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A Case Study on Integrating an Eco-Design Tool into the Construction Decision-Making Process

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Abstract: To enhance the sustainability of construction and meet the sector's environmental agenda, it is essential to comprehensively scrutinize the environmental, social, and economic impacts of construction projects from the project's design stage. Such assessment is of utmost importance to minimize the impacts of both new construction and rehabilitation projects and is particularly critical during the selection of building materials and construction solutions. This work reports improvements in functionality and user-friendliness of an eco-design tool (UAveiroGreenBuilding) targeting the construction/rehabilitation sector and previously developed within our research group. The optimized version of the eco-design tool underwent validation through the assessment of competitive window frame materials (e.g., wood, PVC, and aluminum) for potential implementation in a rehabilitation project. Windows with PVC frames were identified as the preferred window configuration due to their superior environmental performance and favorable economic profile. Additionally, a digital communication interface was developed to connect the eco-design tool with building information modeling (BIM) projects, achieved through a routine integrated using a Dynamo application. Such successful integration not only streamlined and expedited the data transfer process by obviating the need for manual input but it also enabled the storage of environmental data throughout the life cycle of the project using a simple and reliable data storage protocol.

Keywords: eco-design tools; circular economy; environmental assessment; sustainable construction; BIM

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1. Introduction

The European Union aims to achieve climate neutrality by 2050 and has implemented several initiatives to stimulate the transition from a linear economy to a circular and knowledge-based development model, of which the European Green New Deal is the most ambitious and iconic example [1–3]. The European Green New Deal recommends that EU member states adopt a plethora of measures aimed at reducing greenhouse gas emissions and implementing regenerative actions to remediate past environmental hazards [3]. With similar goals, aiming to simultaneously provide economic growth and address societal challenges, the United Nations established 17 Sustainable Development Goals (SDGs) in 2015 to encourage the global adoption of environmentally responsible development models. Several Sustainable Development Goals (SDGs) are directly linked to the value chain of construction, which traditionally operates within a linear economic model characterized by high resource consumption and waste production [4–9]. Currently, the construction sector is accountable for extracting over 30% of the global natural resources, consuming approximately 34% of global energy, and using approximately 16% of all freshwater consumed [10,11]. In addition, the construction sector generates approximately 35% of all waste produced globally and around 40% of the anthropogenic greenhouse gas emissions [3]. Therefore, the construction sector will play a pivotal role in mitigating global warming and addressing societal distresses stemming from climate change [12–15]. For the construction sector to transition from a linear economic model, it is crucial to implement systematic eco-design assessments in construction projects [8,16]. When applying eco-design criteria, the environmental impacts of construction projects are evaluated alongside conventional decision-making factors such as cost, time, and quality of construction, aiming to maximize the project's overall efficiency during all stages of its life cycle [17,18]. However, to ensure the adoption of eco-design criteria, it is necessary to provide the industry with reliable assessment tools to enable assertive and effective decision-making based on clear, objective, and independent information regarding the performance of competitive construction solutions [19].

Environmental product declarations (EPDs) contain relevant information on the life cycle assessment (LCA) of construction materials and products, including resource consumption and environmental impacts generated throughout their life cycle [20]. LCA follows the European standard EN 15804:2013 [21], while the European standard EN 15978:2011 [22] prescribes the protocol for quantifying environmental indicators to be included in EPDs. Despite the relevance of the information contained in these documents, interpreting the information therein can be challenging for unspecialized professionals, often discouraging their use or resulting in erroneous analyses, thus compromising the decision-making process and potentially worsening the environmental and economic performance of construction projects [23]. Recently, some efforts have been devoted to developing environmental assessment tools based on EPDs and LCAs to facilitate the adoption of eco-design criteria in construction projects [24–26]. Bourgeois et al. [26] presented the preliminary results of an eco-design assessment tool that was developed in-house and based on EPDs and LCAs (UAveiroGreenBuilding project). This research reports on further optimization steps and validation through application of the developed tool to a real rehabilitation project.

Additionally, some authors have proposed the integration of environmental assessments into building information modeling (BIM) software [27,28] and, foreseeably, other virtual technologies such as computer-aided engineering, IoT, artificial intelligence, and virtual reality [29–31]. Such integration aims to facilitate information management and may eventually be associated with digital product passports (DPPs), which will be critically important for promoting digitalization and sustainability in construction [32,33]. Herein, the integration of the previously developed eco-design tool with BIM was also explored to further facilitate the tool's broader and more effective use in construction projects, with the ultimate goal of contributing to a more efficient, sustainable, and circular construction sector.

