
D—Construction and demolition phase	D.1—Safety	D.1.1—Contractor certification according to OHSAS 18,001	1
	D.2—Constructive solutions and site management	D.2.2—Demolition plan and CDW management	10
E—Maintenance	E.1—Building maintenance	E.1.1.—Maintainability and durability of construction materials	7

The evaluation of the methodology applied to the case study was performed by analyzing the results of the call for tenders, and the responses of the participants, particularly the winning one, to the optional award criteria regarding environmentally sustainable aspects.

4. Case Study

The case study involved the decontamination and renovation of a brownfield in the Municipality of Inveruno in the Province of Milan, Italy, including an extensive demolition phase of the existing buildings in the industrial site and the subsequent construction of a new school complex for a total amount of EUR 15 M. Brownfields are defined as polluted and abandoned sites where urban transformation interventions combine remediation and reuse [41]. Soil protection, reducing land degradation and consumption are fostered both at International, European and National level [42][43][44], consequently the recovery of existing abandoned buildings and brownfields are prioritized by CAM at project level [45]. Despite that, land consumption in Italy maintained a rate of 2 square meters of land irreversibly lost every second in 2019, and the highest percentage of consumed land belongs to the Lombardy Region [41], justifying the choice of the case study, since brownfield renovation is critical for the Province of Milan. The main goals of the case study application are: to integrate environmental sustainability by recycling demolition materials, and by reducing the use of raw materials and green fields during the construction phase; to integrate social sustainability through the transformation and rehabilitation of a brownfield into a new school complex area that will be open to the municipality.

5. Results

During the preliminary design phase, the output of field surveys supported by close-range photogrammetry were image planes of the to-be-demolished facilities, used for measuring, material recognition, and for conducting analysis in remote mode. All the data and information regarding construction techniques, materials, and related data were gathered and digitized in the digital material inventory, enabling the maximization of the quantity and quality of the recyclable materials by obtaining the fractions of mono-materials that were suitable for reuse or recycling as secondary raw materials. In addition, it supported a detailed demolition planning, allowing to quantify the costs associated with the selective demolition activities by linking each activity to the related expected cost of execution. Consequently, it was possible to obtain a reliable prediction of the selective demolition costs, which represented 127% of the estimated non-selective demolition costs.

During the design phase, the BIM model allowed the estimation of the quantities of the needed construction materials by means of the quantity take-off. Construction materials quantities were then compared with waste quantities stored in the digital material inventory, and finally, some applicable on-site reuse strategies were selected.

During the tender documents definition, the digital material inventory supported the verification of the feasibility of the selective demolition strategies and the identification of selective demolition costs. Regarding the scoring of the bids participating to the call for tender, the average score of the bids was equal to 23.4, with the winning company’s score equal to 25.7/100, i.e. the 95% of the total available score (27/100) in the environmental criteria. Regarding the winning company, based on the waste audit and digital material inventory and on the suggestions from the tender documents regarding selective demolition, as described above, the company proposed an entire plan and site layout for the demolition phase. In addition, they could identify all waste quantities and could select the specific authorized plants needed for recycling and landfilling, starting from the authorized plants suggested in the tender documentation.

