# Promoting Green Public Procurement: a model-based and open-source waste management evaluation in the Italian Design-Build procedure

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**Abstract**
Information Modelling and Management (IMM) can promote the digital and green transition of construction Public Procurement through the definition of environmental awarding criteria and bids compliance checking during the call for tender. The research proposes a model-based, open-source approach for managing and reducing waste quantities starting from the tendering phase. An Italian Design-Build (DB) procurement is exploited as significant case study to test the methodology. The paper shows how current bids evaluation process was mapped and redefined through BPMN 2.0, identifying the parameters for waste quantities through the IFC standard. Then, user-friendly interactive dashboards were developed for visualizing and comparing bids scores. A data-driven and semi-automated evaluation procedure is provided, enabling tendering procedure streamlining, transparency, and sustainability enhancement.

**Keywords:** Green Public Procurement, Information modelling, Process modelling, IFC, BPMN 2.0, BIM, Waste management, Bids evaluation, Environmental criteria

## 1. Background and motivation

Despite the introduction of IMM and new tools brought significant improvements, the construction industry is still characterized by low productivity, lack of interoperability, and high fragmentation. This is mainly due to the lack of formalized processes with clearly identified Information Requirements (IRs) and automated, data-driven procedures to check their fulfillment (Mc Kinsey, 2017; Orae et al., 2017; ECSO, 2021; Spagnolo et al., 2022).
Such issues are particularly significant in public procurement, usually underestimated even if it represents 14% of GDP (Gross Domestic Product) and could have significant impacts in the long run (Chan et al., 2022; EU Commission, 2017). Despite the recent impulse to improve this phase through the introduction of electronic procurement (i.e.; e-procurement), it is still poorly digitalized and characterized by a high fragmentation and inefficiency (EU Commission, 2017; EU Commission, 2022). Indeed, the still "paper-thought" approaches complicate information management and tender evaluation, resulting in low transparency and collaboration, affecting procurement duration, time of payment and the project's quality. Thus, EU directives (2014/24/EU Directive) and Italian regulations strongly promote digital and data-based approaches to enhance public procurement productivity with a high return on investment (EU Commission, 2017; ECSO, 2021; Muench et al., 2022). The Public Clients represent big buyers and asset owners who can lead the construction supply chain towards efficient processes with improved sustainability through the correct application of GPP (ISO 24000:2017). Italy was pioneering by introducing it as mandatory in all public tenders through the L.D. 50/2016 and the MEAT (Most Economically Advantageous Tender) criterion, fitting the 2014/24/EU Directive. It encouraged awarding contracts against objective criteria ensuring compliance with transparency, non-discrimination, and equal treatment. Nonetheless, GPP is still low adopted, mostly due to the lack of staff training and competencies with issues in drafting sustainability criteria in tender documents (Locatelli et al., 2022; Pellegrini et al., 2021; OAV, 2022; Lavagna et al., 2019). A worsening factor is the lack of evaluation tools, preventing Public Clients from completely controlling project impacts in terms of performance and sustainability.

There is an increasingly urgent need for tools to consider the environmental impact of design choices in the application of GPP, as the construction industry produces about 30% of the European (EU) total waste with raw material consumption amounting to 50% and a high environmental footprint (Rodriguez-Morales et al, 2022; Pellegrini et al., 2021). It is crucial to introduce waste management policies for recycling and reuse as much as possible and lower the construction's environmental impact (Pellegrini et al., 2020; Muench et al., 2022).
According to the EU Green Deal (art.58), the recent Italian National Strategy for the Circular Economy states that minimum environmental criteria, known as CAM (M.D. 23 June 2022), and GPP constitute one of the main tools for the development of circular supply chains. The construction industry is among the strategic sectors on which it is a priority to ensure the effective integration of CAM in public tenders, also to comply with the DNSH (Do No Significant Harm) principle, mandatory for all the NRPP (National Recovery and Resilience Plan) funding. The effective inclusion and application of CAM criteria in calls for tenders is crucial, aiming at enhancing the current laborious and often disregarded evaluation, due to a large amount of data to be considered, and to the lack of clear protocols and guidelines, staff skills, evaluation tools, and the clear definition of contractual or tender clauses (OAV, 2022; Pellegrini et al., 2021, Lavagna et al., 2019; EU Commission, 2021). Data-driven and digital systems are core to improve tender efficiency and promote GPP adoption as bids IRs can be settled to evaluate and monitor CAM criteria application, and environmental impact from a lifecycle perspective by crossing costs and performance through MEAT. Such an evaluation criterion is strongly promoted by EU directives and national regulations, even though it presents some criticalities (Di Giuda et al., 2015; EU Commission, 2021). It requires the verification and control of multiple variables and finding the information necessary to calculate them within the numerous bidding documents is quite difficult. Often, the evaluation results are superficial and lack objectivity as it is handled by a judging commission of experts, based on their own experience. The chosen bid does not always turn out to be properly the best in terms of performance, quality, costs and sustainability. Thus, MEAT application and GPP adoption can be enhanced through data-driven and model-based bid evaluation, avoiding relying on implicit knowledge from documents and reports, enabling the easy extraction of needed information, and providing automatic compliance checks against client and regulatory IRs. At this aim, an efficient IMM strategy is recognized as a game changer (Mc Kinsey Global Institute, 2017; Sacks et al., 2018; Pellegrini et al., 2021), allowing IRs definition in a clear way that cannot be misunderstood or misinterpreted (Locatelli et al. 2022; Spagnolo et al., 2022). The full digitalization of the procedures, task automation, and a more objective, transparent efficient tender evaluation method can be supported by consistent and complete information and models. In particular, the Design-Build (DB) procurement proved to be suitable for such an implementation, as the geometry of the building is defined and the tender is based on the evaluation and comparison of improving proposals (Sacks et al, 2018; Pellegrini et al., 2021; Ciribini et al., 2016).
The study proposes an open-source and data-driven approach for the semi-automated evaluation of bids through the MEAT criterion. It is framed in a broader context of redefining the entire Italian DB procedure (Meschini et al., 2023) through the adoption of IMM, recognized as valuable to overcome some gaps such as checking bids consistency and compliance with the tender criteria (Di Giuda et al., 2015; Pellegrini et al., 2021). The proposed approach is based on the exploitation of the Business Process Management Notation (BPMN 2.0, 2011) for the formalization and redefinition of the current DB processes in a fully digital, open-source and model-based perspective, presented in (Meschini et al., 2023). It highlighted the shortcomings of the current Italian e-procurement through the MePA platform (Consip, 2017) in supporting data-driven decisions. Thus, it was redefined by exploiting IMM and the open IFC standard (ISO 16739) to improve digitalization, interoperability, and accessibility of data, also identifying automatable tasks, among which the IRs compliance checking and tender evaluation. An efficient, objective and transparent tender evaluation method can be supported by consistent and complete information and models, designed according to clear IRs. At this aim, the paper presents a replicable methodology, whose feasibility was tested on a real case study starting from waste management criteria, crucial for the correct application of CAM and the DNSH principle. It illustrates how tender IRs can be defined considering for each material, identified by the European Waste Code (EWC), four parameters useful for assessing the quantities of material reused, recycled and landfilled, both hazardous and non-hazardous. These parameters can be exported through the IFC standard agreeing to the regulations' interoperability requirement and then exploited to feed algorithms for calculating bids' scores. Finally, the results are made available through interactive dashboards enabling to visualize and compare them both at the level of the individual criterion/sub-criterion and globally. The dashboards can also report KPIs useful as synthetic indicators to quickly estimate bids' environmental impact. The WGR (Waste Generation Rate) was selected for the case of waste management (Lu et al., 2022). The presented methodology provides a user-friendly tool and the systemic evaluation of bids, currently prevented in current public procurement procedures. Once validated, can be replicated for other criteria up to cover the entire tender evaluation. This can result in a more transparent and efficient approach, supporting more aware and sustainable decisions through consistent and complete information and protocols.