Therefore, this work herein reports the development of an efficient eco-design tool that facilitates informed decision-making during the design phase of construction projects and details a case study on window frames, recurrent in rehabilitation projects and crucial to the energy and environmental performance of buildings. In addition, this work demonstrates an innovative integration of an eco-design tool with BIM, introducing a promising research topic that is significant for advancement in the digitalization of the construction industry.

2. Methodology

2.1. UAveiroGreenBuilding Eco-Design Tool

2.1.1. Database Structure

Bourgeois et al. [26] developed a decision-support tool based on eco-design concepts to evaluate the environmental and economic performance of competitive building materials and construction solutions. The eco-design tool relies on mandatory information available in EPDs to ensure a good level of harmonization and data comparability. In addition, the exclusive selection of product-specific EPDs aimed to further limit the effects of uncertainties in the outputs. Future improvements to the eco-design tool may include uncertainty characterization, sensitivity analysis, and iterative refinements, which are, however, beyond the scope of this work. The database built includes environmental impacts, resource consumption, and potential end-of-life scenarios, determined according to EN 15804:2013 [21] and EN 15942:2021 [34].

Project-detailing information should be included in the new version of the tool, comprising:

- Code: an alphanumeric token (e.g., A11) should be created to identify each EPD. This token is essential for automating data transfer processes and communication with BIM.
- Case: information should be provided to identify the case study under analysis (e.g., window frame solutions).
- Material/solution: identification of the building material/construction solution (e.g., PVC window frame).

Environmental data collected from EPDs comprise fourteen indicators.

- Classification: materials should be classified as either new or repurposed/recycled.
- Program: the registration system where the EPD is deposited should be referenced (e.g., INIES).
- Registration code: the EPD and ECO Platform codes should be included for ease of traceability.
- Standard: the EN norm used to quantity environmental impacts should be disclosed. This information is of utmost importance, as environmental indicators determined as prescribed by EN 15804:2012+A1:2013 [21] and EN 15804:2012+A2:2019 [35] may not be comparable.
- Publication and expiration date: such information should be included to guarantee up-to-date data. A maximum timeframe of 2 years is recommended for accurate results. This information also provides a time reference for long-term data storage and future analysis.
- Manufacture and location: relevant information for traceability and determination of the environmental impact associated with transport operations. Herein, the manufacturers' details will be omitted, and commercial information will not be disclosed.
- Functional unit: a functional unit should be indicated and used to conduct unbiased comparisons of competitive materials and building solutions.
- System boundaries: systems boundaries should be disclosed, and equivalent boundaries should be considered when comparing competitive solutions. For example, a construction solution in which a significant number of environmental indicators are available should not be compared with an equivalent technical solution with only few indicators available (which, therefore, would risk compromising subsequent analysis of the results).
- Recycled material: the inclusion of recycled materials should be declared, and recycled materials should be identified.

2.1.2. Materials Input Flow

Information on input materials in construction must be provided to compare competitive solutions by product category. The data entered into the eco-design tool comprise several parameters extracted from the database structure by selecting the EPDs of the materials under analysis. The tool generates an Excel sheet compiling the information on environmental impacts, resource consumption, and potential output material flows. The collected data on environmental impacts and resource consumption are then normalized by dividing individual values by the maximum value observed among equivalent products in each impact category. This normalization step serves the purposes of standardizing all impact categories on a dimensionless scale ranging from 0 to 1, without being influenced by the nominal values and units of individual impact categories as present in the EPDs.

The normalized data are processed by the eco-design tool to generate radar charts for easy visualization of the environmental performance of different products and to calculate the overall impact area to provide a numerical indicator for comparison. In the current version of this tool, the impact areas and resource consumption areas were determined as proposed by [36], according to Equation (1):

$$\text{Total Area} = 0.5 * \sum_{i=1}^{n} r_i * r_{i+1} * sin\left(\frac{360}{n} * \frac{\pi}{180}\right) \tag{1}$$

where n stands for the number parameters, and r_i and r_{i+1} stand as the dimensionless values of adjacent environmental/resource consumption indicators.

