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Article

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A multicriteria model to evaluate tenders for green procurement of public works

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Abstract

Public procurement is quite an important activity in the European Union as it corresponds to more than 13% of the GNP in the EU (2017), and public works account for more than €500 000 M, which is about 25% of the total public procured value. The construction sector is responsible for about 38% of energy-related carbon emissions and 50% of resource consumption. Therefore, procurement of public works (PPW) should be considered a strategic instrument to pursue sustainable policies, but, quite often, the award criterion does not consider the sustainability objectives. The authors present in this paper a new multicriteria model to evaluate tenders to award design or design and build contracts for public works, respecting the principles of public procurement expressed by the European Directives of 2014 and pursuing the sustainability objectives according to the so-called Green Procurement. This model can be easily applied as it is confirmed by its application to the study of the procurement of a new public hospital in Portugal.

Keywords

Award criterion, Green Procurement, Multicriteria model, Public Works.

1. Green procurement of public works: Literature review

The procurement of public works (PPW) corresponds to more than 25% of total public procurement in the European Union, with a value of more than €500,000 M in 2017 (European Commission, 2019). The general objective of any construction design is achieving sustainability concerning the environmental, economic, and social dimensions, or fulfilling the so-called Triple Bottom Line (TBL), according to (Robert and Guenther, 2006). Notwithstanding, green procurement of public works gives special attention to the environmental dimension.

The environmental impacts of the construction sector are quite impressive (World Economic Forum, 2022a), as it is responsible for 36% of the energy consumption, 38% of energy-related carbon emissions, and 50% of resources consumption. Therefore, several green building rating systems have been developed (Ziqi, 2011), emphasizing "different aspects of sustainability, but all fall into six basic categories: energy efficiency, water efficiency, site and environmental impact, indoor environment quality, material conservation, and facility management and operations". This explains the importance of green procurement of public works well expressed by a multiplicity of handbooks, papers, and EU Directives promoting and discussing Green PPW (GPPW), as shown by (Apolloni et al., 2019) and by the comprehensive reviews by (Chersan et al., 2020; Kadefors et al., 2021; Cheng et al., 2018; Rosell, 2021), with each including more than 60 relevant references. However, as shown by (Khan et al., 2018) and (Grandia, 2019), there are quite significant barriers, and, unfortunately, in many European countries, the adopted award criterion in many procedures is still the minimal price, as shown in Tables 1 and 2, and in (Tavares, 2021), which is not appropriate when pursuing a GPPW philosophy. This contradiction led to the publication of multiple papers in recent years to address this theme. Nevertheless, they present perspectives about future developments rather than effective models that can easily be applied, namely (Braulio, 2020), (Wurster et al., 2021) and (Jimenez et al., 2019).

The European Commission defines Green Public Procurement (European Commission, 2011) as *"a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life-cycle when compared to goods, services and works with the same primary function that would otherwise be procured"*.

The concept GPPW is the application of the Green Public Procurement to the contracting of public works. Its application has been studied by several authors, such as (World Economic Forum, 2022b), recommending the consideration of the following aspects:

"When specifying materials, include criteria to reduce their embodied environmental impacts and resource use (these may be based on a life-cycle assessment):

• Give preference to designs that incorporate high efficiency or renewable energy systems;

• Give importance to indoor air quality, natural light, comfortable working temperatures, and adequate ventilation;

• Require the use of water-saving fittings (separate GPP criteria are available for sanitary tapware and toilets and urinals);

• Install physical and electronic systems to support the ongoing minimization of energy use, water use, and waste by facility managers and occupiers;

• Include contract clauses related to the installation and commissioning of energy systems, waste and materials management, and the monitoring of indoor air quality;

• Give contractors responsibility within the contract for training users of the building on sustainable energy use and, where they have ongoing responsibilities, for monitoring and managing energy performance for several years after construction".

The "Action Plan for Net-zero Carbon Buildings", has been also proposed by the World Economic Forum (World Economic Forum, 2022b), considering that the green objectives should be achieved by minimizing the "carbon footprint" covering the five stages of a building life after an initial stage of conception and selection of macro alternatives. These stages are specified in Figure 1.

Figure 1 - Stages of a building life (after the initial stage)

Figure 2 discriminates the dimensions approached in each dimension (RICS, 2017).

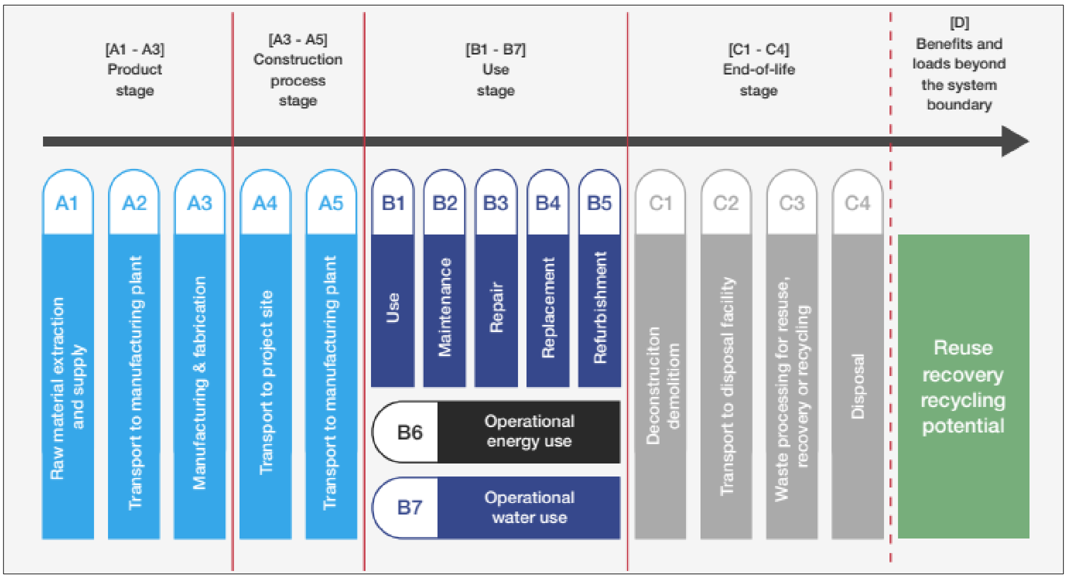

Figure 2 - Dimensions approached in each life cycle stage of a building (after the initial stage)