## 2. Methodology

In (Meschini et al., 2023) the theoretical framework of the research was presented, showing how the current DB Italian procurement with MEAT criterion can be re-defined into an open-source, model-based approach, exploiting digitalization and IMM potential. The formalization of the current DB procurement approach and its re-definition confirmed the potential of (BPMN 2.0, 2011) in effectively representing processes, and providing their machine-readable translation which can be exploited by a BPMN engine through a digital platform. It enabled also to identify the automatable tasks with a strong innovative impact on DB procedures: (i) the information content model checking, (ii) the checking of bids' anomalies and (iii) the semi-automatization of the bid's evaluation through MEAT criterion. This could overcome current criticalities which prevent the exploitation of information models, losing much of digital potential. The overall idea is that the system runs on a web platform that includes tendering data, IFC models and processes formalized in BPMN. As bidders upload their IFC models, they are assigned an ID and they are automatically checked against IRs, defined according to the Client's and regulatory requirements. Models that do not pass the check are discarded noting the exclusion, those that pass the check are translated into .csv, enabling querying the data necessary for the verification and evaluation of the tender criteria with automated scoring, and finally the project with the best score according to the MEAT criterion is awarded. The process provides the visual comparison of bids and individual criteria, and all steps can be notarized ensuring increased transparency, reliability, and automation, thanks to the fully digitalized, data-driven evaluation process. This eliminates the issues related to information asymmetry, ensuring information trust and transparency throughout the process with possible disputes, additional costs and time delay. The redefined process takes place with the validation and publication of the definitive project by the Public Client, published on the platform and made available to the bidders as an information model.

The formalization of the current DB procedure through the MePA platform (Consip, 2017), and its redefinition through BPMN 2.0 presented in (Meschini et al., 2023) enabled to understand the relationship between stakeholders, individuating the IRs that the bidding models must fulfill. The paper focuses on the bid's evaluation subprocess, aiming at defining a replicable methodology for the semi-automated MEAT evaluation of quantitative criteria, while qualitative criteria evaluation remains a human task. The main outcomes consist of the formal definition of the identified IRs for the development of information and modelling protocols, including their mapping through the IFC standard, ensuring interoperability. Due to the urgent need for tools promoting GPP adoption, a replicable bottom-up approach is adopted, defined starting from CAM and waste management criteria evaluation. It involves the following steps which will be in-depth described in the following sections:

- BPMN 2.0 formalization of the criterion evaluation process which could be quantitative, evaluable through an algorithm, or a performance criterion evaluable through a micro-service;
- Definition of related IRs needed and mapping in IFC standard;
- Score calculation through tailored algorithms, after exporting IFC bidding models in Excel sheets;
- Development of analytic dashboards to easily visualize and compare bid scores both at the level of the single criterion and the whole bids.