The economic profile of competitive solutions was also examined by the eco-design tool by considering both acquisition and maintenance costs. Maintenance costs have been estimated over a pre-defined lifespan and by considering the periodicity and unit cost of maintenance actions according to Equation (2):

$$\text{Life cycle maintenance cost}(€) = \frac{\text{Cost per action}(€) * \text{Estimated life (years)}}{\text{Periodicity (years)}} \tag{2}$$

2.1.3. Materials Output Flow

The eco-design tool includes waste production assessment features for both the project and execution phases of construction works. Output materials coming out of the construction work should be recorded separately to allow the verification of the projected waste quantities upon project completion.

The assessment is performed considering the following material destinations: reuse, repair, recycling, energy recovery, and landfill. The quantities of each waste stream should be specified per destination. The total waste production and relative percentage per destination are computed automatically, and the tool generates radar charts for easy interpretation of waste destination distribution. This feature of the tool can be particularly useful for designing decommissioning and deconstruction plans, and can potentially be coupled with other innovative technologies (e.g., BIM, VR, IoT) [29–31], to elaborate detailed execution plans, further contributing to enhancing resource and economic efficiency, as well as maximizing the valorization of end-of-life materials.

2.2. Case Study

To test the eco-design tool, a partial rehabilitation of a building located at the University of Aveiro Campus, the Central Technical Area (CTA), was considered for this case study (Figure 1a). The CTA building was built in 1987 and basically consists of a reinforced concrete structure with masonry walls [37]. The selected case study considered the replacement of the existing window frames (263 m^2, Figure 1b) and examined three competitive alternative solutions: PVC, aluminum, and wood window frames. All windows considered in the project are located at ground level; therefore, specialized assembly methods and equipment were not considered in the analysis. In addition, to ensure an unbiased assessment of environmental and economic performance, competitive solutions with comparable U-values were selected: 1.30 $W/(m^2 \cdot K)$ for wood and PVC window frames; 1.80 $W/(m^2 \cdot K)$ for aluminum window frames. An exhaustive survey was conducted to identify aluminum frames with a U-value closer to 1.30 $W/(m^2 \cdot K)$; however, this was not feasible.