The UNEP handbook (UNEP, 2021) is quite explicit about the need to pursue a circular economy, a concept that in recent years has gained increased importance by multiple policymakers and researchers (Geissdoerfer et al., 2017), and the mandatory adoption of the Life Cycle Cost (LCC) to assess the cost of each construction. Furthermore, the benefits assessment should also cover direct and indirect impacts, so performance-based formulations can appropriately evaluate the balance between costs and benefits. The LCC and life cycle assessment (LCA) concepts integration in different business areas has been investigated by multiple authors throughout the years (Rebitzer, 2002). Nonetheless, it was originally designed for procurement purposes in the US Department of Defense (White & Ostwald, 1976), and it is still commonly applied in the military sector as well as in the construction industry (Woodward, 1997). A typical product life cycle diagram is presented in Figure 3.

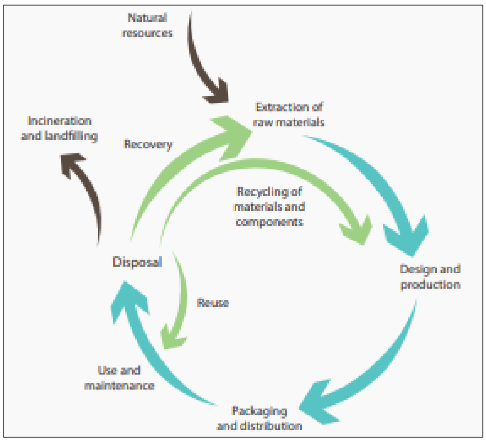

Figure 3 – Typical product's Life Cycle Diagram[1]

Furthermore, the benefits assessment should also cover direct and indirect impacts, so performance-based formulations can appropriately evaluate the balance between costs and benefits.

[1] https://www.lifecycleinitiative.org/starting-life-cycle-thinking/what-is-life-cycle-thinking/ (accessed in 14/09/2022)

According to Directive 2018/844/EU on Energy Performance of Buildings – EPBD of the European Union, "*new public buildings or significant rehabilitation of buildings should comply with the so-called label of 'nearly zero-energy building (NZEB)",* and so a significant objective for GPPW is redesigning the energy system to reduce the carbon emissions and to achieve the NZEB target. The definition of the NZEB concept and its requirements are presented in (Szalay & Zöld, 2014) and in the recast of the older EPBD 2010/31/EU.

Summing up, GPPW implies setting up requirements and a multi-attribute award criterion, as it is also recommended by the (Confederation Suisse, 2014), considering the following attributes:

A) Net energy consumption and percentage of the renewable percentage to minimize the carbon footprint and to achieve NZEB;

B) Consumption of other natural resources (water, raw materials, etc.) and use of recycled materials, hence promoting the circular economy along the whole life cycle of each construction;

C) Adoption of LCC as a criterion to describe the procurement cost;

D) Use performance-based indicators to evaluate the balance between benefits and costs of each tender.

The authors believe that besides these attributes, the formulation of others based on relevant risks related to the life cycle of the constructed system should be considered, and they will be proposed in the next section.

Therefore, the evaluation of each tender (i=1,…,M) implies the adoption of a set of descriptors (D(j) with j=1,…,N), with each one representing one relevant attribute (j=1,…,N). The score of each tender (i) according to attribute i, S(i,j), should be defined in terms of D(i,j), which is the configuration of D(j) for tender i.

Thus, the inevitability and need to take into account the concerns underlying the GPPW justify three main research questions:

R1) Which principles should be respected by GPPW?

R2) Which procedural option to form a construction contract?

R3) What criteria to adopt in the GPPW?

The answers to questions R1), R2), and R3), will be developed in Sections 2, 3, and 4, respectively. In Section 5, a case of application of this methodology to a Portuguese hospital (Seixal Hospital) is presented.

2. Which principles should be respected by GPPW?

The principles to be respected by GPPW include those expressed by the EU 2014 Directive on Public Procurement 2014/24/EU (European Union, 2014) and those including the objectives and the criteria of Green Procurement. The most relevant to developing a model to evaluate tenders are presented in the following sections.

2.1 Sequential separation between the stage of selection of candidates and evaluation of tenders

The Directive establishes separate and sequential stages for the selection of candidates and the evaluation of tenders (Articles 56º to 58º) as it is clear from:

Article 56 º General principles:

"1. Contracts shall be awarded on the basis of criteria laid down in accordance with Articles 67 to 69, provided that the contracting authority has verified in accordance with Articles 59 to 61 that all of the following conditions are fulfilled:

(a) the tender complies with the requirements, conditions and criteria set out in the contract notice or the invitation to confirm interest and in the procurement documents, taking into account, where applicable, Article 45;

(b) the tender comes from a tenderer that is not excluded in accordance with Article 57 and that meets the selection criteria set out by the contracting authority in accordance with Article 58 and, where applicable, the non-discriminatory rules and criteria referred to in Article 65."

This last point and the articles there referred to indicate the existence of a first stage, in which there is the selection of the economic operators whose tenders, if presented, will be evaluated in the second stage. This first stage selects candidates that comply with all the legal obligations mentioned in Article 57 and meet the pre-defined non-discriminating criteria and objectives elicited in the contract notice or the invitation to confirm interest, as described in Articles 58 and 65. The second stage is only available for the accepted candidates and aims to award the most economically advantageous tender from the defined set.

It should be noted that Article 27º1 of the quoted Directive allows the public authorities to introduce selection criteria in the open procedure and that Article 56º2 allows that selection to be after the evaluation of tenders. Still, it does not enable mixing the award and selection criteria in the same evaluation stage. In any case, proposed methods incorporating selection and award criteria in the same decision, as suggested by (Zhang, 2020), violate the rules set up by the Directive.

