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Information Modelling Management and Green Public Procurement for Waste Management and Environmental Renovation of Brownfields

Laura Pellegrini [1,*], Mirko Locatelli [1], Silvia Meschini [1], Giulia Pattini [1], Elena Seghezzi [1], Lavinia Chiara Tagliabue [2] and Giuseppe Martino Di Giuda [3]

[1] Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, 20133 Milano, Italy; mirko.locatelli@polimi.it (M.L.); silvia.meschini@polimi.it (S.M.); giulia.pattini@polimi.it (G.P.); elena.seghezzi@polimi.it (E.S.)

[2] Department of Computer Science, University of Turin, 10149 Turin, Italy; laviniachiara.tagliabue@unito.it

[3] Department of Management, University of Turin, 10134 Turin, Italy; giuseppemartino.digiuda@unito.it

* Correspondence: laura1.pellegrini@polimi.it; Tel.: +39-02-23-995-749

Abstract: 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) trends are still growing. The literature review analyzed IMM and CDW management implementation during design phases 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 was 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 and included a 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. The replicability of the methodology is demonstrated by positive results of present and previous case studies.

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

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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 [1,2]. In addition, over one half of annual material input returns as waste in the industrialized countries every year [3]. 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 [4]. Considering the high consumption of raw materials and the high level of discard production, the CDW management process must be reengineered to reduce scrap 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 [5]. Waste management in the Architecture, Engineering, Construction, and Operations (AECO) industry requires adopting a 'cyclic' rather than a 'linear' approach [6]. The transition toward a circular economy approach in the AECO sector is aligned with the global framework to avoid dangerous climate change effects set by the Paris Agreement [7].

Most of existing studies adopted Building Information Modelling (BIM) approaches to introduce environmentally sustainable practices, specifically to the AECO industry, in the building design phase from the designer and contractor's points of view [8]. Few studies have analyzed the integration of BIM and Green Public Procurement (GPP) in construction procurement to evaluate the environmental impact of the bids [9]. 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 [10] and the poor competences in the Italian context in drafting calls for tender documents including environmentally sustainable criteria [11].

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.

During the preliminary design phase, digital techniques for field surveys and data management are applied by a defining waste audit and a related digital inventory of materials. This supports proper selective demolition planning and demolition waste management. During the design phase, the creation of BIM models for the designed facilities enables construction waste management and the definition of on-site reusing and off-site recycling strategies for demolition waste materials.

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.

This research will provide the Public Client a method to integrate and evaluate CDW minimization and selective demolition criteria from the design phase to the call for tenders phase of a public construction process, thus encouraging construction companies to propose and apply sustainable practices. This will also help companies to embrace circular economy principles and processes by renewing and enhancing their own business models. The efficacy of the proposed methodology is evaluated through the analysis of the responses from construction companies during the call for tenders, and in particular, the responses from the winning one.

In previous studies, the described methodology was tested on a green field of a new construction project, namely a public school facility in Melzo, Italy [12]. In the present research, the model is applied to a brownfield renovation, including an extensive demolition phase and the final design and construction of a new public school complex in Inveruno, Italy. The selection of the case study aims to demonstrate the positive outcomes of the model application to support the proper renovation of brownfields, thus promoting renovation processes to recover the quality of community land. Furthermore, the application of the model on a case study that is more complex than the previous one mentioned above can demonstrate the replicability of the proposed methodology.

2. Regulatory Framework and Guidelines

The main regulatory frameworks regarding GPP and waste management are hereafter investigated as the foundation of the proposed methodology. This section aims to analyze the topics describing global goals and directions while presenting the Italian position on the issues. In addition, soil protection and brownfield regulations are briefly analyzed since the case study is a brownfield revamp for new construction. The analyses are performed at the (Figure 1):

1. International/global level: identifying global strategic goals and actions in order to define the direction and guidance toward sustainable practices;
2. European level: describing the general framework and the main guidelines;
3. National level: analyzing Italian regulations and, if existing, regional specifications and requirements.

Figure 1. Regulatory levels.

Finally, at the end of each of the following sub-sections, the key aspects that the proposed methodology aims to address are presented.

2.1. Green Public Procurement

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 [13] and reducing environmental impacts [14]. Since public organizations and institutions wield a purchasing power of 15 to 30% of the national gross domestic product [10], GPP is supported and promoted at the international level as a means of driving the market towards innovative and sustainable practices [15].

At the European level, the Directive 2014/24/EU introduced the possibility of including tender clauses related to environment protection, the minimization of negative impacts, and waste management by promoting and monitoring the implementation of GPP [16,17]. In addition to that, the Directive 2014/24/EU emphasizes the critical role of public procurement in reaching a smart, sustainable, and inclusive growth [17].

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. The main causes, especially when considering smaller municipalities, are the lack of staff training and competences regarding GPP, and issues in drafting tender documents that include sustainability criteria [11].

Concerning GPP implementation, the presented research aims to:

- provide Public Clients a method for GPP and environmentally sustainable criteria integration that can be further applied and adapted by municipalities;
- test the effectiveness of the proposed methodology through the presented case study.

2.2. Waste Management

Fundamental objectives to achieve a sustainable development, which are set at international level, are the efficient use of natural resources and the 3Rs approach, i.e., reduce, reuse, and recycle, for waste minimization and management [19,20]. A critical step for waste management regards the definition of the concept of Extended Producer Responsibility (EPR) [21]. The focus is shifted from the phase in which waste already exists to the entire product lifecycle to the responsibility of manufacturers in terms of waste generation and to the need for the sustainable use of resources and waste minimization [22].

In the European framework, attention to both the design phase supporting the EPR approach and the conscious choices of materials, i.e., recyclable, recycled, durable, non-hazardous, and local materials and products, and the concept of waste as a resource, is stressed [23,24]. The definition of selective demolition is also proposed, highlighting the need to integrate it in standard design procedures [23]. Furthermore, 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 [5]. Waste audits exploit their major potential if performed during the design phase since they enable a detailed estimation of the costs of the selective demolition, separation, recycling, recovery, and landfilling of materials. Consequently, a correct estimation of costs can be encompassed in the total budget for the call for tenders, supporting a successful accomplishment of the process [25].

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) [18], which requires the reuse, recovery, or recycling rate of about 70% by weight of non-hazardous waste in cases such as renovation, maintenance, and demolition. Methodological hints and principles for demolition and material removal and requirements to conduct a pre-demolition audit were also defined in 2017 by a specific Ministerial Decree [26].

Concerning CDW management implementation, the presented research aims to:

- define a waste audit method for the preliminary design phase;
- integrate CDW management in the entire construction process with increased interest on the design phase, on sustainable resource use, and on waste minimization.

2.3. Soil Protection and Brownfield Rehabilitation

Brownfields are defined as polluted and abandoned sites where urban transformation interventions combine remediation and reuse [27,28]. At international level, soil protection, reducing land degradation and consumption, and strategies for regreening city spaces are among the 2030 Agenda Goals for Sustainable Development [14,29].

The EU targets to achieve zero net land take by 2050 [30]. In fact, soil is fundamental for life on Earth and is a non-renewable resource [31]. Spatial planning strategies for urban expansion cause most of soil sealing. The EU Commission emphasized the need to implement good practices to reduce the negative effects of soil consumption and, in particular, to reduce soil sealing [32,33], identified as major threats to the environment [31].

Given the condition of fragility and criticality of the territory, soil protection, the sustainable management of natural resources, and arrested land consumption and desertification are crucial for the Italian context [34]. The Italian brownfield regulation falls under waste regulations, in which brownfield redevelopment is divided into site environmental remediation and subsequent urban redevelopment [35]. At the regional level, Lombardy Regional Law 16/2017 defined a digital catalogue of brownfields and introduced the concept of 'ecological soil balance' and economic incentives for brownfield renovations and limitations on green fields use for new construction projects [36,37]. In addition, at project level, CAM introduced the need and indications to reduce land use and sealing, prioritizing the recovery of existing abandoned buildings and brownfields [26].

Concerning brownfield renovations, the presented research aims to:

- test the proposed methodology on a brownfield renovation;
- evaluate the advantages of proper waste audit definition and CDW management for the extensive demolition phase planning of an abandoned industrial area.

3. Background

As presented in the previous section, CDW management and minimization as well as GPP adoption in the construction sector are promoted and sustained both at the international, European, and national level. Nevertheless, the level of waste generated by the AECO sector is still growing. EUROSTAT 2019 Waste Statistics compared waste generation trends in European industrialized sectors in the period of 2004–2018 [4]. While other industrialized sectors had reduced their waste generation by over 20%, the construction sector had increased its waste production by about 20% since 2004 (Figure 2) [4].