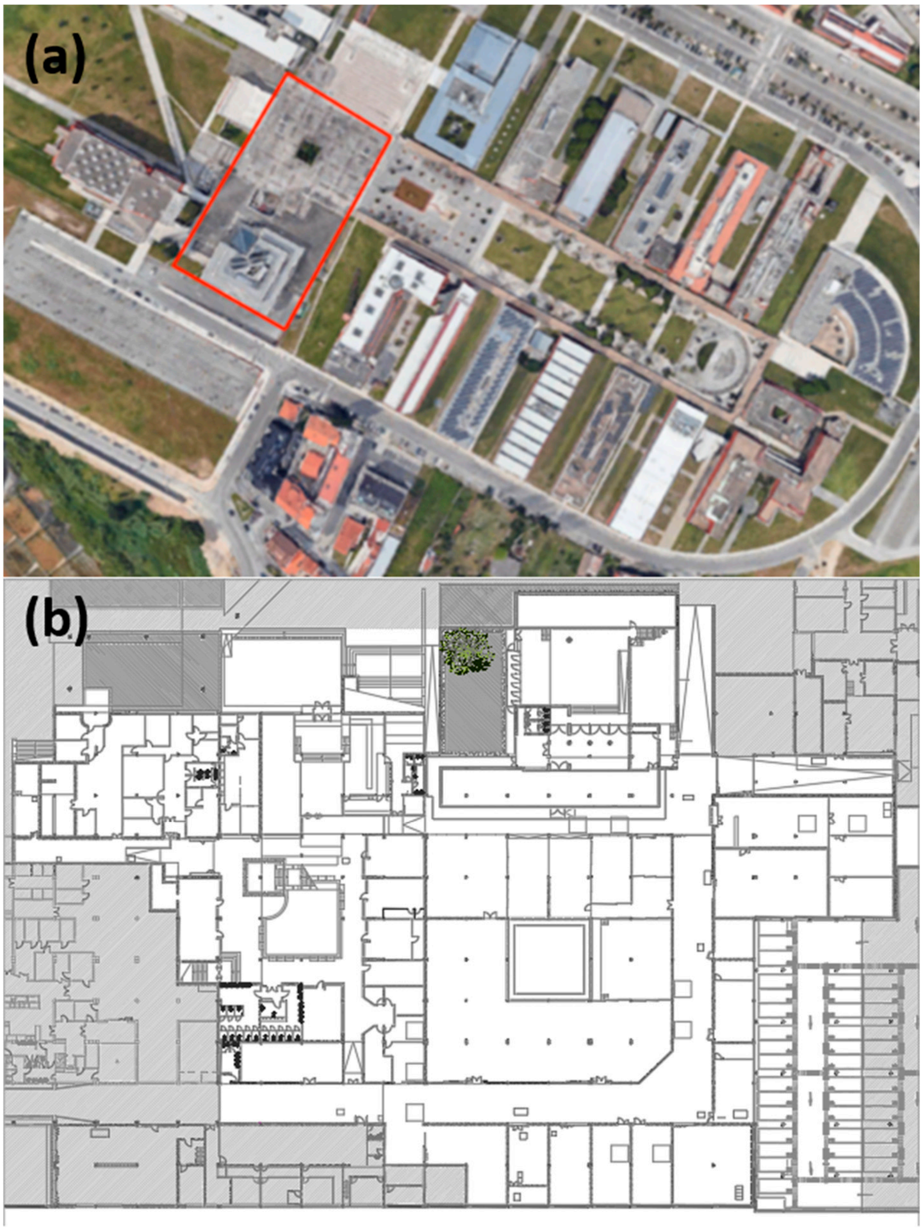


Figure 1. University of Aveiro Campus. (**a**) The red line highlights the Central Technical Area and (**b**) the plant of the Central Technical Area.

For each window frame material, three EPDs from the INIES platform (France) were selected as potential suppliers, and their impact indicators were examined using the developed eco-design tool. The best-performing solution for each window frame material was considered from the comparison of the alternative solutions.

Connectivity with Building Information Modeling (BIM)

The integration with BIM projects was designed by exporting the environmental data generated by the UAveiroGreenBuilding eco-design tool in "*.xls" format. Dynamo, a visual BIM programming application, was employed to create an ad hoc routine able to transfer extracted information for BIM of the construction solutions identified as optimal by the eco-design tool.

3. Results and Discussion

3.1. Case Study: Comparison of Window Frame Solutions

Tables 1–3 show data sourced from the EPD of the window frame solutions considered here. The three selected EPDs could be directly compared because they follow the same standard and possess the same functional unit and system boundaries (Table 1). In addition, the publication and expiry dates were consistent with the period of analysis (2023/2024). Table 4 shows the normalized environmental impacts of different window frame solutions. The normalized environmental impacts were computed by the eco-design tool, and the resulting radar chart can be seen in Figure 2.

Table 1. Sourced data of different window frame solutions.

Parameters	Case: Window Frame Material		
Code	A11	A22	A33
Material/solution	PVC	Aluminium	Wood
Classification	New	New	New
Registration program	INIES	INIES	INIES
DAP registration code *	-	-	-
ECO platform code *	-	-	-
Standard	EN 15804:2012+A1:2013 [21]	EN 15804:2012+A1:2013 [21]	EN 15804:2012+A1:2013 [21]
Publication date	January 2021	October 2022	November 2022
Expiring date	January 2026	October 2027	November 2027
Manufacturer *	A	B	C
Region	France	France	France
Description	PVC window frame	Aluminium window frame	Wooden window frame
Functional unit	m^2	m^2	m^2
System boundary **	A/B/C/D	A/B/C/D	A/B/C/D
Recycled materials	No	Yes	No
Incorporated recycled material	-	Aluminium	-

* Commercial details have been intentionally omitted by the authors. ** A—production stage and construction process stage; B—use stage; C—end-of-life stage; D—benefits and load.

Table 2. Environmental impacts of different window frame solutions.