### 2.1 BPMN 2.0 formalization of the criteria evaluation process

The first step concerns the BPMN 2.0 formalization of the sub-process related to the evaluation of each criterion or sub-criterion involved, namely the bid evaluation process based on the MEAT criterion in the DB procurement. BPMN 2.0 enables to provide an intuitive graphical notation yet capable of representing complex semantics and providing machine-readable processes (i.e. .xml format), exploitable to call external interventions from both microservices and users. The BPMN formalization is key to define an effective Information Management approach as it simplifies the understanding of business processes and tasks for users of diverse backgrounds and expertise. It enables to clearly identify which input and output should be available, from whom, when, and which data the bidding models can provide (i.e., IRs). It enables also to identify which tasks can be automated or not, and the microservices which the platform should invoke, allowing the redesign of processes in a fully digital, data-driven fashion. This is key for the definition of IRs linked to each task, especially in model-based approaches, as it allows to define them and know how the model should be fed to provide the right information and enable decisions connected to it (Corneli et al., 2021). Bidding models and procedural information can be stored through the platform in a machine-readable way, ensuring bidding model's consistency against the IRs, and the identification of needed outputs for each criterion and sub-criterion evaluated. Queries and rules to extrapolate needed IRs and data can be defined and included in guidelines and information protocols to be provided with the tender documents. This sub-process, in the current e-procurement through MePA platform (Consip, 2017) is totally handled by the judging commission, whereas in the revised data-driven and model-based approach, it can be initiated by the judging commission, but then performed within the platform. The calculation and attribution of scores can be automated, with the platform extracting the necessary data from each bid model, retrieving the

necessary microservices and calculation algorithms, and returning the scores for each criterion and sub-criterion in a provisional ranking list that must be reviewed and approved by the judging commission. A semi-automated and more objective evaluation method can be provided, leaving the judging commission with a notarial role, and the evaluation of qualitative criteria.

2.2 Definition of Information Requirements through IFC standard

As stated by (Ciccone et al., 2023), two main obstacles can be identified when dealing with IMM and the development of digital processes with automated tasks: ensuring defined and clear information (i.e. IRs) and translating them in a machine-readable format. These issues can be overcome by defining guidelines and protocols to model data in a structured way and exploiting open formats for better interoperability. Indeed, the formalization of processes enables to define the IRs as unambiguously interpretable overcoming the limitation posed by the high level of implicit knowledge which characterizes current procedures, leading users to free interpretations with a lack of efficiency and quality due to information interpreted "at will", with a high degree of subjectivity (Spagnolo et al., 2022). In dealing with BIM and IMM, the definition of IRs is crucial, particularly for automatable tasks and the definition of a lifecycle perspective. They should be defined depending on the scope for which the model and the data will be used and for the specific information exchange within a business process. Indeed, according to ISO 19650:2019, an IR is defined as: "the specification for what, when, how and for whom information is to be produced" and is satisfied through information exchange among actors.

Thus, as suggested by ISO 29481-1:2017, after the BPMN 2.0 formalization of the evaluation process for the selected criterion, the IRs can be identified, defining how to export them through the IFC standard, enabling to seamlessly share information about the construction project during the whole lifecycle (Borin & Zanchetta, 2020). The most diffused IFC version currently is the IFC2x3 due to its stability, but recently the IFC4 ADD2 TC1 version, published as an international standard (ISO 16739, 2018) is becoming quite diffused due to better management of some properties. The IFC4 was chosen to enhance consistency through the whole IFC schema, enabling round-tripping of IFC models (i.e., export from one software and import to another), and optimizing files after feeding the model with datasets. Some improvements concern the correction of technical issues from IFC2x3.

The IRs needed to evaluate each criterion must be specified in the tender document named “Information Specification”, required by current regulation and corresponding to the EIR defined by ISO 19650:2019 series. In the aim of defining the IRs useful to evaluate the environmental impact or the WGR of the bidding models, an openBIM approach should be selected (Ciotta et al, 2021; Borin & Zanchetta, 2020). At this aim, IFC Property Sets are useful to define IRs and specify the properties which some elements of the model should fulfil. For each criterion and sub-criterion to be evaluated, a set of properties should be defined and assigned to IFC classes involved through a Property Set, so-called “PSet”. Such information modules represent a model for assigning certain properties to IFC classes such as performance and dimensional properties. They can be standard or customised, for objects or their types. The schema defined 420 standard PSets but they have usage limitations as they can only be assigned to the class for which they have been defined (e.g. IfcWall, IfcBuilding...) and can contain only certain properties. Thus, it is common practice to define custom PSets (Ciccone et al., 2023; Armijo et al., 2021; Ciotta et al., 2021) exploiting different ways according to the authoring software used. The optimal solution would be exploiting open-source modellers, but there are yet few and they require some IT skills, still not so common in the construction industry, especially within Public Clients and small enterprises. Furthermore, these kinds of modeler are quite recent and often still in beta, non-stable versions, requiring frequent and substantial updates. Another issue concerns the type of IFC viewers as certain exported properties are viewable or not such as the properties of materials exported from Autodesk Revit. Quite diffused viewers such as BimVision or Solibri prevent displaying them, at least most of them, while viewers such as FzViewer or ACCA usBIMviewer enable their visualization. IFC represents still the best way for interoperability and defining IRs thanks to its good level of flexibility, indeed, the loss of information is often due to the roundtrips in authoring software and stratagems are needed to obtain the desired export, or what is intended to do should be adapted to the software available.

## 2.3 Score calculation

After defining the IRs for each criterion to be evaluated and how to export them to IFC through PSets, it must be defined how the scores are calculated.

The selection of the software and tools exploited was made aiming at improving interoperability and facilitating data management, avoiding disruptive changes in current procedures or the need for special IT skills, with the risk of unsuccess. Accordingly, due that Microsoft Excel and Office Suite are the software widely used by Public Clients, and due to their common use, .csv format is chosen to provide interoperability. In particular, the IRs exported through a .ifc file can be converted into a .csv file through an open-source and free application (Nist File Analyzer) which enables viewing all the exported IFC entities and their attributes at once through a spreadsheet,

for a better understanding of their relationship. The selected tool provides high customization thanks to options to select which types of IFC entities are processed and to report some of the IFC entity Inverse relationships. Each row in the worksheet contains the attributes for an instance of an IFC entity, allowing the easy extrapolation of needed quantities feeding the evaluation algorithms, defined through Excel spreadsheets. Exploiting spreadsheets ensures high replicability and enables to easily automate the score calculation tasks, independently of the platform used for the tendering phase. The calculation of the scores through the MEAT criterion is provided via a multicriteria aggregation system, aggregating them with the results of the qualitative criteria evaluation made by the judging commission. One spreadsheet is used for each evaluation criterion, correlated with as many 'sub-sheets' as each sub-criterion. Then, a final collation sheet for the aggregation of the single results is used to determine the overall score of each bid.