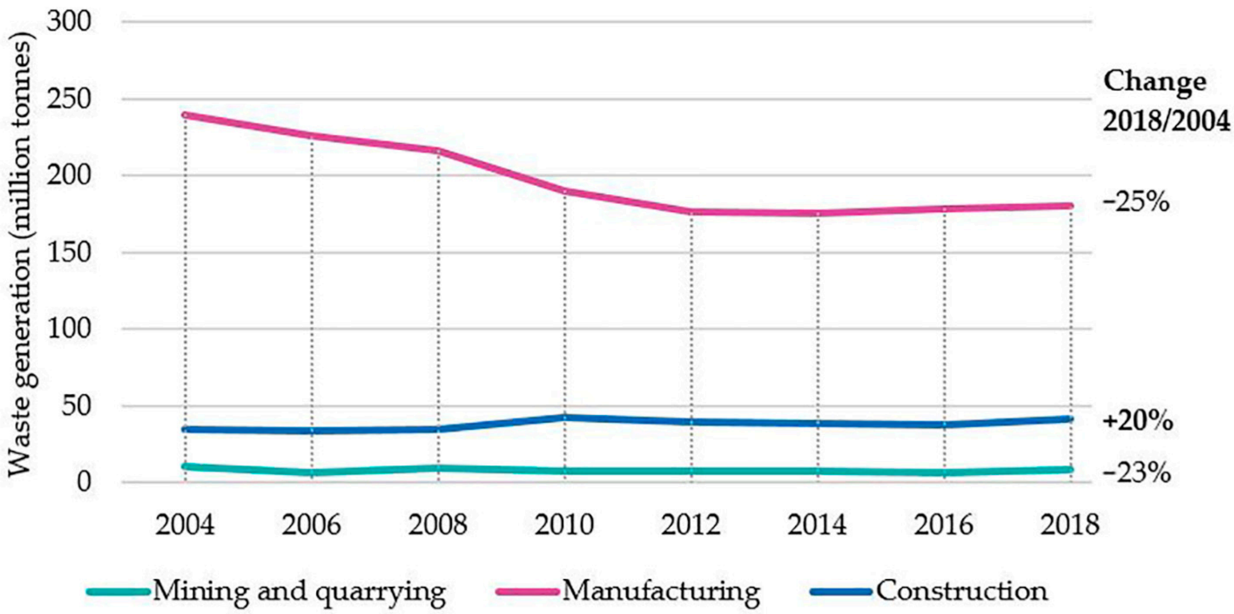

Figure 2. Comparison of current waste generate trends in the construction, mining and quarrying and manufacturing sectors, excluding major mineral wastes, EU-28, 2004–2018. Data source: EUROSTAT 2019 (env_wasgen).

The following sub-sections investigate the barriers that currently limit the introduction of sustainable practices in the AECO sector and drivers that can promote and guide the adoption of CDW management and minimization strategies.

3.1. Barriers to Waste Management Adoption in Construction Sector

The main barriers to the reduction of waste generation are represented by socio-economic factors [38,39], and these are described in Table 1.

Table 1. Barriers for the implementation of sustainable practices in AECO industry.

Barriers	Effects on the Construction Process
Incomplete design documents and information asymmetry between designers and contractors	Causes most errors and rework during the construction phase [40], consequently triggering waste generation [41,42] and increasing the risk of project time and cost overruns.
Non-collaborative culture	One of the main causes of waste generation [43], producing an unclear definition of responsibilities and inconsistent tender documents [44]. The contractor is usually not involved in design choices, increasing the risk of waste generation during the construction phase [45].
Blame culture	Actors of the different stages blame other specialists for generating waste [46,47] with a consequent shift in the responsibility for waste generation.
Waste inevitability culture	All actors see waste generation as unavoidable [6]. In standard practice, owners and contractors have usually already paid for waste treatments, transportation, and landfilling; therefore, selective demolition and the adoption of the 3Rs approach are seen as burdens.
Difficulty of innovating	Difficult replication of good practices and innovative applications in future projects due to the temporary relationships between the construction process parties [48].
Lack of training in applying innovative methods and technologies	Difficult application of innovative methods and technologies by the contractor [6].

The proposed methodology aims to overcome the identified barriers by:

- promoting and demonstrating the concept of waste as a resource and as a possible source of income;
- involving the contractor in the design phase to enhance the collaboration and to enable the proper application of CDW management and minimization strategies by adopting the Design Build (DB) tender model;
- providing a replicable methodology to support the adoption of sustainable strategies and innovative methods by construction companies.

3.2. Drivers to Waste Management Adoption in Construction Sector

The main drivers for CDW management and minimization strategies and GPP implementation in the AECO sector are:

- Legislative drivers: as presented in the Regulatory framework section, the implementation of environmentally sustainable practices is promoted at all levels. Consequently, Public Clients can encourage the introduction of sustainable practices by implementing GPP tender processes and by using their purchasing power to opt for environmentally friendly goods, services, and works. In addition, positive public applications can highlight the advantages and possible income deriving from selective demolition, waste separation, and the recycling as secondary raw materials, such as, as an example, the high-quality recycling of aluminum.
- Business drivers: companies are facing the need to adopt sustainable strategies in order to maintain and enhance their competitiveness. In addition, companies are starting to focus not only on economic value but also on the company's social responsibilities and stakeholder engagement [6].
- Managerial and technological drivers: Information Modelling and Management (IMM) approaches can allow companies to overcome the barriers of sustainable practice integration by reducing design errors and information asymmetry, improving collaboration, and supporting waste quantity measurement and control [39].

4. Literature Review

This section aims to investigate previous applications of IMM approaches to support the integration of environmentally sustainable practices in the AECO sector. The literature review briefly analyzes:

- digital survey techniques for the preliminary analyses of existing areas;
- the integration of BIM and CDW management during the design phase;
- GPP implementation supported by IMM approaches.

4.1. 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 different approaches for digital field surveys that are investigated: photogrammetry and laser scanning.

Photogrammetry is a well-established digital image-based survey technique that extracts data from 2D pictures, and places them in 3D spaces [49], providing 3D measurements and producing points clouds for several engineering fields [50]. Close-range photogrammetry considers measurement distances within 300 m between cameras and buildings [51]. Photogrammetry allows the safe and easy analysis of unsafe buildings [52] with a reduced number of on-site field surveys, and enables further analysis of the buildings in remote mode. In addition, it is less expensive than laser scanning techniques [53], and non-experts can conduct surveys using common, portable, and lightweight digital cameras [54]. However, photogrammetry cannot provide automatic modelling of BIM objects; the points cloud can be used as a basis for the creation of the BIM model.

Laser scanning can be considered as one of the most innovative approaches in the field, and aims to convert real objects into information-rich BIM objects. Modern laser scanning techniques are less expensive than traditional ones, such as terrestrial or aerial laser scanning [55]. However, the conversion process from the points cloud to a 3D plain model and then to an information-rich BIM model is still a time-consuming and expensive task [56]. Recent studies have tested Artificial Intelligence (AI) techniques to achieve an automatic or semi-automatic and therefore faster and less expensive conversion [57,58].

In summary, photogrammetry enables safe, low-cost field surveys but lacks automatic BIM object modelling capabilities. On the other hand, laser scanning enables the conversion from points clouds to BIM models, but it is more expensive and is still a developing technique.

4.2. BIM Methods for Waste Management

Better data and information flow means improved decision-making processes and, in addition, enhanced capacity to manage and decrease CDW streams. IMM methods play the double role of managerial and technological drivers [6], supporting the implementation of sustainable strategies and waste management practices during all stages of the construction and demolition processes [39,42]. Digital methods and techniques are demonstrated to guarantee the consistency of the information flow during the entire construction and demolition process through several applications [59–62]. Regarding the integration of BIM and CDW minimization and management, most of the existing studies focused on CDW reduction and management during the design phase. Cheng and Ma [63] proposed a BIM-based system for estimating and planning demolition and reconstruction activity by reducing the waste stream. They proposed an automated and accurate waste estimation methodology using the quantity take-off enabled by a BIM-model with a fast and more cost-effective approach. The authors addressed the lack of data and information that afflicts the estimation task during the demolition planning and reconstruction activities [64] in order to support the decision-making process. The correct quantification of waste, which must provide waste typology and dimensions, is in fact critical for effective and proper waste management [65]. Cheng et. al. [66] investigated how BIM implemented during the design phase could support CDW reduction during the construction phase by eliminating the root causes of waste generation through clash detection, quantity take-off, phase planning, site utilization, and digital prefabrication. The study aimed to maximize the homogeneous fractions of mono-materials by using BIM, and they proposed a BIM-based waste management planning and execution system to monitor the minimized and disposed waste [66]. Akinade et al. [67] proposed a BIM-based Deconstructability Assessment Score system (BIM-DAS) to compare several design options by identifying the best technological solution for deconstructability purposes and the most influential design factors influencing deconstructability. Deconstruction is defined as the possibility of disassembling a whole or a single element of a building, enhancing the technical component of reuse and recycling [68], leading the sector to reach a zero-waste economy [69–72]. Liu et al. [73] investigated a BIM-aided construction waste minimization framework, aiming to support designers in addressing waste causes during the decision-making processes of the design stages. Guerra et al. [74] investigated an automated waste estimation system, aiming to streamline the waste estimation process and support more efficient waste management during the design phases. The authors implemented their research for the visual planning of construction waste, discretizing waste generation in quantities for on-site reuse and off-site recycling, and identifying specific activities in the construction schedule where reuse is possible [75].

The literature review highlighted the extensive implementation of BIM methodologies to support CDW management during the design phases through the parametric modeling, visualization, and simulation capabilities of BIM. Existing studies showed promising results, with possible waste reduction of 4–15% by using BIM during the design phases [76]. 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 [8].

4.3. IMM Approaches for Green Public Procurement Implementation

Green Public Procurement aims to purchase goods at a good value for money during the whole product lifecycle, while supporting environmental protection and reducing negative environmental impacts [14]. For that reason, green purchasing criteria are fostered by global, European, and national regulations. Despite this, the topic of IMM approaches for GPP implementation is not often investigated, and few applications in the construction sector can be found in the scientific literature. Palmujoki et al. [77] stated that environmental requirements are considered as contract award criteria, but the majority of purchasers still tend to favor past practices to avoid violating the legal principles of free competition and transparency, and possible legal disputes. Wong et al. [78] highlighted the importance of the Public Client in taking a proactive role in pushing green procurement adoption in the AECO sector. Through questionnaire surveys and interviews, the study identified environmental government regulations and client requirements in tendering as main factors to enhance GPP in the construction process. In addition, the use of IMM approaches was identified as a facilitator for the adoption of green design approaches in the construction process [78]. Barbini et al. [9] proposed a system to integrate life-cycle data in a BIM library to support Green and Digital Pubic Procurement processes in the Italian context. The research emphasized the positive outcomes of using digital technologies to achieve environmental sustainability objectives in a virtuous circle between green and digital approaches.