2.2 Transparency and equal treatment

Article 18º of the Directive, 2014/24/EU quite clearly states that:

"1. Contracting authorities shall treat economic operators equally and without discrimination and shall act in a transparent and proportionate manner."

The principle of transparency has been subject to case law, namely by the so-called Lianakis case (CJEU, 2008), confirming that *"transparency also requires the selection and award processes are based on known criteria. This means that the criteria for assessing the suitability of tenderers and for assessing the tenders in order to award a contract must form part of the minimum information contained in the letter of invitation or contract notice."*

Therefore, the information available to the candidates when preparing their tenders should include the descriptors D(j) with j=1,…,N as well as the score functions S(i,j) in terms of D(i,j) set up by the public contracting authority so that scores are well understood.

This principle excludes any model that will make score functions unavailable when submitting tenders.

The principle of equal treatment has also been clarified by the Court of Justice of the European Union (CJEU, 2005): *"...the equal treatment principle requires that comparable situations are not treated differently and those different situations are not treated similarly unless such a difference or similarity in treatment can be justified objectively".*

This means that the score obtained by each tender should be independent of the features of any other tender. This principle has important implications for the adopted procedure to assess the score of each attribute for each tender. Two approaches have been adopted by several authors violating this condition, meaning that they should be rejected to avoid legal impugnation:

a) Defining S(i,j) not just in terms of D(i,j) but also in terms of Max D(i,j) and Min D(i,j) with I=1,…,M for each j using: S(i,j) = (D(i,j) - Min D(i,j))/ (Max D(i,j) - Min D(i,j)).

   Let be given an example with two attributes, j=1,2, and a set of three tenders, i=1,2,3, denoted by A, B, and C with the following descriptors between 0 and 10:

Tender	Attribute 1	Attribute 2	Final Score	Final Score with D
A	9	8	0.89	0.83
B	7	9	0.67	0.88
C	6	6	0	0.63
D	1	6	-	0

   The final score of each tender is also presented, assuming that the two attributes are equally important, revealing that A is the winner.

   The authors of B may be expecting to be defeated. Hence, they may promote a so-called dummy tender, D, not intending to be the winner but to help B become the winner.

   The final scores are now presented in the last column, becoming B the winner. This example confirms that this approach does not comply with the studied principle.

b) A second approach is based on pairwise comparisons between tenders. Several models based on pairwise comparisons have been proposed to support the ranking of tenders, such as AHP (Analytical Hierarchical Processing) (Saaty, 1980 and 1988) and DEA (Marcarelli & Nappi, 2019; Leśniak et al., 2018; Falagario, et al., 2012). However, unfortunately, the score obtained for each tender depends on the contents of the others. Hence, it is vulnerable to the risks related to "dummy" applications. Let this problem be illustrated by the case discussed by Belton & Stewart (2002) and applied again to the evaluation of tenders:

   Three tenders, A, B, and C are evaluated by three equally important criteria, I, II, and III. Considering this scenario, the pairwise comparison matrices using AHP are given by:

Tender	A			B			C		
	I	II	III	I	II	III	I	II	III
A	1	1	1	1/9	9	8/9	1	9	8/9
B	9	1/9	9/8	1	1	1	9	1	9
C	1	1/9	9/8	1/9	1	1/9	1	1	1

   The obtained estimates for the value of A, B, and C using the Saaty model are 0.45, 0.47, 0.08, and so B ranks first. However, if another application, D, is included and the pairwise comparisons with A, B, and C are given by:

Tender	A			B			C		
	I	II	III	I	II	III	I	II	III
D	9	1/9	9/8	1	1	1	9	1	9

The new estimates for A, B, C, and D values are 0.37, 0.2, 0.06, and 0.29, meaning that now A comes first, confirming the possibility of having a rank reversal, as reported by Dyer (1990) and proven by this example. A similar problem can affect other methods based on binary comparisons using differences rather than ratios (e.g., Bana e Costa & Vansnick, 1994), as shown by Tavares et al. (2008). The adoption of arbitrary and given alternatives to be used for binary comparisons has also been proposed to avoid this shortcoming, but that implies that the decision-maker will just compare each tender with such arbitrary alternatives avoiding any comparison between tenders. Unfortunately, such restriction is hardly feasible and understandable by any decision maker.

The limitations of these two approaches explain why the authors adopt the general formulation of the MAUT (Multi-Attribute Utility Theory) method (Dyer, 2016; Fishburn, 1970), which has a complete theoretical foundation based on the probability theory, the axioms of preferences, and the utility theory (Løken, 2007). The MAUT model is based on a weighted average of the scores assigned to each tender, and so the final score for i will be given by the weighted average of the scores S(i,j) = w(j).S(i,j) for each I and being w(j) the weight assigned to j (∑w(j) = 1).

This means that three major problems must be studied to apply this model:

How to define the attributes and specify the descriptors with j=1,…,N?

How to relate S(i,j) with D(j), being j=1,…,N?

How to estimate w(j) with j=1,…,N?

These three questions will be addressed in the following sections.

2.3 Adoption of the "Most Economically Advantageous Tender" (MEAT) award criterion

Article 67º of the EU Directives states that:

1. *"Without prejudice to national laws, regulations, or administrative provisions concerning the price of certain supplies or the remuneration of certain services, contracting authorities shall base the award of public contracts on the most economically advantageous tender.*
2. *The most economically advantageous tender from the point of view of the contracting authority shall be identified on the basis of the price or cost, using a cost-effectiveness approach, such as life-cycle costing in accordance with Article 68, and may include the best price-quality ratio, which shall be assessed on the basis of criteria, including qualitative, environmental and/or social aspects, linked to the subject-matter of the public contract in question (…)."*

The adopted model for integrating the specified criteria should include the weight assigned to each criterion as it is ruled by Article 67º-5:

"The contracting authority shall specify, in the procurement documents, the relative weighting which it gives to each of the criteria chosen to determine the most economically advantageous tender, except where this is identified on the basis of price alone."