### 2.4 Development of analytic dashboard for score comparison and bids evaluation

The final step of the methodology concerns the crucial task of results processing and visualization through analytical dashboards, created to compare offers against individual criteria/sub-criteria, and for an overall comparison against the global scores.

Dashboards are analytic and interactively searchable tools built around model data and scoring spreadsheets. As stated, among Public Clients a significant amount of data is currently managed in Microsoft Excel or .csv format. Open-source Business Intelligence tools such as Grafana could be exploited, but they need some IT skills, which are one of the current gaps to overcome, especially during the transition from paper-based to model-based and fully digital approaches. In the future they could be considered, as well as other formats or technologies that allow further flexibility and customization, also for the definition of IRs and models' queries. Thus, aiming at reducing the investment to switch to the new approach and ensuring interoperability through already used tools, Microsoft Power BI was selected. It is internationally recognized as one of the most suitable software to handle large amounts of data and allows to work on datasets without changes to the source dataset, preventing original data loss. It enables interactive dashboard development, facilitating information visualization and understanding. This is core for the immediate and effective evaluation of bids during the tendering phase as it enables to display and compare different parameters, KPIs, and performances from various domains.

## 3. Proof of concept: waste management evaluation in a DB procurement for a new school

As a proof of concept, the methodological path and tools described are contextualized and implemented through a real DB procurement with MEAT, exploited in previous research to define an IMM approach to tender evaluation (Pellegrini et al., 2021), aiming at testing its feasibility. The case study concerns the DB procurement for the executive design and construction of the new primary school in Melzo, near Milan. It had a total budget of €5 million (under the Community threshold) and involved the construction of a single building of 3'523 square meters for 500 students (Pellegrini et al., 2020). Even though in 2015 there was no regulatory requirement for BIM, it was exploited for the final tender design, through Autodesk Revit and design parameters useful to evaluate various services put out to tender. At the time, the use of IFC was not mandatory either, so no offer models were exported to IFC, nor were the parameters mapped against it. The BIM model was developed as a pilot research case study while the tendering procedure was carried out traditionally.

The DB procurement is based on a fixed geometry of the building, and the bidders can propose only performance improvements evaluated through the complicated MEAT criterion. Thus, to ensure greater consistency and control of the bidders' declarations during the tendering process, the tender documents included bid sheets with a clear indication of what should be submitted and how. This enabled to streamlining of the evaluation process and control the consistency of the documents (Di Giuda et al, 2015). In the re-designed approach, model-based and open-source, the sheets are the ones that must be partly fed with data from the BIM models, exported in IFC and converted in .csv, used for scores calculation. When submitting the offer, the bidder must upload the .ifc file and fill in sheets to collect further necessary data. The application of CAM was not foreseen at the time of the tender, but the reference regulatory framework envisaged the control of hazardous waste and environmental criteria including the assignment of more than 40 points. Among them, the waste management criteria, directly and indirectly, involved 15 out of 80 points dedicated to the technical offer, in addition to 10 points for the economic offer and 10 for the time offer. Criterion C.2.3 (Table 1), related to the construction phase, required the development of a waste management plan to maximize the quantities of reused and recycled wastes, as requested by CAM. Indeed, waste management was included among the evaluation criteria to reduce environmental impact by requiring the waste strip-out, separating it into hazardous and non-hazardous, and indicating the quantities of recycled, reusable, and landfilled material.

**Table 1.** Procurement awarding criteria with selected CAM related criteria highlighted

| Category | Criterion | Sub-criterion |
|---|---|---|
| A – Passive elements | A.1-Thermal transmittance<br>A.2-Building materials<br>A.3-Environmental requirements | ….<br>A.3.1 – Contractor certification (UNI EN ISO 14001)<br>A.3.2 – Producers' certifications (UNI EN ISO 14001) |
| B – Active elements | B.1Plant system operation<br>B.2-Plant system component<br>B.3-Increased electricity from renewable sources<br>B.4-Smart resources use | …..<br><br>…..<br> |
| **C – Construction phase** | C.1-Safety<br>**C.2-Construction solution and site management** | C.1.1-Contractor certification (OHSAS 18001)<br>C.2.2-Construction site layout<br>**C.2.3 – Waste management**<br>…. |
| D – Maintenance | D.1-Building maintenance<br>D.2-Plant system maintenance | ….. |

## 3.1 BPMN 2.0 formalization of waste management criterion evaluation

After the analysis of the paper-based evaluation of waste management criterion C.2.3 through MEAT approach, the related sub-process, invokable by the overall DB process (Meschini et al, 2023), was formalized in BPMN 2.0 according to the model-based, open-source, and semi-automated method proposed (Figure 1). As shown in Figure 1, it foresees two pools: the BIM server and the judging commission, exchanging information through the platform. When the platform receives the request to evaluate sub-criterion C.2.3, the sub-process is instantiated and queries the dataset related to the first bid, extracting the necessary values, and supplying them to the spreadsheet for scoring. This process must be reiterated for each bid received and, once all the scores are defined, they feed a dashboard to compare the offers against C.2.3 sub-criterion, which in turn feeds the dashboard for the overall evaluation of the tender and bids comparison. Indeed, this is also the sub-process exploitable to invoke the dashboards and display the results of bid evaluations through the platform.