According to the literature review, little investigation has been conducted on the integration of IMM approaches and GPP. However, the definition of a method for the Public Client can be critical considering the high purchasing power of Public Administrations [10] and the poor competence in the Italian context in drafting tender documents that include environmentally sustainable criteria [11].

5. Methodology

The proposed methodology is divided in the following sub-sections:

4. Discussion on the literature review findings and the resulting goals of the research project, and choices for the definition of the proposed methodology;
5. Methodology for the preliminary design phase focusing on the analyses needed to plan appropriate selective demolition activities and involving the definition of a waste audit with a digital material inventory;
6. Methodology for the design phase focusing on the use of BIM models for CDW management and sustainable resource use;
7. Methodology for the call for tender phase focusing on the integration of sustainable award criteria, including CDW management, resource management, waste minimization, and selective demolition criteria, in the GPP tender documents in order to promote their application during the final design and construction phases.

5.1. To BIM, or Not to BIM?

The literature review highlighted the successful applications of BIM for sustainability and during the design phase in particular. However, less investigated topics are the application of digital methods to optimize the planning of the demolition phase of existing buildings and to support the Public Client during the call for tenders phase, including environmentally sustainable criteria.

Regarding BIM adoption for the demolition phase planning, the creation of a BIM model exclusively for demolition purposes shall be carefully evaluated. The availability of a BIM model of the to-be-demolished building is an undoubted advantage for CDW management [67], supporting deconstruction, and reusing and recycling activities [68]. However, most of the existing buildings do not have a BIM model, and creating one is challenging [79]. In addition, when generating a BIM model that is exclusively for the demolition phase, many benefits and optimizations that justify the effort of producing a BIM model are invalidated [25]. In general, the IMM approach aims to support decision-making processes by focusing on organizing and digitizing data and information in a structured form. Data and information must be available, up-to-date, precise, and provided to the right person, at the proper time, and in the correct format [80,81], in a concurrence with process and information management [82]. Therefore, data should accomplish two fundamental pre-requisites: (I) information readiness and (II) information processability [83]. Databases are comparable to BIM models in fulfilling the two above-mentioned pre-requisites since BIM models can be assimilated to the relational databases that are required for 3D geometrical visualization [73]. In addition, the creation of a digital database is less time and effort consuming than producing a full BIM model.

Consequently, the presented methodology proposes the adoption of IMM approaches by using a digital database to manage CDW and for the proper planning of selective demolition activities. The creation of a BIM model, on the other hand, is proposed for the design phase, supporting sustainable resource use and waste minimization strategies. Concerning the call for tenders phase, the methodology proposes a framework for the introduction of award criteria regarding sustainability aspects in the tender documents, and for the evaluation of the environmental impact of the bids (Figure 3).

In summary, the research aims to provide the Public Client with a model to adopt sustainability practices focusing in particular on CDW management and minimization and selective demolition practices, that are supported and managed via IMM approaches during the design and call for tenders phases.

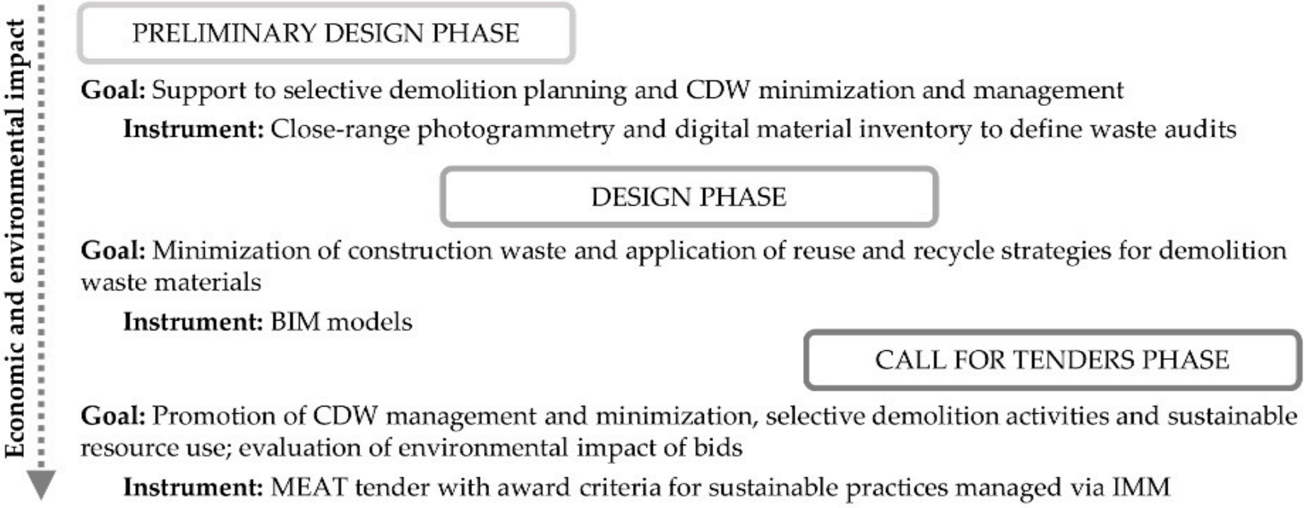

Figure 3. General scheme of the model's objectives and instruments.

5.2. 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. A general scheme of the methodology is presented in Figure 4.

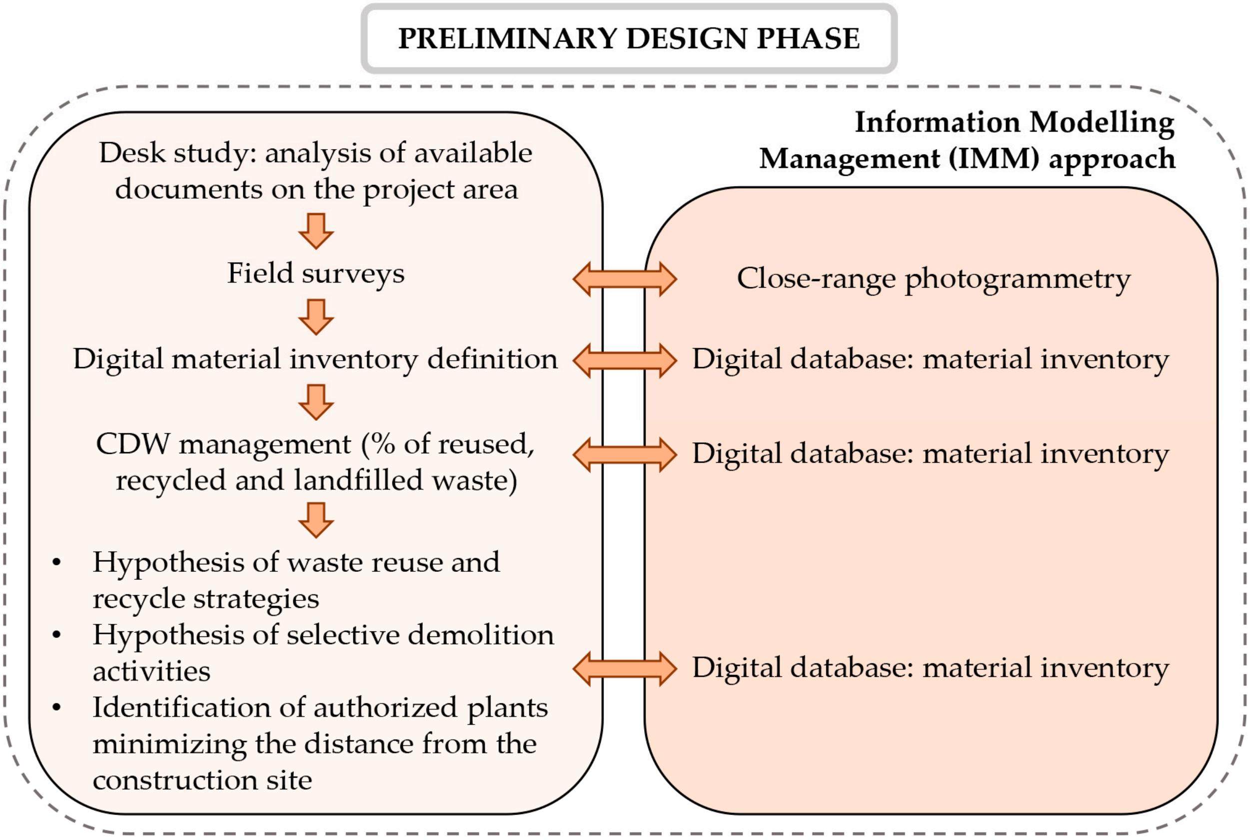

Figure 4. General scheme for waste audits during the preliminary design phase within a IMM approach.

In order to collect the information needed to define the digital material inventory, close-range photogrammetry was considered. The output of close-range photogrammetry are points clouds realized from the images collected on site. 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. The digital material inventory allows the organization and management of a higher quantity of data by going beyond the basic level of information of a standard inventory of materials [5]. The proposed digital material inventory structure is shown in Table 2, and includes:

- Basic information, including material estimation and description;
- Detailed information, including material types and European Waste Codes (EWC);
- An improvement of the basic levels of reporting hazardous and non-hazardous materials by considering three levels of reporting: (a) hazardous, (b) non-hazardous and recyclable, and (c) non-hazardous and reusable on site. The three levels enable an easier definition of waste management strategies through the prior identification of recyclable and reusable materials;
- The identification of recyclable materials and authorized recycling plants in the proximity of the project site to minimize the carbon emissions for waste transportation, hence promoting a circular economy approach at the local scale [25].