Parameters	Case: Window Frame Material		
Code	A11	A22	A33
Material/Solution	PVC	Aluminium	Wood
GWP (kg CO_2 equiv.)	5.17×10^1	6.03×10^1	5.27×10^1
ODP (kg CFC 11 equiv.)	2.35×10^{-6}	5.57×10^{-6}	6.62×10^{-6}
AP (kg SO_2 equiv.)	2.65×10^{-1}	1.91×10^{-1}	2.03×10^{-1}
EP (kg $(PO_4)^{3-}$ equiv.)	4.70×10^{-2}	1.07×10^{-1}	7.11×10^{-2}
POCP (kg C_2H_4 equiv.)	1.34×10^{-2}	2.14×10^{-2}	1.40×10^{-2}
ADPE (kg Sb equiv.)	2.24×10^{-3}	1.28×10^{-3}	1.31×10^{-3}
ADPF (MJ, N.C.V.)	9.03×10^2	8.64×10^2	6.41×10^2

GWP—global warming potential—total; ODP—ozone depletion; AP—acidification; EP—eutrophication; POCP—photochemical ozone formation; ADPE—abiotic depletion potential—non-fossil resources; ADPF—abiotic depletion potential—fossil resources; N.C.V.—net calorific value.

Table 3. Resource consumption of different window frame solutions.

Parameters	Case: Window Frame Material		
Code	A11	A22	A33
Material/solution	PVC	Aluminium	Wood
TRR (MJ, N.C.V.)	5.17×10^{1}	6.03×10^{1}	5.27×10^{1}
TRNR (MJ, N.C.V.)	2.35×10^{-6}	5.57×10^{-6}	6.62×10^{-6}
MS (kg)	2.65×10^{-1}	1.91×10^{-1}	2.03×10^{-1}
CSR (MJ, N.C.V.)	4.70×10^{-2}	1.07×10^{-1}	7.11×10^{-2}
CSNR (MJ, N.C.V.)	1.34×10^{-2}	2.14×10^{-2}	1.40×10^{-2}
Use of net freshwater (m^3)	2.24×10^{-3}	1.28×10^{-3}	1.31×10^{-3}

TRR—total use of renewable primary energy resources; TRNR—total use of non-renewable primary energy resources; MS—use of secondary material; CSR—use of secondary renewable fuels; CSNR—use of non-renewable secondary fuels; N.C.V.—net calorific value.

Table 4. Environmental impacts after normalization of different window frame solutions.

Parameters	Case: Window Frame Material		
Code	A11	A22	A33
Material/solution	PVC	Aluminium	Wood
GWP (kg CO_2 equiv.)	0.86	1.00	0.87
ODP (kg CFC 11 equiv.)	0.35	0.84	1.00
AP (kg SO_2 equiv.)	1.00	0.72	0.76
EP (kg $(PO_4)^{3-}$ equiv.)	0.44	1.00	0.67
POCP (kg C_2H_4 equiv.)	0.63	1.00	0.65
ADPE (kg Sb equiv.)	1.00	0.57	0.58
ADPF (MJ, N.C.V.)	1.00	0.96	0.71

GWP—global warming potential—total; ODP—ozone depletion; AP—acidification; EP—eutrophication; POCP—photochemical ozone formation; ADPE—abiotic depletion potential—non-fossil resources; ADPF—abiotic depletion potential—fossil resources; N.C.V.—net calorific value.