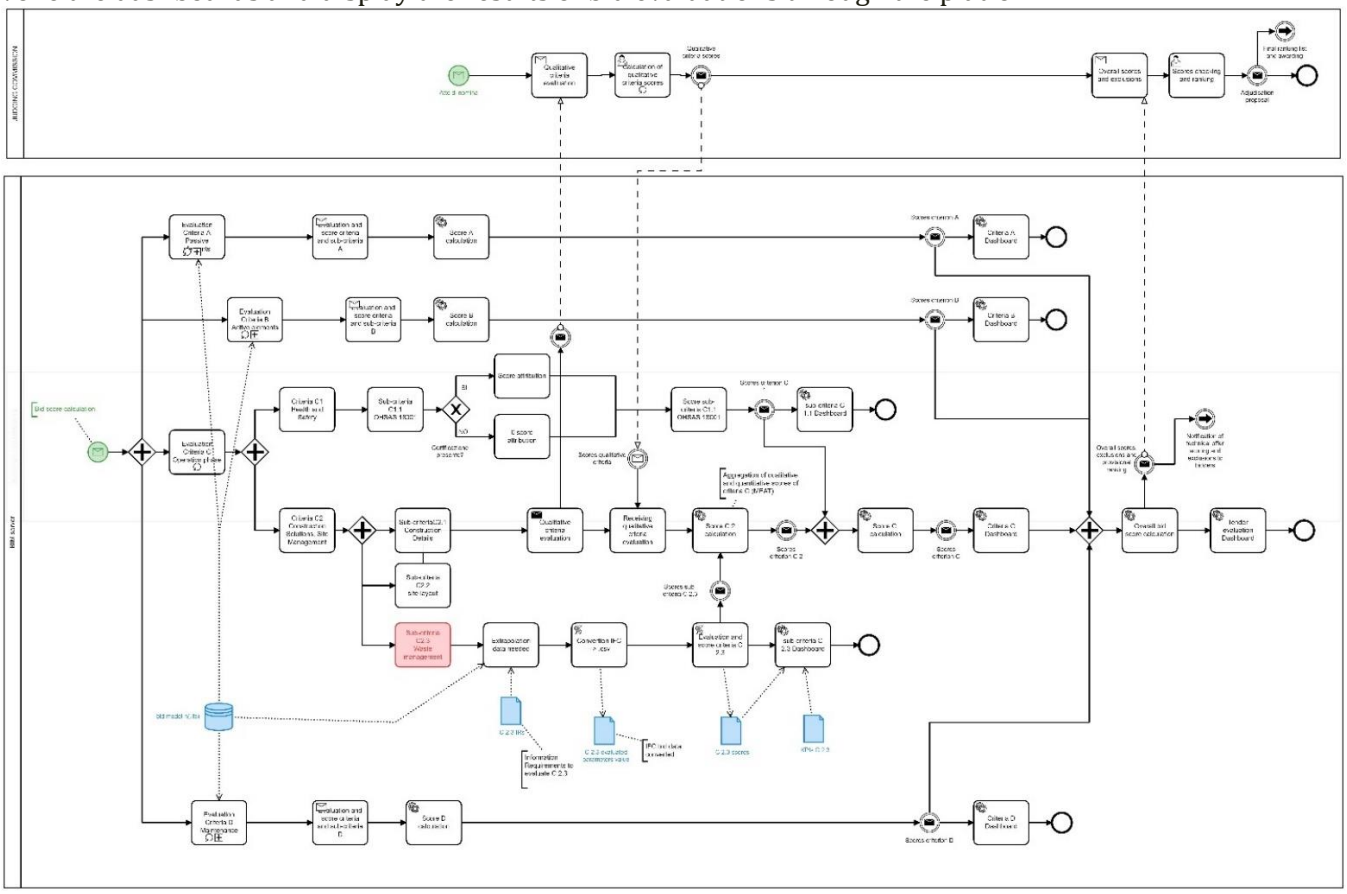

**Figure 1.** BPMN 2.0 sub-process for criterion C 2.3 score calculation through MEAT

### 3.2 Definition of IRs and Property Set for waste management criteria evaluation

After the definition and formalization of the evaluation process for criterion C 2.3, the related IRs and Property Sets have been defined. The evaluation of waste quantities can be addressed in three ways: per material, per element, or for the whole project. Ideally, to evaluate criterion C 2.3 and get more control over the quantities and types of waste, it would be better to define the four identified quantities and the EWC for each material, through a tailored PSet. There is not yet a PSet for waste management among the standard buildingSMART PSets. The one related to environmental impact is the PSet_EnvironmentalImpactValues which is not related to materials but to elements such as walls, and it contains only hazardous or non-hazardous waste without considering the recycled, reused, and disposal quantities. Thus, a customized PSet was defined. It was not possible to exploit exactly the methodology illustrated due to two issues: (i) the evaluation of the tender was made on comprehensive quantities, so the quantities of each material were not available for comparison; (ii) issues concerning the exportation of material properties from the authoring software. Indeed, the school was modelled through Autodesk Revit, the software foreseen various ways to export IFC models. To provide maximum flexibility and customization, it was exploited the "DefaultUserDefinedParameterSets" which requires a .txt file with a script to define the Property Set "Waste Quantities" (Table 3) but it presents some issues with the definition of properties for the materials. In Autodesk Revit, it is possible to assign customized properties to a material, but it is not yet possible to export it through IfcMaterialDefinition as foreseen by the IFC4 ADD2 TC1. The software enables to export PSets related to IFC elements such as IfcWall or IfcDoor and so forth, several tests were made as confirmation. Thus, the parameters useful to evaluate criterion C 2.3 were exported through a customized PSet related to bidding project parameters defined through the IfcProject class. The PSet works properly for evaluating the tender, even if it is a bit of labouring to define four parameters for each material (i.e. EWC code) in the project. The IRs to be considered are shown in Table 2, while the related PSet in Table 3. Basically, the following four quantities must be considered for each ECW:

- OF_WST_EWC_NH_REU, indicating the reused non-hazardous material
- OF_WST_EWC_NH_REC, indicating the recycled non-hazardous material
- OF_WST_EWC_NH_DIS, indicating the non-hazardous material for disposal
- OF_WST_EWC_H_DIS, indicating hazardous material for disposal.