Table 2. Structure of collected data in the digital material inventory.

EWC Code	Material Description	Quantity	% of the Total (in Weight)	Waste Management Strategy Hypothesis	Distance of Proposed Recycling Plant
		[m^3/kg]	[%]	[Reuse; recycle; landfill]	[km]

The digital material inventory is then used to define proper selective demolition activities and their related costs. Consequently, a more reliable estimation of the costs for the demolition phase can be included in the total budget for the subsequent design and call for tenders phases. In addition, selective demolition plans can be defined considering actual waste quantities and components.

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.

5.3. 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 (Figure 5).

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:

- Store all graphic and non-graphic information, drawings, and documents of all the disciplines of the design phase;
- 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;
- Identify materials producing the highest quantities of construction waste.

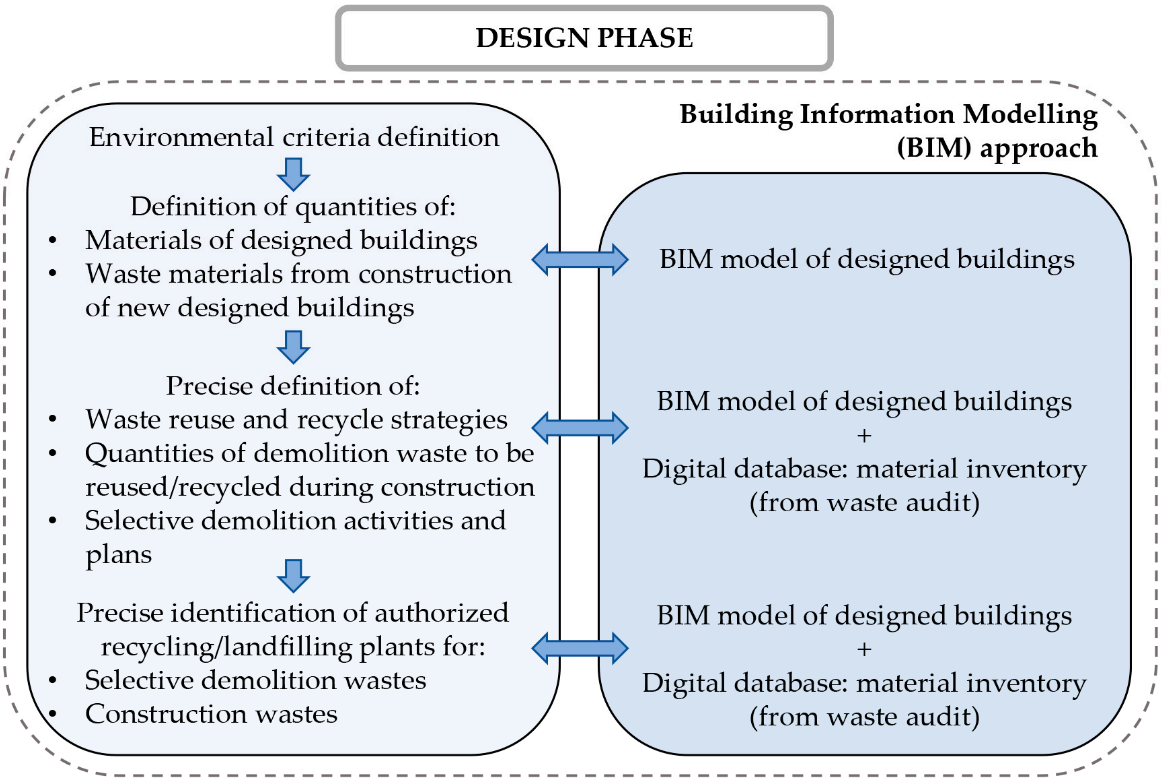

Figure 5. General scheme for waste management during the design phase within a BIM approach.

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.

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

GPP and IMM methodologies are considered as key aspects to introduce and integrate sustainable practices in AECO industry. This sub-section describes the innovative approach to the call for tenders phase, aiming to evaluate and compare the bids according to their environmental impact, and regarding the aspects of CDW minimization and management, and selective demolition procedures.

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. The presence of a unique actor for the two stages eases a more efficient information transfer with the Client and a more collaborative process, which also ensures an easier management of the procurement and construction processes for the Client [84]. As a consequence, the DB model represents a valuable framework for the application of IMM approaches [85]. In addition, if the construction company realizes the final design, company characteristics and standard procedures can be taken into account. As a result, the final design can be optimized according to the capabilities and characteristics of the company itself.

The call for tenders process based on the DB model implies the MEAT evaluation system introduced by D.Lgs. 50/2016, as recalled by Section 2.1. The evaluation of the bids is based on objective alpha-numerical criteria. The assessment of the quality of the bids is based on the rankings on the defined criteria (Table 3), thus promoting the automation of the evaluation process. The environmental criteria considered in this research concerned the following sustainability aspects [86]:

- Selective Demolition Procedures Criteria: procedures that should be defined according to the waste audit and digital material inventory;
- Demolition Waste Management Criteria: considering demolition materials as defined by the waste audit. It was necessary to define recyclable demolition waste by at least 70%, a mandatory requirement introduced by CAM (Section 2.2). The digital material inventory represents a fundamental annex of the tender documents for the identification of demolition materials and waste;
- Recommended Authorized Recycling Plants: minimizing the distance from the construction site and the carbon emissions from waste transport according to the analyses of the waste audit and the digital material inventory;
- Construction Materials and Waste Management Criteria: their quantities, characteristics, level of recyclability or reusability to achieve recyclable construction materials by at least 70%, a mandatory requirement introduced by CAM (Section 2.2);
- Construction Technical Solutions and CDW Management: on-site reuse strategies for demolition waste materials according to the BIM-based analyses;
- Construction Technical Solutions: procedures to increase the levels of durability, maintainability, safety for construction, and to decrease the waste generation.

Table 3. 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

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, thus increasing their possibility of winning the call for tenders, and, at the same time, promoting the application of sustainable practices among the participants. In particular, the call for tenders assigned 80 out of 100 points to the technical offer. Among them, 27 points regarded the environmental criteria (Table 3), covering more than 25% of total points. Moreover, environmental criteria were linked to safety aspects by the sub-criterion D.1.1, requesting the OHSAS 18001 certification of the construction company safety management processes (which has been replaced by International Standard ISO 45001 in 2018) [87,88].

In addition, the criteria and sub-criteria used to evaluate the bids in the tender are aligned with LEED certification criteria (Table 4) [89].

Table 4. Parallelism between LEED credits and evaluation sub-criteria of the proposed tender.

Evaluation Sub-Criterion	LEED Credit
A.1.1—Distance of the production site of materials	MR Credit: Sourcing of Raw Materials: products sourced (extracted, manufactured, and purchased) within 100 miles (160 km) of the project site are valued at twice their base contributing cost, up to a maximum of 200% of the cost.
A.3.1—Contractor certification according to UNI EN ISO 14001 A.3.2—Producer certification according to UNI EN ISO 14001	ISO 14001 (evaluating environmental management system of companies) is not directly linked with LEED (evaluating building environmental performance). However, it has been demonstrated that companies implementing ISO 14000 standards are more likely to be able to provide buildings with higher energy and environmental performance, and consequently, higher LEED ratings [90,91].
D.2.2—Demolition plan and CDW management	MR Credit: Construction and Demolition Waste Management: develop and implement a construction and demolition waste management plan and achieve points through waste prevention and/or diversion.

The following paragraphs describe the sub-criterion D.2.2 (Table 3) and the related scoring system. Sub-criterion D.2.2 is related to CDW management and is aligned with the LEED "Material and Resource (MR) Credit: Construction and Demolition Waste Management". The intent of the LEED requirement is the reduction of "construction and demolition waste disposed of in landfills and incineration facilities through waste prevention and by reusing, recovering, and recycling materials, and conserving resources for future generations.", and specifically, the considered MR Credit aims "to divert at least 50% of the total construction and demolition materials from landfills and incineration facilities." [89].

Sub-criterion D.2.2 divides waste that the company expects to produce by:

- Re-usable waste on site, identifying the expected methods and, when necessary, the treatments to make waste reusable;
- Recyclable waste, identifying the related methods of separation of different types of waste on site;
- Landfilled waste, divided for hazardous and non-hazardous waste, including the disposal methods and, when necessary, treatments to be landfilled.
- Specifically, the following data shall be defined for each waste material (Table 5):
- EWC codes;
- Description of construction activities producing the waste materials;
- Total amount of m-th non-hazardous waste material $Q^i_{Rif,\ m}$ and of p-th hazardous waste material $Q^i_{Rif,p}$ (unit of measurement: kg);
- Percentage of non-hazardous waste material to be reused on site $\%^i_{Riu,\ m}$;
- Percentage of non-hazardous waste material, excluding excavated soil, to be recycled $\%^i_{Ric,\ m}$;
- Percentage of non-hazardous waste material, excluding excavated soil, to be landfilled $\%^i_{Sma,\ m}$;
- Percentage of hazardous waste material as defined by Directive 2008/98/CE to be landfilled $\%^i_{Sma,\ p}$.

Table 5. Example of table for expected waste quantities, types, and EWC codes.