Furthermore, special attention is given to the definition of the Life Cycle Cost (Article 68º):

"1. Life-cycle costing shall to the extent relevant cover parts or all of the following costs over the life cycle of a product, service or works:

(a) costs, borne by the contracting authority or other users, such as (i) costs relating to the acquisition, (ii) costs of use, such as consumption of energy and other resources, (iii) maintenance costs, (iv) end of life costs, such as collection and recycling costs.

(b) costs imputed to environmental externalities linked to the product, service or works during its life cycle, provided their monetary value can be determined and verified; such costs may include the cost of emissions of greenhouse gases and of other pollutant emissions and other climate change mitigation costs.

3. Which procedural options to form a construction contract?

Several approaches have been adopted to develop a construction by a public contracting authority, namely:

a) Using a two-stage process: contracting the conception and design followed by a contract to execute such design, often named by Design-Bid-Build (DBB).

b) Forming a single contract, including the conception, design, and construction (so-called Design and Build – DB - contracts, see (Lupton, 2019)).

Several authors as (Riecke, 2004, Moolenar et al., 2009 & Moolenar, 2010) have presented comparative analyses of these approaches under the perspective of the contracting authority.

The main advantage of the two-stage approach is making separate decisions based on specific selection and award criteria avoiding any compensatory trade-off between the aspects of design and execution. Still, the second approach avoids a lack of coordination between design and construction and doubts about responsibility for arising problems, errors, cost, or time overruns. Actually, in this second approach, the client (the public contracting authority) has "just a single point of responsibility for architecture, engineering and construction services", as noted by Roth, 1995.

Several authors have compared the performance of these two approaches, DB and DBB, showing that in most cases, DB has significant advantages, namely, reducing time and cost overruns (Molenaar, 1999, Sullivan et al., 2017).

Nowadays, the financing, operation, and maintenance of the constructed system can also be contracted following the Public-Private Partnerships approach (see Cui et al., 2018), and so, in this case, the contract will also cover the financing as well as the maintenance and operation of the construction along with its total or partial life cycle (so-called DBO - Design Build Operate or Design Build Finance Maintain – DBFM - contracts according to several authors such as Patterson & Trebes, 2013).

These new types of contracts have the advantage of introducing automatic incentives to achieve higher levels of efficient design and construction because the contractor will have to pay for the eventual lack of efficiency during the contracted operational period (Morledge et al., 2021).

The EU Directives allow all these different contracting options, which reinforces why using this integrated approach to contracting is becoming more popular in most EU countries.

Sustainable contracting of public works is better approached by the last type of contracting because LCC will be directly allocated to the contractor, avoiding the risk of using estimates which are not close to reality (Adamtey, 2021).

The procedures to form each type of these contracts have also been enriched by new options presented by the EU Directives, but the most relevant for GPPW are the following:

a) Open Procedure, which is based on a competition opened by notice;

b) Restricted Procedure (also opened by notice), which includes an initial stage to select the candidates that can bid;

c) Competitive Procedure with Negotiation (also opened by notice), which includes a stage to negotiate attributes subject to competition that can concern financial, quality, sustainability, or innovation aspects.

d) Competitive dialogue, which includes:

   a. A first stage publishing a notice with the objectives and requirements set up by the contracting authority.

   b. A second stage including the presentation of alternatives solutions proposed by the selected bidders.

   c. An evaluation stage to select one of these solutions and the presentation of the corresponding procedure documents.

   d. Tendering and awarding stage

GPPW implies having bidders with a high level of competence on sustainability issues deserving high levels of trust by the public contracting authority. Thus, the first option tends to be less recommended than the second, and specific models to fulfill such selection have been proposed (see Tavares and Arruda, 2022).

The third option is by far the most flexible approach because it includes a negotiation stage enabling to adjust the tender to the needs and objectives of the contracting authority. Article 26º of the Directive 2014/24/UE defines the required conditions to allow the application of this procedure:

"(a) with regard to works, supplies, or services fulfilling one or more of the following criteria:

(i) the needs of the contracting authority cannot be met without adaptation of readily available solutions;

(ii) they include the design or innovative solutions;

(iii) the contract cannot be awarded without prior negotiations because of specific circumstances related to the nature, the complexity or the legal and financial make-up or because of the risks attached to them;

(iv) the technical specifications cannot be established with sufficient precision by the contracting authority with reference to a standard, European Technical Assessment, common technical specification or technical reference within the meaning of points 2 to 5 of Annex VII".

Therefore, it applies to most cases of innovative and sustainable GPPW, namely to contracts DB, DBO, or DBFM.

In any of these procedural options, considering the four criteria presented in Section 1 plus the relevant risks is incompatible with the award criterion based on the minimal price because all other dimensions are not formulated as attributes subject to competition. Therefore, this recommendation of the European Union to use MEAT by formulating alternatives as the life cycle cost or the cost-effectiveness is entirely appropriate to promote GPPW. Unfortunately, a significant percentage of public works and services in the EU is still awarded by the minimal price criterion, as can be confirmed by the statistics of public procurement (in https://ted.europa.eu/TED/browse/browseByMap.do) of 2021 presented in Table 1 and concerning the procedures with a value higher than the EU thresholds justifying their publication of notice through TED.

Table 1 - Number of public works and services published in TED and awarded (or in the awarding process) by following the MEAT criterion in the EU in 2021

	Services	Works
Central Public Administration	9240 (77%)	1055 (51%)
Regional and Local Authorities and Agencies	34565 (86%)	6131 (32%)
Others	26825 (77%)	6345 (53%)
Total	70630 (81%)	13531 (41%)

The contracts concerning services are also included because they are essential and cover all design contracts. These statistics confirm that a considerable amount of public works competition uses the minimal price award criterion, and such percentage is significantly higher for Regional and Local Authorities plus Agencies (RCAA). However, results are better for services, and for this type of contract, the RCCA group uses the MEAT criterion more often than the other groups. In Figure 4, the global comparative analysis for the EU Member States shows the high disparity of results between States and between Services and Public Works. This last conclusion can also be withdrawn from the data in Table 2.