**Table 2.** Excerpt of the IRs for waste quantities evaluation

| Parameter | ECW code | Description | Domain | IFC class | m.u. | Type |
|---|---|---|---|---|---|---|
| OF_WST_170107_NH_REU | 170107 | demolition/mixing of concrete, bricks, tiles and ceramic | Project information | IfcProject | kg | Real |
| OF_WST_170107_NH_DISP | 170107 | demolition/mixing of concrete, bricks, tiles and ceramic | Project information | IfcProject | kg | Real |
| OF_WST_170405_NH_RIC | 170405 | demolition / iron and steel | Project information | IfcProject | kg | Real |
| OF_WST_170405_NH_DISP | 170405 | demolition / iron and steel | Project information | IfcProject | kg | Real |
| OF_WST_170203_NH_RIC | 170203 | demolition / plastic | Project information | IfcProject | kg | Real |
| OF_WST_170203_NH_DISP | 170203 | demolition / plastic | Project information | IfcProject | kg | Real |
| …… | …… | …… | …… | …… | …. | …. |

**Table 3.** Example of Property Set "Waste Quantities"

| Property Set | Properties | | | |
|---|---|---|---|---|
| | Name | Unit | Value | Description |
| Waste Quantities | OF_WST_170107_NH_REC | Real | IfcProject | Mixing of concrete, bricks, tiles and ceramics, Non-Hazardous, for RECycle |
| | OF_WST_170107_NH_REU | Real | IfcProject | Mixing of concrete, bricks, tiles and ceramics, Non-Hazardous, for REUse |
| | OF_WST_170107_NH_DISP | Real | IfcProject | Mixing of concrete, bricks, tiles and ceramics, Non-Hazardous, for DISposal |
| | OF_WST_170107_H_DISP | Real | IfcProject | Mixing of concrete, bricks, tiles and ceramics, Hazardous, for DISposal |
| | OF_WST_170405_NH_REC | Real | IfcProject | Mixing of iron/steel Non-Hazardous, for RECycle |
| | OF_WST_170405_NH_REU | Real | IfcProject | Mixing of iron/steel Non-Hazardous, for REUse |
| | …… | …… | …… | …… |

In this way, it is possible to extract the data needed and feed a spreadsheet, through which the four percentages of reused, recycled and landfilled materials useful for CAM evaluation are calculated, as well as the score for criterion C.2.3, according to the aggregate compensatory criterion.

### 3.3 Semi-automated score calculation

Once the IRs and PSets for export had been defined, the project was exported to IFC 4 ADD2 TC1, checking if the defined parameters were correctly exported through the Open IFC viewer (Figure 2).

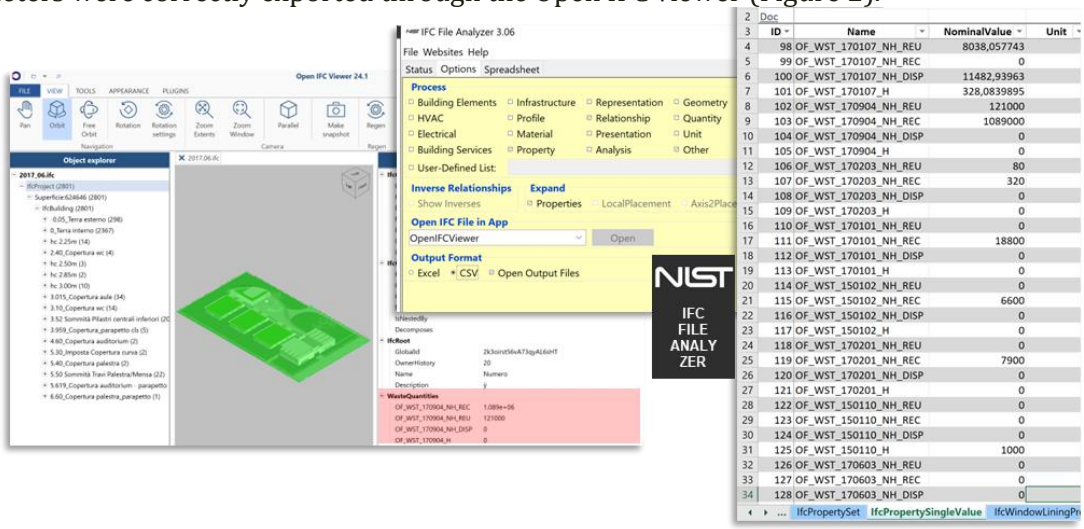


**Figure 2.** – Check of the correct IFC exportation through the PSet Waste Quantities, and conversion in .csv

Then, using the NIST file analyser application, the IFC was converted into a .csv file manageable with Microsoft Excel (Figure 2), so the data needed can be extrapolated to feed the spreadsheet for criterion C.2.3, through which the score is calculated according to the aggregate compensatory criterion and the formula detailed in the tender specifications (Pellegrini et al., 2020), not reported for the sake of synthesis.

### 3.4 Analytic dashboard development for score visualization and comparison

The final step concerns the core task of results processing and visualisation through analytical dashboards, created to compare offers against individual criteria/sub-criteria and for an overall comparison against the global scores. The dashboards enable also to visualize the WGR of each bid as a KPI useful to monitoring waste generation and environmental impact, usually used to benchmark construction waste management performance (Lu et al., 2022), with a view to improving the performance continuously. It is exploited to predict the generation of construction and demolition waste, here considering mixed waste materials generated during the construction phase, according to the bids. WGRj (kg/sqrm), related to the j-bid, was calculated as follows:

$$WGR_j = \sum_{j=0}^{n} \frac{W_j}{A} \qquad (1)$$

Where Wj is the total amount of waste of the j-bid, in kilograms, A the school gross floor area (3523 sqrm).