EWC Code	Construction Activity	Amount of Waste [kg]	Non-Hazardous Materials			Hazardous Materials
			% Reused	% Recycled	% Landfilled	% Landfilled
Non-hazardous material EWC code	Construction activity description	$Q^i_{Rif,\ m}$	$\%^i_{Riu,\ m}$	$\%^i_{Ric,\ m}$	$\%^i_{Sma,\ m}$	-
Hazardous material EWC code	Construction activity description	$Q^i_{Rif,\ p}$	-	-	-	$\%^i_{Sma,\ p}$

Considering each EWC non-hazardous waste code, the sum of the percentages $\%^i_{Riu,\ m}$, $\%^i_{Ric,\ m}$, $\%^i_{Sma,\ m}$ shall be equal to 100% since it corresponds to the total amount of that specific non-hazardous waste material. On the other hand, for each EWC hazardous waste code, the single percentage $\%^i_{Sma,\ p}$ shall be equal to 100% since the entire quantity of a hazardous waste material is represented by this percentage.

The quantities of each m-th non-hazardous waste material to be reused ($Q^i_{Riu,\ m}$), recycled ($Q^i_{Ric,\ m}$), and landfilled ($Q^i_{Sma,\ m}$) shall be calculated as follows:

$$Q^i_{Riu,\ m} = Q^i_{Rif,\ m} \cdot \%^i_{Riu,\ m};\ Q^i_{Ric,\ m} = Q^i_{Rif,\ m} \cdot \%^i_{Ric,\ m};\ Q^i_{Sma,\ m} = Q^i_{Rif,\ m} \cdot \%^i_{Sma,\ m}$$

In addition, the quantities of each p-th hazardous waste material to be landfilled ($Q^i_{Sma,\ p}$) shall be calculated as follows:

$$Q^i_{Sma,\ p} = Q^i_{Rif,\ p} \cdot \%^i_{Sma,\ p}$$

The total amount (in kg) of non-hazardous waste to be reused (Q^i_{Riu}), recycled (Q^i_{Ric}), and landfilled ($Q^i_{Sma-Nper}$; $_{\mathrm{Nper}}$: subscript for non-hazardous waste) shall then be calculated as follows:

$$Q^i_{Riu} = \sum\nolimits_{m=1}^{N} Q^i_{Riu,\ m}\ ;\ Q^i_{Ric} = \sum\nolimits_{m=1}^{N} Q^i_{Ric,\ m}\ ;\ Q^i_{Sma-Nper} = \sum\nolimits_{m=1}^{N} Q^i_{Sma,\ m}$$

The total amount (in kg) of hazardous waste materials to be landfilled ($Q^i_{Sma-per}$; $_{\mathrm{per}}$: subscript for hazardous waste) shall also be calculated as follows:

$$Q^i_{Sma-per} = \sum_{p=1}^{N} Q^i_{Sma,\ p}$$

where N is the total number of materials from Table 5.

The total amount of waste (Q^i_{TOT}) is the sum of recycled, reused, and landfilled waste, considering both non-hazardous (subscript $_{\mathrm{Nper}}$) and hazardous materials (subscript $_{\mathrm{per}}$).

$$Q^i_{TOT-Nper} = Q^i_{Riu} + Q^i_{Ric} + Q^i_{Sma-Nper}$$

$$Q^i_{TOT-per} = Q^i_{Sma-per}$$

$$Q^i_{TOT} = Q^i_{TOT-Nper} + Q^i_{TOT-per}$$

The total percentages of materials for reusing, recycling, and landfilling of non-hazardous (subscript $_{\mathrm{Nper}}$) and hazardous materials (subscript $_{\mathrm{per}}$) shall be defined as follows:

$$\%^i_{Riu} = \frac{Q^i_{Riu}}{Q^i_{TOT}}\ ;\ \%^i_{Ric} = \frac{Q^i_{Ric}}{Q^i_{TOT}}\ ;\ \%^i_{Sma-Nper} = \frac{Q^i_{Sma-Nper}}{Q^i_{TOT}}\ ;\ \%^i_{Sma-per} = \frac{Q^i_{Sma-per}}{Q^i_{TOT}}$$

Finally, it is possible to calculate the coefficient $D\%^i_{D.2.2}$:

$$D\%^i_{D.2.2} = \%^i_{Riu} \cdot coef_{Riu} + \%^i_{Ric} \cdot coef_{Ric} + \%^i_{Sma-Nper} \cdot coef_{Sma-Nper} + \%^i_{Sma-per} \cdot coef_{Sma-per}$$

where $coef_{Riu}$, $coef_{Ric}$, $coef_{Sma-Nper}$, and $coef_{Sma-per}$ are defined in Table 6.

Table 6. Waste management coefficients for non-hazardous and hazardous waste materials according to waste treatments.

Classification of Waste	Waste Management Coefficient Code	Waste Management Coefficient Value
Reused non-hazardous waste materials	$coef_{Riu}$	100%
Recycled non-hazardous waste materials	$coef_{Ric}$	80%
Landfilled hazardous waste materials	$coef_{Sma-per}$	75%
Landfilled non-hazardous waste materials	$coef_{Sma-Nper}$	50%

The final score for criterion D.2.2 of the i-th offer shall be calculated as follows:

$$P^i_{D.2.2} = D\%^i_{D.2.2} \cdot P_{D.2.2}$$

where:

- $P^i_{D.2.2}$ is the score of the i-th offer for criterion D.2.2;
- $P_{D.2.2}$ is the maximum score that sub-criterion D.2.2 can reach;
- $D\%^i_{D.2.2}$ is the scoring percentage that multiplies the maximum score available for the criterion, obtaining the i-th offer's score as defined above.

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.

6. 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. The project area was classified as a brownfield in the open data set of the Lombardy Region.

6.1. Case Study Selection: Importance of Soil Protection and Brownfield Rehabilitation

Brownfields are defined as polluted and abandoned sites where urban transformation interventions combine remediation and reuse [27,28]. As recalled in Section 2.3, the brownfield phenomenon and the importance of preserving green fields is widely acknowledged in Europe as well as in the Italian context. Despite that, land consumption in Italy maintained a rate of 2 square meters of land irreversibly lost every second in 2019 [28]. The most affected land type is green fields, i.e., areas with agricultural vocation. Green fields are three times more affected by land consumption than urban areas. In 15 out of 20 Italian regions, the consumed land exceeds 5% of the complete regional area. In particular, the highest percentage of consumed land, which is equal to 12,1%, belongs to the Lombardy Region [28]. Consequently, the remediation, reuse, and redesign of brownfields within a circular economy approach could enable the reduction of land consumption by avoiding taking advantage of green fields and helping achieving zero net land consumption by 2050 [30]. In addition, CDW management strategies can be even more effective when applied to brownfields [27,28]. Furthermore, disused former industrial areas inside urban contexts generate processes of environmental and social degradation, and their renovation can help in contrasting this combined phenomenon, representing, at the same time, an opportunity to redesign dense urban areas and to rethink the distribution of functions and services [37].

The presence of about 1,260 hectares of brownfields in the Province of Milan, corresponding to over twice the area of the Milan historical center [37], justifies 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.

A previous stage of the research project was discussed in an article by Pellegrini et al. [12], which also reported a brief preliminary description of the case study presented here, which was not yet fully developed. The tender has now been awarded, and this study describes the advantages, limitations, and effectiveness of the proposed method based on the analysis of the case study results.

6.2. Existing Area and Design of the New School in Inveruno

The project area has a total area of 18,229 square meters. There are several existing underground structures, portions of masonry, and a large surface covered by concrete floor. In addition, the area hosts a vegetable oil refinery building, which is 32 m tall with concrete walls and a composite steel-concrete deck (Figure 6). The project includes the decontamination of the brownfield and the selective demolition of the disused industrial buildings and concrete surfaces.

Figure 6. Project area in Inveruno showing the highest of the to-be-demolished existing buildings (on the left) and the existing underground structures (on the right).

Regarding the design of the school complex, this process involved the construction of secondary and primary school buildings and an auditorium. The school buildings have a courtyard shape, and in the courtyards, squares and gardens are located (Figure 7). All of the buildings and the external area surrounding the school facilities can be used separately from students, teachers and school staff and can be used by the citizens of the municipality. This represents a fundamental aspect concerning social sustainability for the transformation and rehabilitation of the brownfield.

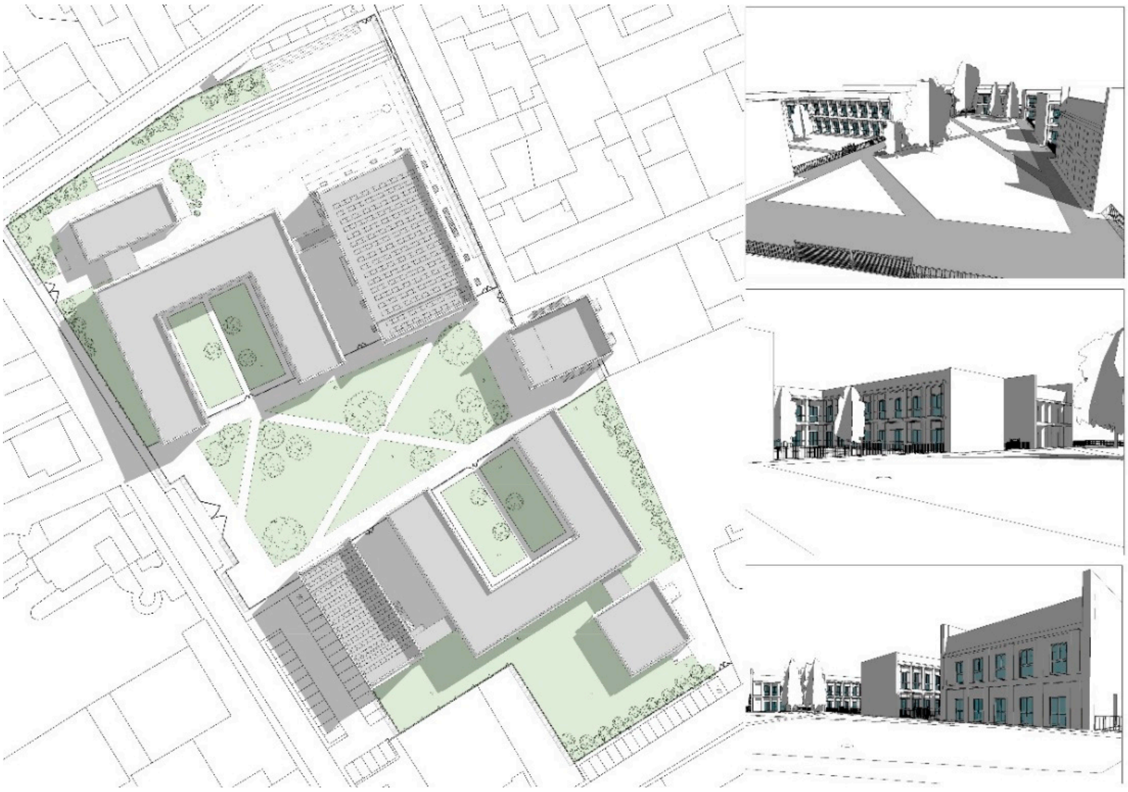

Figure 7. Design configuration of the new school complex in Inveruno, Italy.