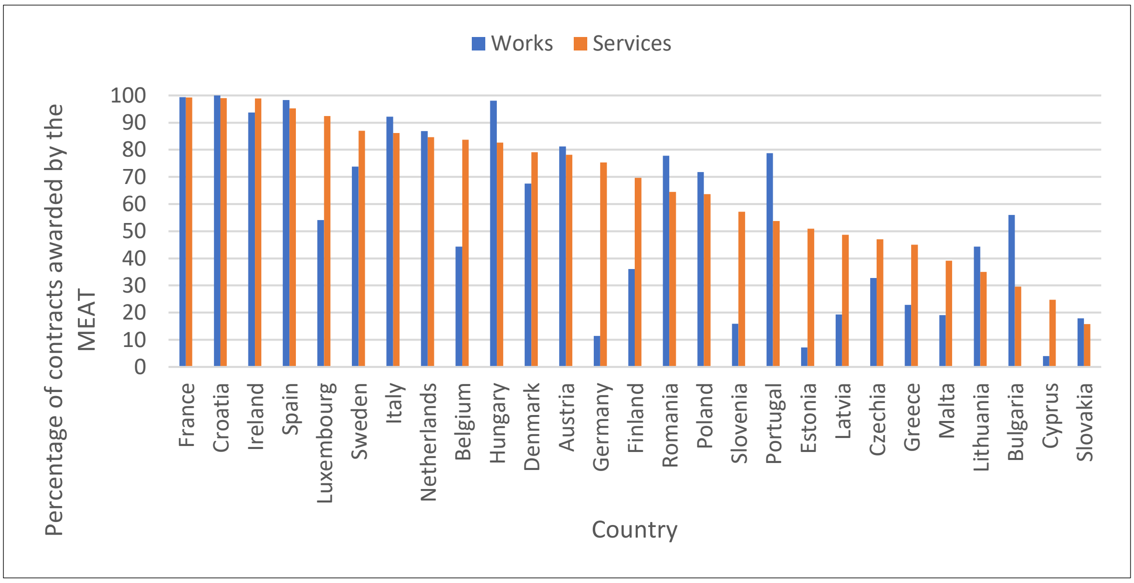

Figure 4- Percentage of contracts published in TED and awarded by MEAT in each Member State of the EU in 2021

It should be noted that these statistical data concern contracts formed after the publication of a notice by TED, thus meaning that they have a value higher than the EU thresholds (European Commission, 2021):

Table 2 - EU thresholds for public contracts (Directive 2014/24/EU)

Contracting authorities:	Supplies and Services Contracts:	Public Works:
Central Government	140,000€	5,382,000€
Other authorities	215,000€	5,382,000€

These results confirm the need to have operational models applying MEAT to evaluate tenders according to the GPPW. Therefore, the proposed model is presented in the next section.

4. The proposed award criterion for GPPW

The proposed award criterion to evaluate tenders includes two dimensions concerning the allocated resources and benefits plus a third dimension concerning risk impacts. Thus, the formulated criteria are:

A) Life cycle cost (LCC) covering the acquisition, the operation (use), the maintenance, and the environmental costs, plus the cost related to the end of the life cycle.

B) Expected benefits (EB) expressed by a utility function describing the generated value for the beneficiaries

C) Risk impacts (RI)

Criterion A should be described by the traditional initial cost measured by the price of the contract plus the discounted operational and maintenance costs added to the environmental costs due to energy and water consumption as well as those due to the toxic and non-toxic wastes (DC):

a) Net consumption of unrenewable energy, which is estimated in terms of the consumption (lighting, climatization, specialized equipment) and the renewable production (solar, wind, and biomass);

b) Net consumption of water estimated in terms of total consumption less recycled water (excluding the water obtained from rainfall and snow);

c) Toxic and non-toxic waste management.

Criterion B should be described in terms of the expected value of the generated benefits for the different groups of users of the system to be built above the minimal levels imposed by the documents of the procedure. Such benefits can be estimated in terms of descriptors, depending on the specific system to build. Still, they are often related to accessibility, internal comfort, internal mobility, and architectural quality. The evaluation of each descriptor can be achieved either through simulation models (for instance, to estimate the average time spent to have access or wasted in internal moves) or by surveys eliciting the evaluation of less quantified aspects like the quality of design. In any case, such evaluation should be expressed on the same scale, namely a Lickert scale from 1 to 5. The design quality should consider not just esthetical aspects but also its adaptation to the functions and the ability to cope with future changes (flexibility).

The methodologic contributions of Cost-Benefit Analysis (see Stewart, 1972 and Araújo et al., 2016) are quite useful in identifying and estimating LCC and EB components.

Criterion C should measure how much resilient each tender is to a predefined catalogue of risks. Such catalogue should include a set of hazardous occurrences due to natural causes such wind or seismic vibrations with a specific level as well as occurrence due to malicious human interventions such as cyber-attacks.

Therefore, the descriptor for Criterion A will be defined as a discounted sum of annual costs due to all components defined along the life cycle of the constructed or developed system following the indications of Article 68º of the Directive (2014/24/UE) already quoted. Criterion B will be described by the aggregated value function (B) of the expected benefits above the minimum required levels. The third criterion will be described by a measure of the impact of each risk, k, with $k = 1, \cdots, K$, in terms of each tender (ERI), which will be estimated an adapted version of the "Failure Mode and Effects Analysis (FMEA)", which several authors have proposed (see, e.g., Fattahi and Khalilzadeh, 2018) in agreement with the international standard (ISO 31000:2018). According to this approach, ERI for each risk k, with $k = 1, \cdots, K$, and each tender i, with $i = 1, \dots, M$ will be given by:

$$ERI_{k,i} = P_k * I_{k,i} * D_{k,i} \quad (4.1)$$

being $P_k, I_{k,i},$ and $D_{k,i}$ indicators expressed in a Lickert scale from 1 (best case) to 5 (worst case) representing:

P_k - Probability of occurrence.

$I_{k,i}$ - Magnitude of impacts.

$D_{k,i}$ – Possibility of detection before occurrence.