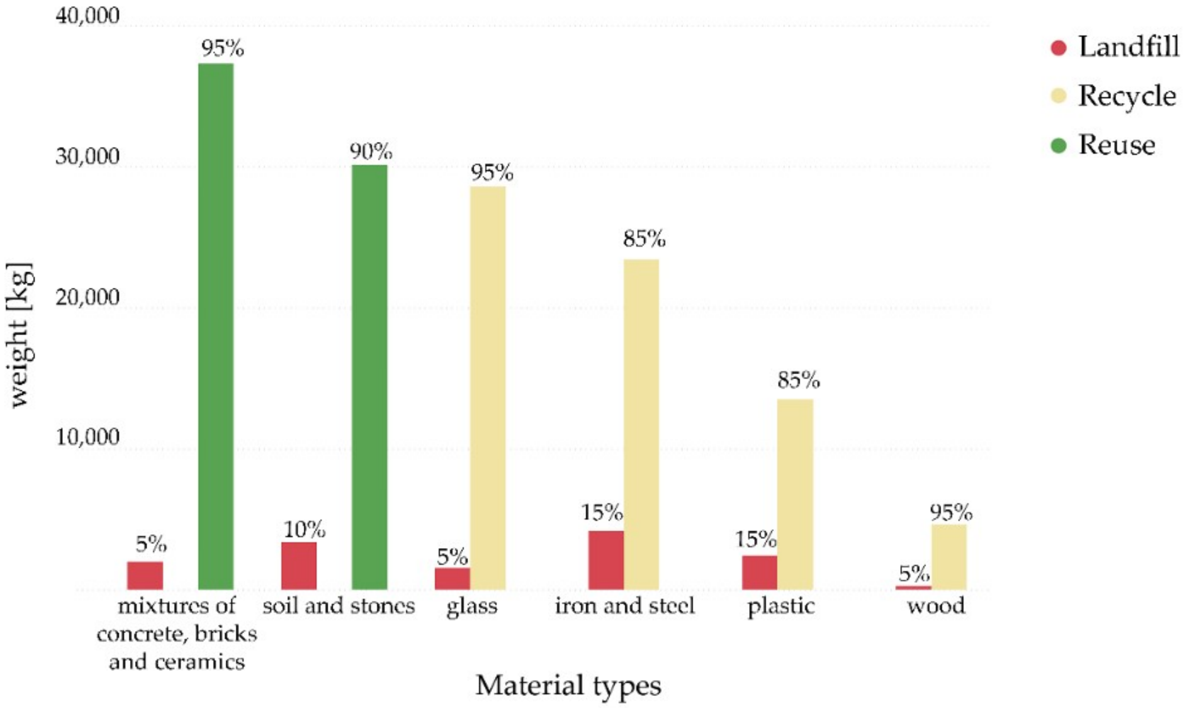

Figure 2. Reused, recycled, and landfilled waste proposed by winning company and divided by material type.

Starting from the BIM-based suggestions for the on-site reuse strategies included in the tender documents, the winning company proposed to reuse most of the concrete, bricks, and ceramic demolition waste materials as secondary raw materials for on-site reusing, comparing the quantities of materials extracted from the BIM model of the designed buildings to the quantities of waste materials recorded in the digital material inventory. Regarding the new school complex construction phase, the winning company used the BIM model in order to define and manage all quantities of waste and recyclable materials from the project, reaching total percentages of reused, recycled, and landfilled waste materials of around 45%, 46%, and 9% respectively.