7. Results

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

During the preliminary design phase, the output of field surveys supported by close-range photogrammetry were image planes of the to-be-demolished facilities (Figure 8). The image planes were used for measuring, material recognition, and for conducting analysis in remote mode.

Figure 8. Image planes of two sides of the abandoned 32-m-high vegetable oil refinery building slated for demolition, obtained via close-range photogrammetry.

All the data and information regarding construction techniques, materials, and related data were gathered and digitized in the digital material inventory, some examples of which are shown in Table 7. The digital material inventory enabled 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.

Table 7. Extract of material inventory data.

EWC Code	Material	Quantity	% of the Total (Weight)	Waste Management Strategy Hypothesis	Distance of the Recycling Plant
17 09 04	Mixed construction and demolition waste, such as concrete and masonry	6716 m^3	45%	Possible reuse on site: Replenishment of underground volumes Formation of embankments Preparation of roadbeds for the path of construction vehicles Draining layer for lamination boxes Possible recycling by crushing on site or in authorized centers	30 km
17 04 05	Iron and steel	746 m^3	51%	Transfer to ferrous materials recycling plant	4 km
17 03 02	Bituminous mixtures	345 m^3	4%	Transfer to authorized disposal facility for non-hazardous waste	20 km

In addition, it supported the definition and adoption of selective demolition strategies (Table 7), by including the following data:

- Types of structures to be demolished;
- Safety measures to be adopted during the demolition activities;
- Material types and their EWC code classification;
- Quantity of materials and related management strategies, i.e., on-site reusing, recycling, or landfilling.

A central aspect that emerged from the field surveys and from the digital material inventory definition was the serious state of abandon of the entire vegetable oil refinery facility. None of the building elements could be dismantled and reused. In addition, the disassembly of the metallic components before the demolition would have been dangerous for the workers. Therefore, the sorting of the metal components was planned for after the demolition of the concrete and brick parts.

In addition to detailed demolition planning, it was possible 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 total costs of the selective demolition phase, which were compared to the costs associated with non-selective demolition procedures. Non-selective demolition procedures consider the demolition of an entire building without any interest in the materials involved and, consequently, does not allow the proper separation of the elements or the fractioning of mono-materials that are suitable for reuse or recycling as secondary raw materials.

For the present case study, selective demolition costs identified with the support of the digital material inventory accounted for EUR 514,381. On the other hand, non-selective demolition costs could be estimated at an amount of about EUR 405,020 by considering a unique parametric cost for the demolition of the total volumes. Consequently, the selective demolition costs represented 127% of the estimated non-selective demolition ones.

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

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.

Among the selective demolition strategies proposed in the digital material inventory, the demolition of the concrete external floor surface and of the concrete parts of the vegetable oil refinery provided a considerable amount of concrete as a homogenous portion of waste. For both the great quantity of waste available and the various possible reuse strategies, the concrete waste was selected to be entirely reused on site (Table 8).

Table 8. Reuse activities of total quantity of concrete wastes as secondary raw materials.

Reuse Activity	Amount of Surface or Volume Covered with Reused Materials	Quantity of Reused Material	% of the Total Concrete Wastes
Aggregate for the preparation of roadbeds for the paths of construction vehicles	2300 m^2 of construction site paths	470 m^3	7%
Replenishment of underground volumes in the project area	5843 m^3 of underground volumes	5843 m^3	87%
Aggregate for sidewalks realization and as draining layer for lamination boxes	2727 m^2 of sidewalks and remaining 144 m^3 as draining layer for lamination boxes	403 m^3	6%

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

This sub-section provides the results of the application of the presented DB call for tenders method to the case study analyzing the specific tender documents, followed by the responses and results of the bids, in particular, those of the winning company bid.

In regard to the tender documents, the digital material inventory supported the verification of the feasibility of the selective demolition strategies to be included in the tender documents. In addition, the digital material inventory supported the identification of selective demolition costs that could also be included in the tender documentation as a part of the overall budget for the proposed project.

Furthermore, starting from the digital material inventory and the BIM-based analyses during the design phase, the tender documents included the hypothesis of the on-site reusing of concrete wastes as secondary-raw-material aggregates. Consequently, a pulverizer was proposed as equipment to be used on site to reduce the dimensions of the inert materials and to make them uniform for further use.

Regarding the scoring of the bids in the environmental criteria described in Table 3, the average score of 10 out of 11 bids, excluding the lowest score, was equal to 23.4, corresponding to 87% of the total available score (27/100) in the environmental criteria (Figure 9). In particular, 10 out of 11 construction companies obtained good scores in sub-criterion D.2.2 (Table 3) by providing data and strategies for CDW management. Only one offer obtained a negative result, i.e., zero points in the sub-criterion, due to a lack of specifications and documentation on CDW management strategies.

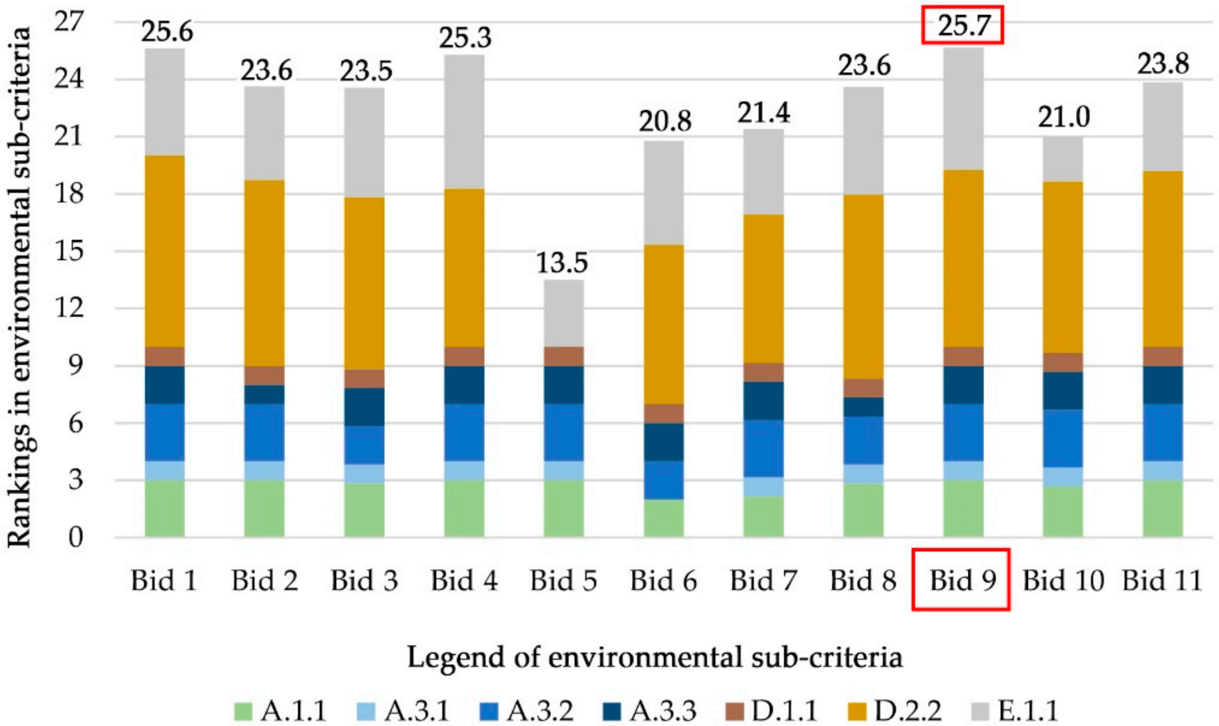

Figure 9. Scores and rankings in environmental award criteria of the eleven bids, including the winning one (Bid 9).

Regarding the winning company (Bid 9, Figure 9), the bid scored a total of 25.7 out of 27 points on the environmental award criteria, which represented 26% of the total 100 points and 32% of the 80 points of the technical offer. 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. The plan included:

- Selective demolition activities;
- Specific work areas inside the demolition site layout;
- Construction vehicles and equipment specific for different areas and activities.

In addition, the plan included safety requirements and indications for the demolition phase, e.g. areas of the site precluded to worker access near the areas where the total demolition of concrete structures would be performed with excavators equipped with demolition grabs. Furthermore, the company linked the analysis of the demolition phase and activities with information regarding the materials provided in the digital material inventory. Consequently, they could identify all waste quantities (Figure 10) and could select the specific authorized plants needed for recycling and landfilling, starting from the authorized plants suggested in the tender documentation. Figure 10 shows the types of materials and the related percentage of reused, recycled, and landfilled waste, aiming to minimize the landfilled waste.