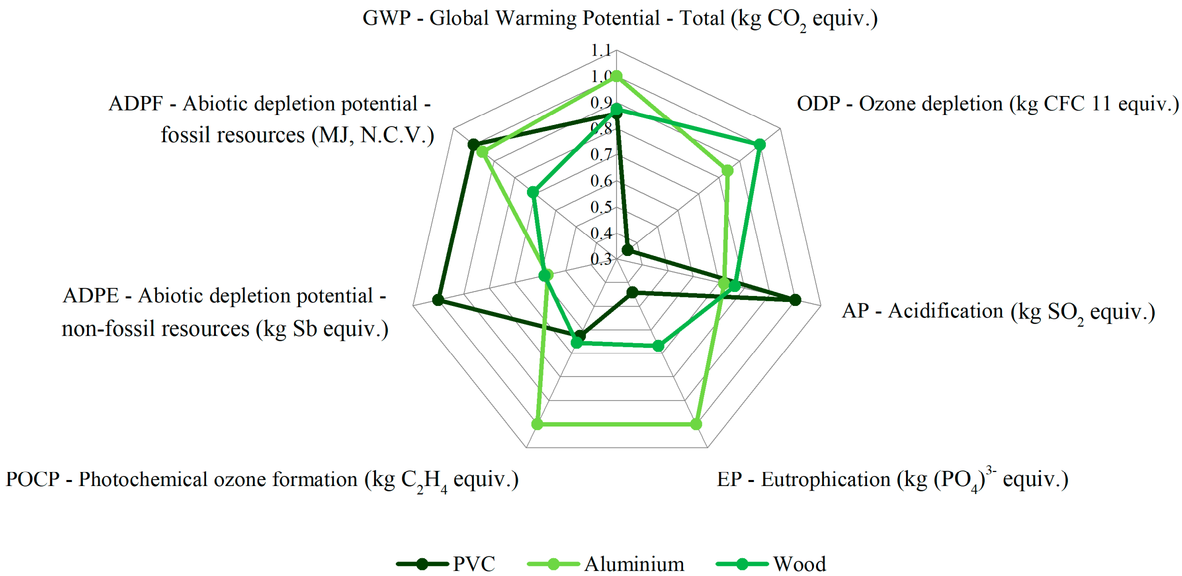


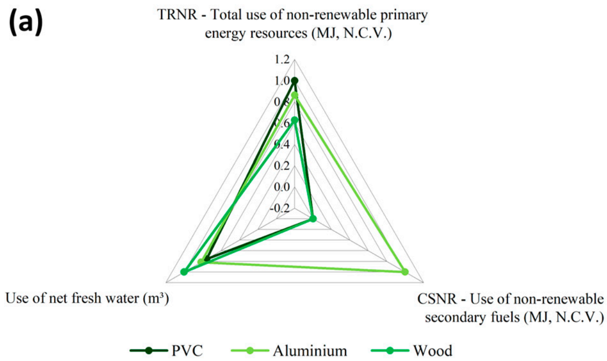
Figure 2. Normalized environmental impact of different window frame materials.

The results show that the different window frame solutions present very distinct impact profiles. Aluminium window frames display the highest global warming potential (GWP), eutrophication (EP), and photochemical ozone formation (POCP), whereas PVC and wood window frames presented the lowest impact in different impact categories. Aluminium window frames presented a total impact area of 2.05 m^2, while PVC and wood window frames display similar impact areas of 1.51 m^2 and 1.56 m^2, respectively. These results demonstrate that selecting aluminum window frames entails higher environmental impacts while, by choosing between PVC and wood window frames, one can obtain lower impacts. Table 5 shows the resource consumption normalized results as explained above in Section 2.1.2, as well as the consumption values of non-renewable and renewable materials, both shown in Figure 3. Aluminium window frames have shown the highest consumption of non-renewable resources (Figure 3a), in line with the environmental impact analysis. The normalized area was found to be 1.03 m^2, whereas significantly smaller areas were found for PVC and wood frames: 0.33 m^2 and 0.27 m^2, respectively. However, the consumption of renewable resources was naturally superior in wood frames (0.49 m^2), surpassing the resource consumption of both PVC (0.06 m^2) and aluminum frames (0.15 m^2). Despite the rather similar global environmental impacts of PVC and wood window frames, wooden frames are deemed preferable due to the primarily renewable nature of the resources consumed.

Table 5. Resource consumption after normalization of different window frame solutions.

Parameters	Case: Window Frame Material		
Code	A11	A22	A33
Material/solution	PVC	Aluminium	Wood
TRR (MJ, N.C.V.)	0.34	0.16	1.00
TRNR (MJ, N.C.V.)	0.86	1.00	0.63
MS (kg)	1.00	0.86	0.07
CSR (MJ, N.C.V.)	0.00	0.00	1.00
CSNR (MJ, N.C.V.)	1.00	0.00	0.00
Use of net freshwater (m^3)	0.82	0.76	1.00

TRR—total use of renewable primary energy resources; TRNR—total use of non-renewable primary energy resources; MS—use of secondary material; CSR—use of secondary renewable fuels; CSNR—use of non-renewable secondary fuels; N.C.V.—net calorific value.



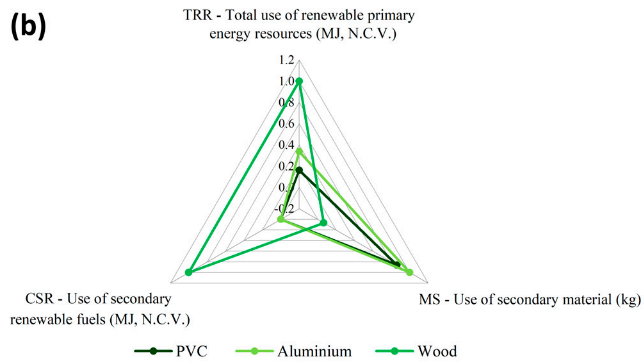


Figure 3. Normalized resource consumption of different window frame materials' (**a**) consumption of non-renewable resources and (**b**) consumption of renewable resources.