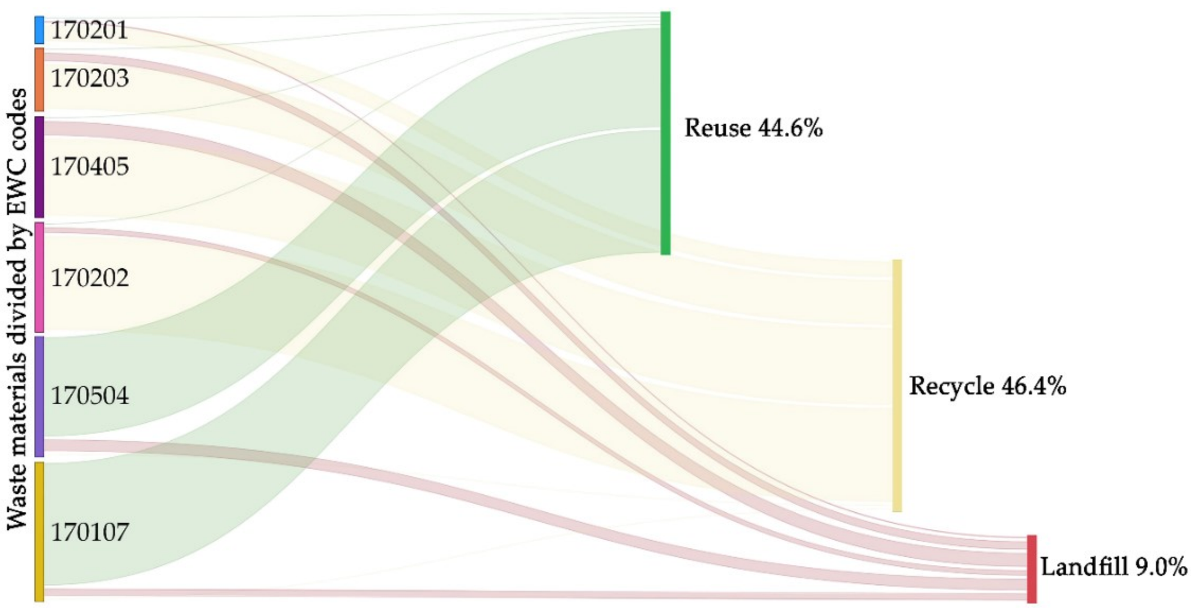

Figure 3. Total percentages of reused, recycled, and landfilled waste.

6. Discussion

Regarding the preliminary design phase, the application of the proposed methodology allowed the definition of a precise and complete waste audit and digital material inventory, which supported the planning and optimization of reuse and recycling practices and selective demolition plans. Close-range photogrammetry for field surveys was the easiest and safest survey technique. The use of a digital database as a material inventory promoted always available and up-to-date data that were organized and structured in a machine-readable form, thus ensuring data readiness and processability and agile data management.

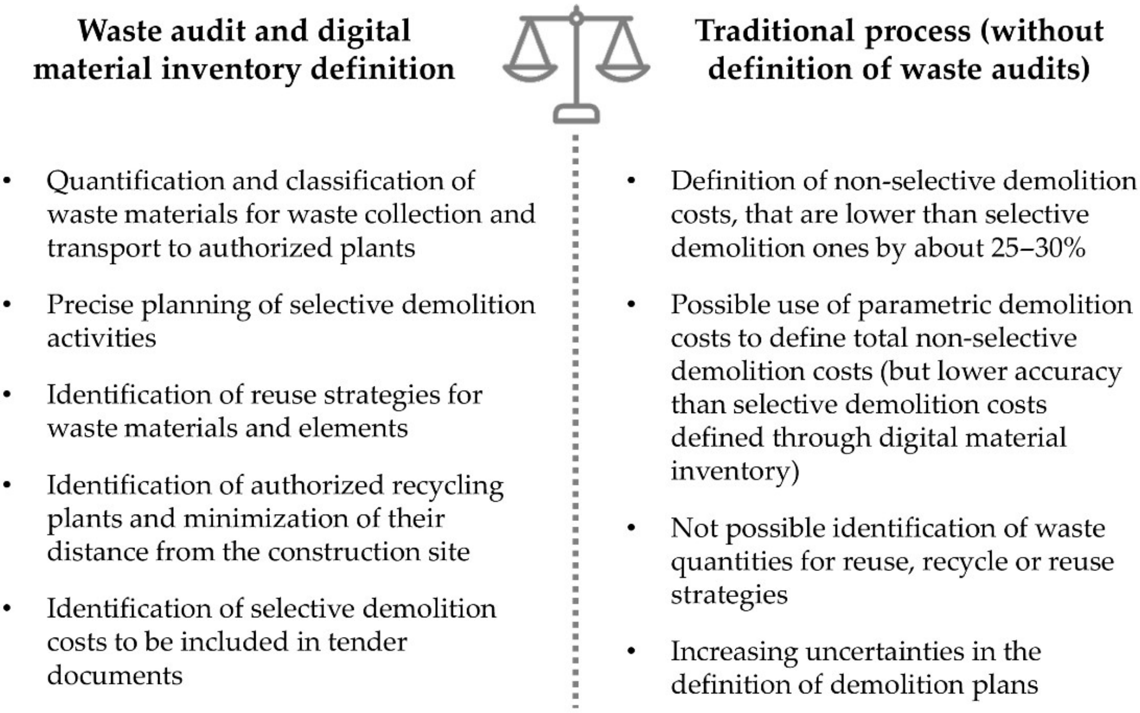

Figure 4. Comparison between the proposed methodology with waste audit and digital material inventory definition, and a traditional process.