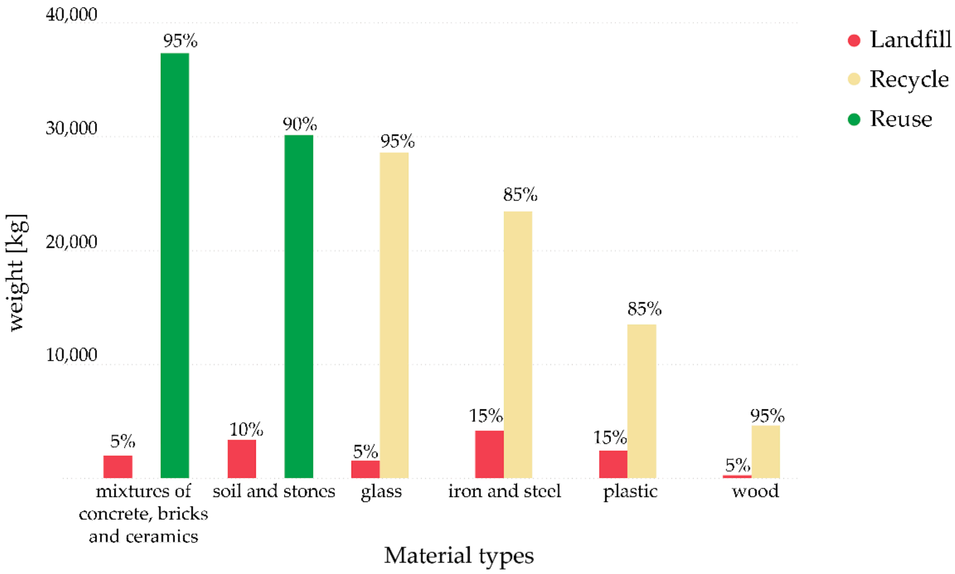

Figure 10. Reused, recycled, and landfilled waste proposed by winning company and divided by material type.

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 (EWC code equal to 170904) as secondary raw materials for the realization of the construction site roadbeds, as aggregate to realize sidewalks, and for the replenishment of underground volumes (Figure 11). The quantities of materials extracted from the BIM model of the designed buildings were compared to the quantities of waste materials recorded in the digital material inventory. Consequently, it was possible to define which quantities of the construction materials could be replaced with reused or recycled materials from the demolition of the existing facilities. In addition, in regard to soil and stones, the company planned for the majority of these materials to be reused on site for external works.

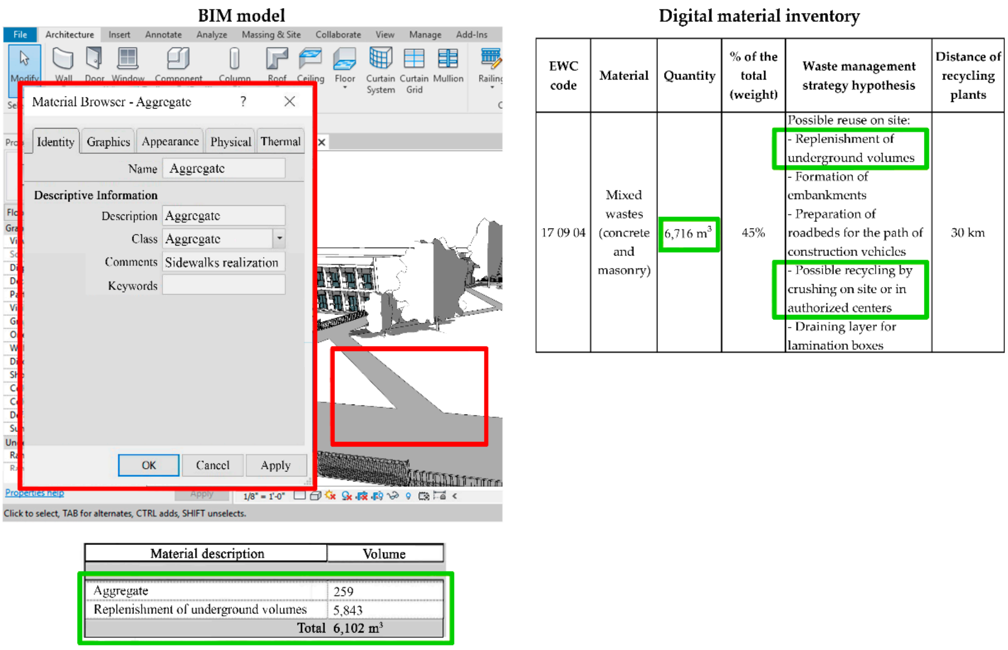

Figure 11. Comparison of design material quantities from the BIM model of the designed buildings, the selective demolition waste quantities from the digital material inventory, and the selection of reuse strategies.

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. Figure 12 shows the total percentages of reused, recycled, and landfilled waste materials, accounting for around 45%, 46%, and 9% respectively. Consequently, over 90% of the waste was planned to be recycled and reused, minimizing the total quantity of landfilled waste accordingly.

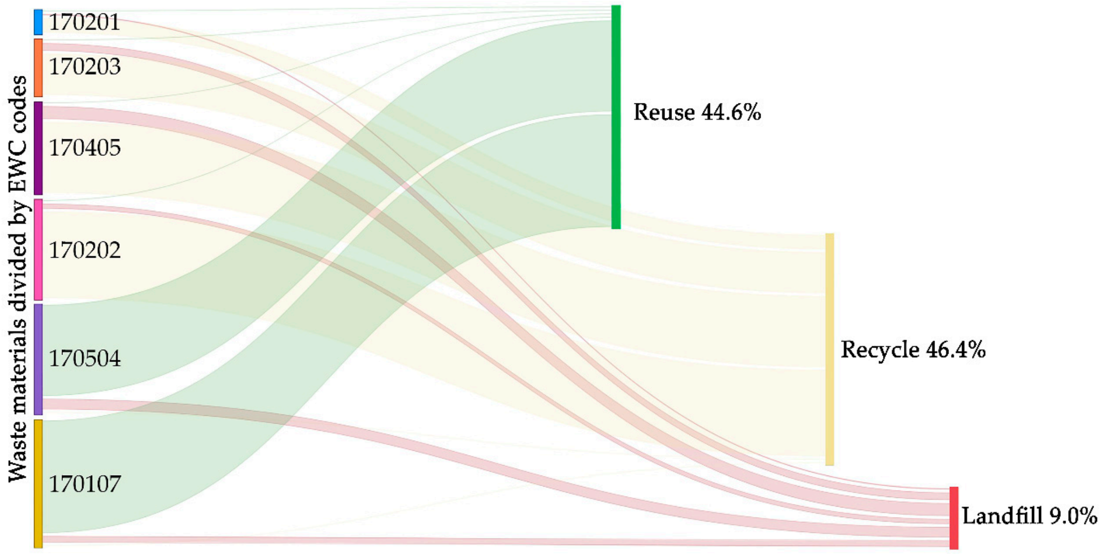

Figure 12. Total percentages of reused, recycled, and landfilled waste.

8. Discussion

This section discusses the results of the application to the case study using IMM approaches during the design and call for tenders phases, which was presented in the previous section.

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 the selective demolition phase. Close-range photogrammetry for field surveys was the easiest and safest survey technique considering the abandoned status and the height of existing facilities [52], allowing for a limited number of on-site surveys and adding the possibility of in-depth analysis in remote mode.

Figure 13 compares CDW management and demolition phase planning in a traditional process and considering the proposed methodology. 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 [80,81]. The case study confirmed that the definition of a waste audit allowed to [5]:

- Support the definition of reuse and recycling practices and the higher quality and easier traceability of waste through the proper identification and separation of materials;
- Plan selective demolition activities with their associated costs of execution;
- Ensure an unbiased competition amongst the participants in the call for tenders that could depend on reliable information regarding existing site and building conditions and demolition costs, allowing them to propose appropriate construction site plans.

Waste audit and digital material inventory definition

- Quantification and classification of waste materials for waste collection and transport to authorized plants
- Precise planning of selective demolition activities
- Identification of reuse strategies for waste materials and elements
- Identification of authorized recycling plants and minimization of their distance from the construction site
- Identification of selective demolition costs to be included in tender documents

Traditional process (without definition of waste audits)

- Definition of non-selective demolition costs, that are lower than selective demolition ones by about 25–30%
- Possible use of parametric demolition costs to define total non-selective demolition costs (but lower accuracy than selective demolition costs defined through digital material inventory)
- Not possible identification of waste quantities for reuse, recycle or reuse strategies
- Increasing uncertainties in the definition of demolition plans

Figure 13. 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. As a matter of fact, if lower non-selective demolition costs had been considered during the call for tenders phase, the actual increased selective demolition costs would have only been identified during the actual demolition phase. This would have caused the necessity of increasing the project budget or could have resulted in disputes between the Public Client and the company, causing time delays or increased costs. Therefore, the correct identification of selective demolition costs is paramount 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, designers, and specialists [39,42]. 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, with positive results both regarding the project budget and the environmental aspects, fostering local circular economy practices, and demonstrating the concept of waste as a resource [23,24].

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

- Support of 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 [11];
- Promotion of the integration of CDW management and minimization, sustainable resource use, and selective demolition procedures among the participants.