Thus, each $ERI_{k,i}$ can be between 1 and 125, and then a standardized measure $ERI^*_{k,i}$ (between 100/125=0.8 and 100) of each $ERI_{k,i}$, can be defined by:

$$ERI^*_{k,i} = \frac{100*ERI_{k,i}}{125} \quad (4.2)$$

Therefore, the total risk for the set of K risks considered is given by:

$$ERT_i = \sum \frac{100*ERI_{k,i}}{125*K} \quad (4.3)$$

Summing up, the award criterion (V) should be now described in terms $of\ DC, B\ and RT$.

The concept of generalized cost, GC, can be defined by:

$$GC = DC + w_R * ERT_i, \quad (4.4)$$

where w_R is an appropriate coefficient expressing the additional cost equivalent to an increase of 1 unit of R.

Then, two approaches to obtain the award criterion, V, can be proposed:

A) Cost-Effectiveness approach
   In this case, V will be defined by:

$$V = \frac{B}{GC} \quad (4.5)$$

   The awarded tender is the tender maximizing V.

B) Multi-Attribute Utility Theory formulation following Dyer et al. (1992).
   In this case, V to be maximized is defined by:

$$V = w_b * B - GC, \quad (4.6)$$

where w_b is an appropriate coefficient expressing the additional cost equivalent to the decrease of one unit of benefit.

Applying the proposed award criterion implies the estimation of the weighting coefficients, w_R and w_b. According to the equation (4.4), the trade-off between C and R is expressed by:

$$\frac{dC}{dERT_i} = -w_R \tag{4.7}$$

and so w_R means the accepted increase of cost C due to the reduction of 1 point of the risk function assuming the linear assumption.

The estimation of w_R can be carried out by a survey asking the following question to a focus group: How much do you accept to increase the cost if R is reduced by 1?

A similar approach can be adopted to estimate w_b as it represents the answer to the question: how much should C be increased to justify an increase of one unit of B?

5. An application: the award criterion for the design contract of a new hospital

5.1 The application of MEAT in Portugal

The comparison between the number of competitive procedures that include the publication of a notice by TED and are awarded by the MEAT criterion in the EU and Portugal are presented in Figure 5. The results of Portugal are lower than the EU estimates for Services, but, on the other hand, the estimates for Public Works are significantly higher than those of the EU.

Figure 5 - Percentage of "works"(left) and "service" (right) contracts published in TED in which the awarding criterion was the MEAT in 2021

It should be noted that these estimates may be different if including contracts formed without prior notice published by TED. This is the case for Portuguese municipalities, as shown in Table 3, which is based on a sample of the four major contracts awarded by 18 Portuguese Municipalities.

Table 3 - Percentage of the four major contracts in eighteen Portuguese municipalities awarded by MEAT between 2018/2019 and 2020/2021

	2018 + 2019	2020 + 2021
Services	8%	32%
Public Works	19%	35%

These results confirm the need to propose models helping the public contracting authorities to generalize the adoption of the MEAT criterion, which is now more critical because public investment is supported by European Funds allocated through the so-called Recovery and Resilience Plan (Council of the European Union, 2021). This plan, which covers the period between 2022-2026 and includes a financial contribution of €16644 M, has approved regulations regarding the use of sustainability criteria (European Commission, 2021). The case of energy is also ruled by national legislation (Decree 101-D/2020), requiring that new public buildings should be NZEB (Nearly Zero - Energy Buildings) (see above §1).

5.2 The case of a new hospital in Portugal

The application of green procurement to public hospitals has deserved special attention due to its environmental, social, and economic importance (see Ng & Runeson, 2008, as well as Ziqi, 2011). The case study presented in this work concerns a new hospital in Seixal, a town located in the Lisbon Metropolitan Area, on the south bank of the Tagus River, about 25km from the city of Lisbon.

Seixal county has an area of 95.50km² and a population of 166,525 inhabitants requiring additional health services. This new hospital will be devoted to secondary health care, working in coordination with a tertiary hospital, *Hospital Garcia de Orta*, located in Almada (about 18km away). This new hospital will offer the following services:

a) External consultations;

b) Outpatient surgery unit;

c) Complementary means of diagnosis and therapy;

d) Basic Urgency;

e) Convalescence Care Unit.

The Functional Program (FP) is the document defining all the requirements and the expected objectives for the new building to be constructed. This FP defines a net built area of 10,865m² and an outdoor parking area of 3,750m². The net area can be converted into the gross area by using a conversion coefficient of 1.8 to include the circulation areas and walls, obtaining a value close to 12,000m² for the footprint area and 19,186m² for the total construction area plus 3,750m² for outdoor parking.

Assuming that the cost per m² is estimated at €1,100, an expense for the construction of the building of €21,104,160 is expected, and this cost should be added to €400,000 for outdoor parking, totaling around €21,504,160. The award criterion to be adopted follows the proposed model, so the procedure used to estimate each magnitude should be discussed.

a) Life cycle cost, DC

The discounted cost, DC, is estimated in terms of the contract price, P' and the discounted cost of the consumption of non-renewable energy, non-recycled water, and waste management, and so these three components should be discussed.

The estimation of consumption of non-renewable energy is obtained by subtracting from the estimated consumption (E_1) the renewable production mainly through solar (E_2) wind (E_3) and biomass (E_4). The estimation of E_1 is carried out by:

$$E_1 = E(ac) + E(shw) + E(light) + E(mt) + E(eq), \tag{5.1}$$

where $E(ac)$ is the consumption by airconditioned systems, $E(shw)$ is the consumption due to hot sanitary water, $E(light)$ is the consumption due to lighting, $E(mt)$ is the consumption due to transportation of materials and goods, $E(eq)$ is the consumption due to specialized health equipment. The consumption of water, W is estimated by:

$$W = W(O) + W(S) + W(H), \tag{5.2}$$

where $W(O)$, $W(S)$, $W(H)$ is the consumption due to irrigation of outdoor spaces, to sanitary and washing, and to human consumption, respectively. The fraction of recycled water (f) should be known, and so the non-recycled consumption (nf) is obtained by:

$$nf = (1 - f) * W. \tag{5.3}$$

Any discount sum implies adopting the life duration, a discounting factor, and the unit costs for the three studied magnitudes. Thus, they should be defined by the contracting authority.

b) Risks

The five major risks considered are:

R_1 – Life cycle risk due to fire;

R_2 - Life cycle risk due to cyber-attack;

R_3 - Life cycle risk due to mishandling of toxic or contaminated materials;

R_4 - Life cycle risk of bio-contamination;

R_5 – Life cycle risk of a power cut;

They will be estimated using the approach FMEA already presented. The assessment of each risk will be done by experts belonging to or supporting the jury of the contracting authority using a Lickert scale and Tables 4 to 6, which present the descriptions supporting the assessment of these risks.