The selective demolition costs represented 127% of the estimated non-selective demolition ones, clearly highlighting the importance of applying proper waste audits and selective demolition planning, in order to correctly identify selective demolition costs to ensure the proper development of the tender and construction phases.

Considering the design phase, the creation and use of a BIM model of the designed buildings allowed the reduction of construction waste and the promotion of waste minimization during design reviews and clash detections between design disciplines. In addition, the possibility of defining on-site reuse strategies, in particular by using concrete wastes as secondary raw materials, resulted in savings for the purchase of a considerable amount of new raw materials.

Concerning the call for tenders, the proposed methodology enabled to:

- Support the Public Client in including sustainability criteria for the evaluation and scoring of the bids, and in analyzing the environmental impact of the bids, while acquiring the necessary competences for proper GPP implementation;
- Promote the integration of CDW management and minimization, sustainable resource use, and selective demolition procedures among the participants.

The high scores of most bids in the environmental criteria demonstrated that:

- All of the bids and the participants recognized the importance of the optional award criteria and decided to gain competences and know-how on the topic;
- The well-defined award criteria supported by the digital material inventory and by the BIM-based design data led the participants to more easily apply and integrate sustainable practices in their procedures.

Regarding the actual winning bid, the environmental factors represented a fundamental part of the offer since numerous points had been assigned to the company on the environmentally sustainable award criteria. The process enabled the maximization of the quantities of recycled and reused waste materials, the proper selection of reuse strategies, and the selection of authorized recycling and landfilling plants by the company.

The Design Build (DB) procurement model allowed the contractor to manage the process flow and information right from the final design stage, enabling the optimization of CDW management and selective demolition plans, and the decrease of CDW production.

7. Conclusions

The construction sector is one of the most polluting industrial sectors in the European Union. Consequently, the adoption of CDW management and minimization strategies and GPP is paramount and is promoted at international, European and National level. However, the literature review showed that a comprehensive application of IMM methods and GPP from the Public Client’s point of view aiming to evaluate and reduce the building environmental impact during the design and call for tenders phases, represents a gap in the literature.

The research proposes a replicable methodology during the preliminary design, design and call for tenders phases to introduce selective demolition planning, CDW management and GPP supported by IMM and BIM methods. The methodology was tested on the case study of a brownfield renovation that included extensive demolitions and the construction of a new school complex in the Province of Milan.

The IMM approach and the BIM model for the design and tender activities, permitted to maintain consistency during the entire process. The selective demolition costs, calculated through the digital material inventory and the demolition plans, represented 127% of the estimated non-selective demolition ones. The correct identification of the demolition costs represents a fundamental aspect that ensures that the whole procedure can be conducted without resulting in disputes, delays, and budget increases.

The demand of the call for tenders was highly focused and accurate, hence ensuring that the offers met the requirements and complied with environmental strategies. In general, the methodology ensured effective CDW management and the precise identification of reuse and recycling strategies. The winning company proposed over 90% of recycled and reused waste materials, minimizing the total quantity of landfilled waste accordingly. The demand guided and pushed the application of sustainable practices by the construction companies. In addition, the method allowed the Public Client to assess the environmental impact of the bids. Furthermore, the Design Build (DB) procurement model enabled an increased collaboration between the Client and the constructor and a less fragmented and more efficient information flow.

The research highlighted the critical role of the Public Client as the actor that can trigger a change in the construction sector by implementing GPP and applying best practices during all the phases, supporting a sustainable construction process. In addition, the study demonstrated the positive effects and results of the application of the methodology for brownfield recovery. The proposed methodology was previously tested with positive results in another case study with a simpler design and without almost any demolition [46]. The positive results of the presented case study, which had a more complex design and included extensive demolitions, resulting in more complex CDW management, selective demolition planning and sustainable resource use, aim to demonstrate the replicability of the methodology.

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