## 4. Results and discussion

The application of the proposed replicable methodology for waste management criteria evaluation in a real case study, developed in BIM albeit before the introduction of CAM, enabled assessing the feasibility, potential and limitations.

Three types of dashboards have been developed so far, for synthesis only one is shown for demonstration purposes (Figure 3), concerning the weights of reused and recycled materials according to the ECW and intended destination. This is core for CAM application as one of the fundamental requirements is that the total reused and recycled material must be greater than 70%, so a verification signal has been introduced. Figure 3 shows how by selecting, for example, the lowest percentage of reused and recycled from the ring graph, the relative offer is highlighted as well as the non-compliance with the CAM criterion, and the weight of materials with related EWC codes. Another type of dashboard enables bids' comparison against the scores relating to the waste management criterion, C.2.3, together with the weights of the different materials for ECW code, as well as the WGR for each bid. The last type of dashboard reports the comparison of the percentages of reused, recycled, and landfilled material of the various offers, and the score from the best one. It allows comparisons with other bids, which can be selected individually, making immediately perceptible why one offer is better or worse.

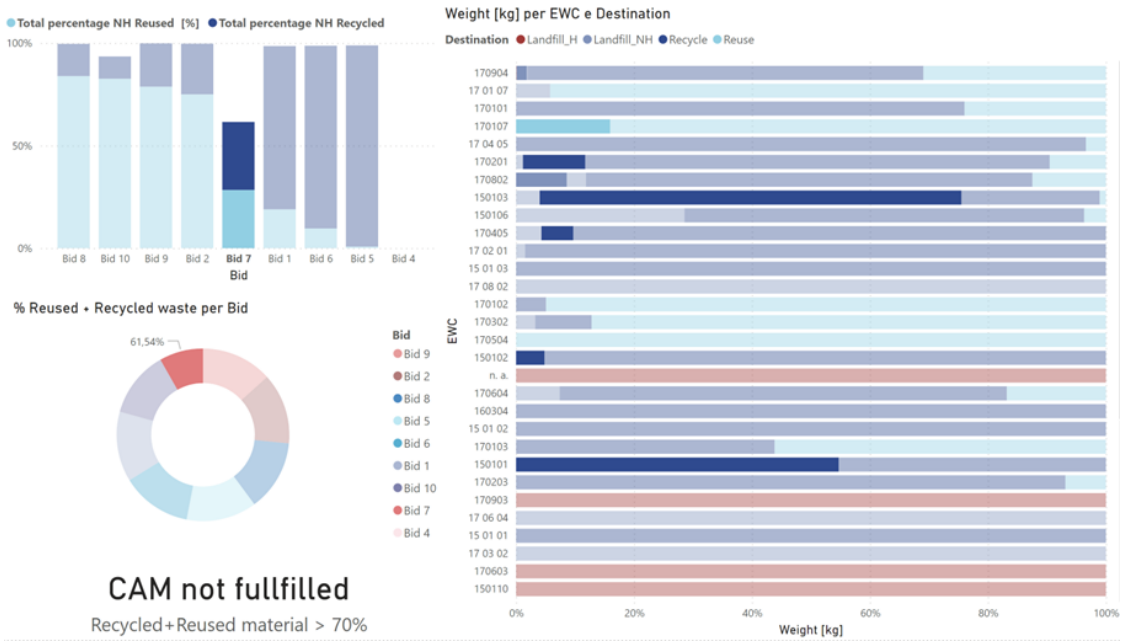


**Figure 3.** – Queried dashboard with the recycled and reused percentages of waste materials check according to CAM criteria of bid 7

The potential of the proposed approach is discussed as expected impacts, as it has not yet been tested through a case study with full CAM criteria. It is planned for future developments, although a strategy is needed to easily handle the large amount of data required, probably by exploiting Machine Learning and Artificial Intelligence as also foreseen by the latest Italian regulations. Some positive impacts are almost certain such as the added value given by data-based information and data-driven processes. Undoubtedly, the proposed innovative approach could streamline current procedures still devoid of automation and based on the delivery of documents. The tendering process efficiency improves as currently the information needed to evaluate the bids must be found in reports and documents, a time-consuming and error-prone task. The Public Client can exploit the developed dashboards to easily visualize and compare the bids, as well as the impact that some design choices have thanks to the WGR KPI, enabling more conscious and effective choices based on performance, costs, and environmental impact. This is key to improving MEAT criterion application more objectively, enhancing sustainability and GPP adoption thanks to the quick and automated check of whether the tender IRs were met, avoiding shifting away from the original intent. The BPMN process modeling provided machine-readable processes and enabled to definition of a replicable methodology for identifying the IRs needed, and semi-automated bids evaluation through the MEAT criterion. Needed data can be stored in the platform and directly queried according to the formalized processes connected. The bids IRs and parameters useful for the evaluation are defined through IFC standard, ensuring the interoperability of the approach. Dealing with Public Procurement and aiming at improving the general validity and replicability of the research, the PoC, and related methodologies were developed to be applied through any web platform. Indeed, it will be necessary to deal with the limitations still given by IFC related to roundtrips in software authoring, exploring the potential of the IDS. It represents the new buildingSMART standard to define project specifications, according to scope and LOIN needed, directly in .xml format, enabling the automated check of IRs, even if it requires IT skills not yet widespread in Public Clients.
Concerning the limitation of having overall quantities of materials, a greater effort requiring the declaration of individual quantities could be too demanding for the tendering phase of the DB procurement. Rather, moving to the executive design phase with a higher LOIN, it will be better to define quantities on an individual element and individual material basis, refining quantity management as well as the analysis and simulation of scenarios based on different possible materials. It could be very laborious, but one possibility is to define the four parameters related to each ECW code on the individual element, for each material layer. The next steps include testing the methodology through a platform to assess whether the automation works and validate the BPMNs, currently validated by procurement experts. In addition, the application of blockchain to notarize both tender documents and bids will be evaluated, providing non-repudiable offers, further transparency and less corruption.
In conclusion, Public Clients can obtain an agile tool to improve CAM evaluation, overcoming paper-based approaches, streamlining tendering procedures, greater objectivity and transparency, as well as compliance with clearly defined IRs, and environmental impact. Furthermore, the methodology based on BPMN, IMM, and open formats for the semi-automated evaluation of quantitative criteria and the clear identification of needed IRs can