Table 4 - Evaluation of the probability of occurrence

Level	Annual probability of occurrence
1	$\leq 1\%$
2	$1 < x \leq 3\%$
3	$3 < x \leq 5\%$
4	$5 < x \leq 7\%$
5	$> 7\%$

Table 5 - Magnitude of impacts

Level	Magnitude
1	Just minor effects in the hospital requiring repairs with a value less than 20000€, without affecting the hospital activities and without having injured people
2	Effects requiring repairs with a value greater than 20000€, without affecting the hospital activities and without having injured people

3	Effects affecting hospital activities for less than 5 days but without having injured people
4	Effects affecting hospital activities for 5 or more days but without having injured people
5	Effects including injured people

Table 6 - Possibility of detection before occurrence

Level	Degree of difficulty
1	In 90% or more of occurrences, it is possible to reduce the magnitude of impacts at least one level of Table 5
2	In 70% to 90% of occurrences, it is possible to reduce the magnitude of impacts at least one level of Table 5
3	In 50% to 70% of occurrences, it is possible to reduce the magnitude of impacts at least one level of Table 5
4	In 30% to 50% of occurrences, it is possible to reduce the magnitude of impacts at least one level of Table 5
5	In less than 30% of occurrences, it is possible to reduce the magnitude of impacts at least one level of Table 5

c) Benefits

The estimated benefits should account for the beneficial impacts above the required minimum levels of service, and so they will cover:

B_1 - Quality of access and parking;

B_2 - Quality of internal circuits;

B_3 - Quality of indoor comfort (temperature, humidity, and ventilation);

B_4 - Quality of the design in terms of the esthetical and environmental integration aspects;

B_5 – Quality of the design in terms of the functionality adaptation and flexibility defined by the ability to change each internal space function.

Each of these attributes will be assessed using a Lickert scale, and its assessment will be done by experts belonging to or supporting the jury using Tables 3 to 7, which present the description corresponding to each level of such scale.

Finally, $B = \sum \frac{B_i}{25}$, with $i = 1, \cdots, 5$, and so it is a standardized measure of the benefits ranging from 1 to 5.

Weights can be allocated to each component of B but they can also be considered equally important, which was the case, so their estimation will not be required.

Table 7 - Lickert scale for B1 criterion: Quality of access and parking

Level	Description
1	• Ineffective and unfunctional road routes; • The circulation routes for ambulances in emergency situations are not separated from other routes; • Pedestrian paths, although confusing, allow access to all entrances of the building, but they are not protected from road traffic; • There are fewer people entries in the hospital building than the expected objectives defined by the Functional Program (FP); • The parking areas do not meet the expectations defined by the FP.
2	Between 1 and 3
3	• Effective and functional road routes; • The circulation routes for ambulances in emergency situations are partially separated from the other routes, but there is the possibility of improvement without major changes to the proposal; • Pedestrian paths allow easy access to the different entrances of the building and are protected from road traffic, despite the coexistence of some unclear situations; • The number of people entries in the hospital is equal to the number defined by the FP; • The parking areas meet the requirements defined in the FP, although there is the possibility of improvement in terms of its organization, circulation, and access.
4	Between 3 and 5
5	• Easy, effective and functional road routes, with the connection between the origins and destinations points, thus contributing to a positive circulation flow; • The circulation routes for ambulances in emergency situations are totally separated from other routes, thus allowing clear and easy access to the emergency service; • Pedestrian paths are correctly separated and protected from road traffic and allow easy access to the different entrances of the building; • The number of people entries in the hospital is equal to the number defined by the FP, and they are functional and well located; • The parking areas meet the requirements defined in the FP, and they are easy to access and correctly organized, thus contributing to a good circulation of vehicles and people.

Table 8 - Lickert scale for B2 criterion: Quality of internal circuits

Level	Description
1	• Services accessibility is not clear, including cases with more than four negligent crossing between different services; • Overall circulation is not appropriate for the functionality of the building;

	• The number and type of vertical circulations axes are not sufficient, and they are not providing the separation between different flows; • Services are not organized logically and operationally according to the procedures and functions to be performed in each area; • The internal circuits are not well designed, including crossing between different circuits; • There is an insufficient specification of specialized functional areas; • Less than 20% of the areas belonging to the same cluster of adjacency are respected; • Less than 50% of the areas belonging to the same cluster of proximity are respected; • There is a shortage of signage in the building, and the existing one is confusing.
2	Between 1 and 3
3	• The direct access to all services is clear and distinct, presenting, however, 2 negligent crossings of other services; • Overall circulation enhances the good functioning of the building; • The number and type of vertical circulations axes are sufficient, but they are not strategically located and distributed and do not guarantee the separation between all flows; • Services are logically and operationally organized according to the procedures and functions to be performed in each area, but some of the services reveal the need for minor improvements; • The internal circulations promote adequate differentiation of circuits, presenting, however, some undesirable crossings that are easy to solve; • There is sufficient specification of specialized functional areas, although there is the possibility of improvement; • At least 50% of the areas belonging to the same cluster of adjacency are respected; • At least 80% of the areas belonging to the same cluster of proximity are respected; • There is sufficient signage in the building, but some are partially confusing.
4	Between 3 and 5
5	• The direct access to all services is clear and distinct, without any negligent crossing between other services; • Overall circulation is differentiated, allowing easy orientation and economy of routes, and contributing to the good organization of the building; • The number and type of vertical circulations axes are recommended, and they are strategically located and distributed, thus allowing a clear separation between all flows, the existence of escape routes, and the distance optimization between services; • Services are logically and operationally organized according to the procedures and functions to be performed in each area, thus increasing their overall efficiency; • Internal circulations promote adequate differentiation of circuits and avoid undesirable crossings; • All specialized functional areas are well specified; • All areas belonging to the same cluster of adjacency are respected; • All areas belonging to the same cluster of proximity are respected; • There is enough signage in the building, and it is all clear.