The high scores of 10 out of 11 bids in the environmentally sustainable award criteria included in the call for tenders 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 (Figure 14), 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, i.e., 25.7/100 total points and the 95% of the total available points regarding the above-mentioned award criteria. In particular, the detailed tender documents supported the selective demolition planning as a critical part of the project by assigning numerous points to correct demolition planning and proper CAM application. In addition, the precise identification of waste materials quantity and information in the waste audit supported the maximization of the quantities of recycled and reused waste materials and the proper selection of reuse strategies by the company. Furthermore, the company was able to select authorized recycling and landfilling plants, minimizing the distance from the construction site to reduce emissions.

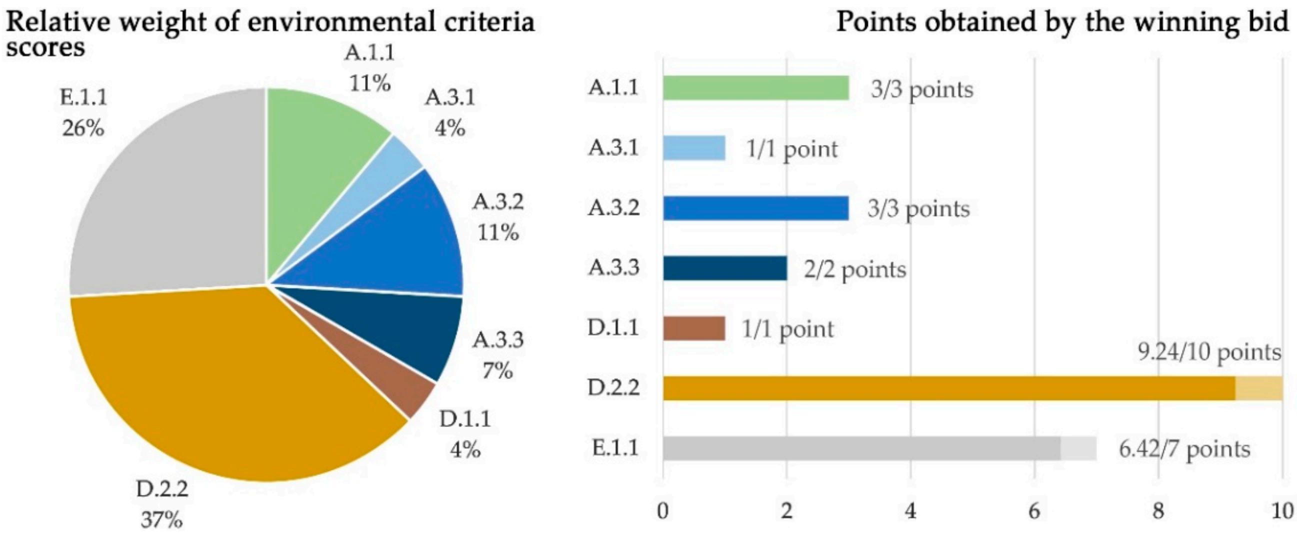

Figure 14. Graph of relative weight of environmental sub-criteria and graph of the scores obtained by the winning bid.

The Design Build (DB) procurement model allowed the contractor to manage the process flow and information right from the final design stage [84], enabling the optimization of CDW management and selective demolition plans, and the decrease of CDW production, which in a traditional tender process would have been linked to design incompleteness or reworking [42–44]. In addition, the contractor's involvement in the final design phase avoided the increased risk of waste generation that typically occurs in the construction phase of a traditional construction process [45].

9. Conclusions

The construction sector produces over 30% of the total amount of waste by volume in the European Union, being one of the most polluting industrial sectors. In addition, since 2004, the amount of construction waste has increased of about 20%, while other industrialized sectors have reduced the waste generation of over 20% [4]. Consequently, the adoption of Construction and Demolition Waste (CDW) management and minimization strategies is paramount. The correct definition of selective demolition plans and strategies is also a fundamental step for proper CDW management when considering projects that involve extensive demolitions.

A review of the regulatory framework at the international, European, and national levels highlighted that environmentally sustainable processes, waste minimization and management, and the implementation of Green Public Procurement (GPP) are needed and are promoted by the United Nations, the European Union, and national governments.

The main drivers for the integration of environmentally sustainable strategies in the construction industry and to overcome the barriers are the following:

- Promoting sustainable strategies by regulations and by Public Clients through design requirements and call for tenders criteria;

- Integrating sustainable strategies into company business models and procedures as a way to maintain and increase their competitiveness;
- Introducing Information Modelling and Management (IMM) methodologies to support the implementation of sustainable strategies.

The literature review on the integration of IMM and BIM methodologies and waste management highlighted that existing studies have mostly investigated these aspects from the designer and constructor's points of view. Few studies have analyzed the integration of BIM and GPP in construction procurement to evaluate the environmental impact of the bids. However, 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 methodology for the preliminary design phase through the definition of a digital material inventory as a fundamental part of waste audits for selective demolition planning and CDW management by adopting close-range photogrammetry to safely perform field surveys of to-be-demolished abandoned buildings. During the design phase, a BIM model is created for the designed buildings to support CDW management and on-site reuse strategies selection. Regarding the call for tenders phase, the methodology involved the definition of environmental award criteria in a MEAT framework, enabling the introduction of GPP and CDW management in the tender process.

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, i.e. the digital material inventory for the preliminary design phase, 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, involving the tendering, project assignment, and the subsequent demolition and new construction phases, 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, including improvements and considerations about on-site reuse strategies, CDW management, and selective demolition plans. In general, the combined use of IMM approaches for the selective demolition phase and demolition waste management, and of the BIM methods for the designed buildings, ensured effective CDW management and the precise identification of reuse and recycling strategies. The demand guided and pushed the application of sustainable practices by the construction companies that recognized the importance and value of introducing sustainable strategies in their own business models. 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. Consequently, it allowed for the better implementation of CDW management and minimization strategies by almost all of the participants. Furthermore, the precise CDW management during the design, tender, and construction phases will support CDW management during the operational phase of the building, promoting proper reusing and recycling strategy application during the whole building lifecycle.

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 model application for brownfield recovery.

The proposed methodology was previously tested with positive results in another case study of the new primary school in Melzo, also using the DB procurement model, but with a simpler design and without almost any demolition [12]. The positive results of the presented case study demonstrate the replicability of the methodology since this case study was a brownfield renovation, with a more complex design, an increased size of the new buildings, and included extensive demolitions, resulting in more complex CDW management, selective demolition planning and sustainable resource use.

10. Further Developments

Further developments of this research will include the use of distributed ledger technology; in particular, the implementation of Smart Contracts based on blockchain technology can be proposed. Thanks to its main features, the use of a distributed ledger can improve information management, and the execution of a Smart Contract can guarantee the immutable and reliable recording of all of the information. The potential integration of a blockchain and IMM methodology can boost the information production, validation, monitoring, and management, offering a transparent, permanent, and shared archiving of the information on a distributed ledger.

For this research case, the proposal of this innovative system permits the proper traceability of all the information related to the materials and the waste cycles pursued in the process. Consequently, this application enables better communication and collaboration among the participants acting in each phase of the construction process, from the planning to the disassembly of the building. The use of a distributed ledger and Smart Contracts in the management of the information related to waste production and management enables the recording and tracking of all the of the relevant data, assuring their access at any time in a reliable way. This means that an IMM based on a blockchain can be considered as a trusty base for the decision-making process, allowing the proper planning and management of construction waste and the environmental impact of the entire process. Based on real and reliable information, more sustainable decision and planning can be conducted in the entire construction industry.

As stated before, despite the fact that some environmental sustainability protocols are mandatory (i.e. CAM in Italy) and that others often provide additional scores in MEAT approaches (e.g. LEED—Leadership in Energy and Environmental Design, ITACA, etc.), an objective and reliable assessment of their compliance is still struggling to be obtained. This is mainly due to the intrinsic complexity and the lack of adequate assessing digital tools. Thus, another development of the outlined IMM approach will concern the introduction of automated sustainability criteria evaluation methods through the integrated simulation of Information Models and automated score attribution systems. This could provide the dual objective of increasing GPP adoption and enhancing digitalization in the tender evaluation processes as required by European Directives. The achievable goals consist of the shortening of the tendering phase, cost reduction as well as avoidance of controversies and corruption. In addition, this will ensure the objective and trustworthy evaluation of sustainability criteria compliance based on the actual use of the building rather than on rough saving assessments. On the contrary, bids will be evaluated through well-defined, clear, and machine-readable criteria in order to digitalize and automate the evaluation process.

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Glossary

AECO: Architecture, Engineering, Construction, and Operations industry. BIM: Building Information Modelling. A BIM method refers to digital techniques used for the modelling and management of information for a built asset and specifically refers to the creation of a digital model of a building. CDW: Construction and Demolition Waste. DB: Design Build. The DB procurement model merges the actors responsible for final design and the construction into a single operator. The Client dialogues with a unique actor, increasing the efficiency of information transfer [84]. EWC: European Waste Code. GPP: Green Public Procurement. GPP aims to purchase goods with good value for money during the whole product lifecycle while supporting environmental protection and reducing negative environmental impacts [14]. IMM: Information Modelling and Management. The IMM approach refers to digital techniques to create and manage information throughout an entire process, allowing for optimized management, organization, querying, computing, and analyzing capabilities. LEED: Leadership in Energy and Environmental Design. LEED is a green building rating system that is used worldwide. It provides a framework for healthy, highly efficient, and cost-saving green and sustainable buildings [89]. MEAT: Most Economically Advantageous Tender. The MEAT is assessed by organizations on the basis of the best price quality ratio, aiming to achieve value for money on a building lifecycle basis. Contracts are awarded based on both quality and price by defining award criteria linked to the subject matter of the contract [18].

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