be easily replicated, up to covering the evaluation of all the CAM and tender criteria, except for the qualitative ones. The framework and methodology are replicable and adaptable also in other international contexts, modifying the IRs accordingly and adapting the process to the regulatory framework.

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## References

Armijo, A., Elguezabal, P., Lasarte, N., & Weise, M. (2021). A Methodology for the Digitalization of the Residential Building Renovation Process through OpenBIM-Based Workflows. Applied Sciences, 11(21), 10429

Beetz, J., André Borrmann, & Matthias Weise. (2018). Process-based definition of model content. In Building Information Modeling (pp. 127–138). Springer.

Borin, P., & Zanchetta, C. (2020). IFC: processi e modelli digitali openBIM per l'ambiente costruito. Maggioli editore.

BPMN, Business Process Model and Notation, Version 2.0 Standard, Object Management Group, OMG 2011

Chan, A. P., & Owusu, E. K. (2022). Evolution of electronic procurement: contemporary review of adoption and implementation strategies. Buildings, 12(2), 198.

Ciccone, A., Ciotta, V., & Asprone, D. (2023). Integration of structural information within a BIM-based environment for seismic structural e-permits. Journal of Civil Engineering and Management, 29(2), 171-193.

Ciotta, V., Ciccone, A., Asprone, D., Manfredi, G., & Cosenza, E. (2021). Structural e-permits: An openBIM, model-based procedure for permit applications pertaining to structural engineering. Journal of Civil Engineering and Management, 27(8), 651-670.

Ciribini, A. L. C., Caratozzolo, G., Bolpagni, M., Ventura, S. M., & De Angelis, E. (2016). The Implementation of Building Information Modelling within an Integrated Public Procurement Approach: The Main Contractor's Perspective. Building up business operations and their logic Shaping materials and technologies, 3, 417.

Consip, 2017 https://www.acquistinretepa.it/opencms/export/sites/acquistinrete/documenti/Help_documentazione/

Corneli, A., Naticchia, B., Spegni, F., & Spalazzi, L. (2021b). Combining blockchain and BPMN coreographies for construction management. In EC3 Conference 2021 (Vol. 2, pp. 34-41). ETH.

Di Giuda G. M. ,Villa V., Loreti L (2015) BIM to manage public procurement with award criterion Most Economically Advantageous Tender, Istea 2015: Sostenibilità ambientale e produzione Edilizia, Milano, 24–25 Sept.

EU Commission (2022) Single Market Scoreboard - Public Procurement.

EU Commission (2017). Making Public Procurement work in and for Europe.

EU Commission (2021), Implementation and best practices of national procurement policies in the Internal Market.

European Construction Sector Observatory (ECSO) (2021), "Digitalisation in the construction sector".

Lavagna, M., Bessi, A., Meneghelli, A., & Moschini, P. (2019). The environmental dimension of detailed design. Experiences and future perspectives. TECHNE-Journal of Technology for Architecture and Environment, 138-146.

Locatelli, M., Pattini, G., Pellegrini, L., Meschini, S., & Accardo, D. (2023). Fostering the consensus: a BERT-based Multi-label Text Classifier to support agreement in public design call for tenders. TEMA, 9(01), 62-73.

Lu, W., Yuan, H., Li, J., Hao, J. J., Mi, X., & Ding, Z. (2011). An empirical investigation of construction and demolition waste generation rates in Shenzhen city, South China. Waste management, 31(4), 680-687.

McKinsey Global Institute "Reinventing construction: A route to higher productivity" report, 2017.

Meschini, S., Di Giuda, G. M., Tagliabue, L. C., Locatelli, M., & Pellegrini, L. (2023). BPMN 2.0 to redefine Italian design-bid procurement in an innovative model-based, open-source approach. EC3 conference, *4*, 1-8.

Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M. and Scapolo, F., Towards a green and digital future, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/54, JRC129319

Oraee, Mehran, et al. (2017) "Where the gaps lie: ten years of research into collaboration on BIM-enabled construction projects."

OAV - Osservatorio Appalti Verdi. I numeri del Green Public Procurement in Italia; Legambiente: Rome, Italy, 2022

Pellegrini, L., Locatelli, M., Meschini, S., Pattini, G., Seghezzi, E., Tagliabue, L. C., & Di Giuda, G. M. (2021). Information Modelling Management and Green Public Procurement for Waste Management and Environmental Renovation of Brownfields. Sustainability, 13(15), 8585.

Pellegrini, L., Campi, S., Locatelli, M., Pattini, G., Di Giuda, G. M., & Tagliabue, L. C. (2020). Digital transition and waste management in architecture, engineering, construction, and operations industry. Frontiers in Energy Research, 8, 576462.

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers. John Wiley & Sons.

Spagnolo, S. L., Signorini, M., Vesanen, T., Pavan, A., & Kousouris, S. (2022). Information Requirements for an Efficient Renovation Process. In Innovative Tools and Methods Using BIM for an Efficient Renovation in Buildings (pp. 1-15). Cham: Springer International Publishing.