Table 9 - Lickert scale for B3 criterion: Quality of indoor comfort (temperature, humidity, and ventilation)

Level	Description
1	• The hospital building orientation does not optimize its solar exposure; • The location and dimensioning of the technical floor and technical areas (central technical equipment and ducts) are not the most convenient ones to cope with FP objectives; • The patios are poorly designed and landscaped; • The finishing options are not adequate to the FP; • The internal design does not promote a human and qualified environment.
2	Between 1 and 3
3	• The hospital building orientation partially optimizes its solar exposure, although there are some severe situations of compartments without natural light that can be modified; • The location and dimensioning of the technical floor and technical areas (central technical equipment and ducts) raise minor adequacy issues, easily corrected without major changes to the proposal; • The patios are well designed but poorly landscaped; • The finishing specifications are adequate to the FP, but they could be improved in terms of longevity and easiness of maintenance; • The internal design partially promotes a human and qualified environment.
4	Between 3 and 5
5	• The hospital building orientation perfectly optimizes its solar exposure. Thus there are no severe situations of compartments without natural lighting that can be modified, and the glazed areas provide solutions for reducing solar lighting; • The technical floor and technical areas (central technical equipment and ducts) are correctly located and dimensioned; • The patios are well dimensioned and landscaped, contributing to the quality of the environment of the hospital; • Finishing specifications are correct and contribute to longevity and ease of maintenance; • The internal design fully promotes a human and qualified environment, which also contributes to an adequate net area/gross area conversion index.

Table 10 - Lickert scale for B4 criterion: Quality of the design in terms of the esthetical and environmental integration aspects

Level	Description
1	• The hospital and external spaces are not integrated in terms of urban and visual perspectives; • There is a lack of quality concerning the coordination between the internal circuits and external road system; • The architectural options do not reflect the mission and nature of the building; • The architectural language that the building conveys leads to several misinterpretations regarding the type of use for which it is intended;

	• The proposed design does not fit into the topographic morphology.
2	Between 1 and 3
3	• The hospital and external spaces are partially integrated in terms of urban and visual perspectives with no physical or visual barrier between them and the surrounding environment; • There are some issues of concern in terms of the coordination between the internal circuits and external road system that can be improved without significant changes to the proposal; • The architectural options partially reflect the mission and nature of the building; • The architectural language that the building conveys does not promote a clear understanding of the type of use for which it is intended; • The proposed solution presents some incompatibility with the topography morphology, causing considerable earthworks.
4	Between 3 and 5
5	• The hospital and external spaces are fully integrated in terms of urban and visual perspectives, thus creating a harmonic environment between those areas and the surrounding ones; • The internal road system is correctly articulated with the surrounding road network, thus not disturbing or even improving the local road system; • The architectural options entirely reflect the mission and nature of the building; • The architectural language that the building conveys promotes a clear understanding of the type of use for which it is intended; • The proposed solution is fully compatible with the topography morphology, thus not requiring any earthworks.

Table 11 - Lickert scale for B5 criterion: Quality of the design in terms of the functionality adaptation and flexibility defined by the ability to change the functions of each internal space

Level	Description
1	• The proposed design does not facilitate changes of functionalities between different spaces because of the bad location of supporting systems (such as the technical floor); • The proposed design does not facilitate changes of functionalities between different spaces because of difficult rearrangement of separation between different units; • The proposed design implies an additional cost higher than 20% if an increase of 20% of the hospital services will have to be adopted in the future; • There is no ability to increase the net area with or without changing the perimeter, in height, or by annexes, without prolonged loss of functionality or prolonged constraint on the building.
2	Between 1 and 3
3	• The proposed design facilitates changes of functionalities between different spaces, although there are some losses of cohesion, or even the appearance of new constraints, for the services, due to bad location of supporting systems; • The proposed design facilitates changes of functionalities between different spaces despite the emergence of difficulties related to the new rearrangement that could lead to

	interventions in the structure of the building and/or special installations with some level of complexity; • The proposed design implies an additional cost between 10% and 15% if an increase of 20% of the hospital services will have to be adopted in the future; • The ability to increase the net area with or without changing the perimeter, in height, or by annexes, without prolonged loss of functionality or prolonged constraint of the building has been demonstrated.
4	Between 3 and 5
5	• The proposed design facilitates changes of functionalities between different spaces without the need for complex structural interventions or special installations due to the bad location of supporting systems; • The proposed design facilitates changes of functionalities between different spaces without any difficulties related to the new rearrangement; • The proposed design implies an additional cost lower than 5% if an increase of 20% of the hospital services will have to be adopted in the future; • The ability to increase the net area with or without changing the perimeter, in height, or by annexes, without loss of functionality or constraint of the building.

A team of experts should support the application of the presented model to each tender to provide an independent and objective estimation of each criterion.

6. Final remarks

The need to pursue green procurement in public works has been discussed and supported by a wide range of international institutions and authors, as reviewed in Section 1 of this paper. Still, the list of published evidence confirming its adoption in real cases is rather small. This contradiction may be due not just to its greater complexity compared to the traditional award criterion based on the minimal price but also to the lack of presentation of award criteria models applicable to different types of contracts.

Therefore, the authors presented a green award criterion for public works based on a multicriteria model based on three major perspectives: the life cycle discounted cost (LCC), the expected benefits (EB), and the assessment of the estimated risks (RI). The methodology of Cost-Benefit Analysis is relevant to support EB and RI estimation, and the authors adopted an adapted version of FMEA to estimate RI.

The proposed model fully complies with the principles and rules of European Public Procurement, as shown in section 2, avoiding the disrespect by such legal framework of other previous contributions, as is the case of Zhang, 2020.

The authors are successfully applying this model to a real and important case concerning the construction of a new hospital in Portugal supported by European Funds and having to comply with strict green requirements such as being an NZEB.

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