The eco-design tool was also embedded with a complementary board featuring the best-performing solution by parameter to provide users with a quick and easy method of evaluating specific parameters during the decision-making process. Table 6 summarizes the performance of the different window frame solutions assessed by impact category. As can be observed, wood and PVC windows are the best performing solutions in a similar number of impact categories (seven and six, respectively), whereas aluminum window frames only presented the best performance in three impact categories, namely acidification (AP), abiotic depletion potential—non-fossil resources (APDE), and use of secondary material (MS).

Table 6. Performance analysis of window frame solutions by impact category.

Parameters	Best Performing Solution
Global environmental impact	PVC
Global consumption of renewable resources	Wood
Global consumption of non-renewable resources	Wood
GWP (kg CO_2 equiv.)	PVC
ODP (kg CFC 11 equiv.)	PVC
AP (kg SO_2 equiv.)	Aluminium
EP (kg $(PO_4)^{3-}$ equiv.)	PVC
POCP (kg C_2H_4 equiv.)	PVC
ADPE (kg Sb equiv.)	Aluminium
ADPF (MJ, N.C.V.)	Wood
TRR (MJ, N.C.V.)	Wood
TRNR (MJ, N.C.V.)	Wood
MS (kg)	Aluminium
CSR (MJ, N.C.V.)	Wood
CSNR (MJ, N.C.V.)	PVC
Use of net fresh water (m^3)	PVC

The eco-design tool also provides information regarding possible output flows for the different window frame solutions at the end of life. Table 7 shows that all the solutions examined can be landfilled or recycled at the end of life, but only wooden frames can be used in energy recovery processes. This information is particularly relevant when analyzed in the regional context of a specific construction project for considering the availability of waste management facilities and recycling centers in their vicinity, thus minimizing transport-related environmental impacts and costs at the end of life.

Table 7. Prospective end-of-life valorization strategies.

Parameters	Case: Window Frame Material		
Code	A11	A22	A33
Material/solution	PVC	Aluminium	Wood
Reuse	-	-	-
Repair	-	-	-
Recycle	X	X	X
Energy recovery	-	-	X
Landfill	X	X	X

In addition to the environmental assessment, the eco-design tool also provides an economic assessment. The economic profile of different window frame solutions was examined in this case study by sourcing financial information from the CYPE Cost Estimator. The total acquisition cost of each solution was determined by multiplying the number of units by the unit cost (Table 8). Maintenance frequency and cost per maintenance action were also collected from the CYPE Cost Estimator and, along with the estimated service life retrieved from the EPD, used to estimate the life cycle maintenance cost (EUR) of each frame solution (Table 9).

Table 8. Acquisition cost of different window frame solutions.

Parameters	Case: Window Frame Material		
Code	A11	A22	A33
Material/solution	PVC	Aluminium	Wood
Functional unit	m^2	m^2	m^2
Units	263	263	263
Unit cost (EUR)	193.98	264.62	302.49
Total acquisition cost (EUR)	51,016.74	69,595.06	79,554.87

Table 9. Maintenance cost of different window frame solutions.

Parameters	Window Frame Material		
Code	A11	A22	A33
Material/solution	PVC	Aluminium	Wood
Action	General maintenance	General maintenance	General maintenance
Service life (years)	30	30	30
Maintenance frequency (years)	10	10	10
Cost per maintenance action (EUR)	4591.98	7655.93	19,888.06
Life cycle maintenance cost (EUR)	13,775.94	22,967.79	59,664.18

A graphic representation of the cost structure is generated by the tool for easy interpretation, as shown in Figure 4. The results of the case study under analysis show that PVC window frames present the lowest acquisition cost (EUR 51,016.74) and maintenance cost (EUR 13,775.94), representing an average total cost per year of EUR 2159.76 over the 30-year service life. Wooden window frames were found the least economically attractive option, with the highest acquisition (EUR 79,554.87) and maintenance costs (EUR 59,664.18), representing an average annual investment of EUR 4640.64. The economic results contrast with the environmental analysis, where wooden window frames were found to be the best-performing solution in the majority of the environmental indicators analyzed.

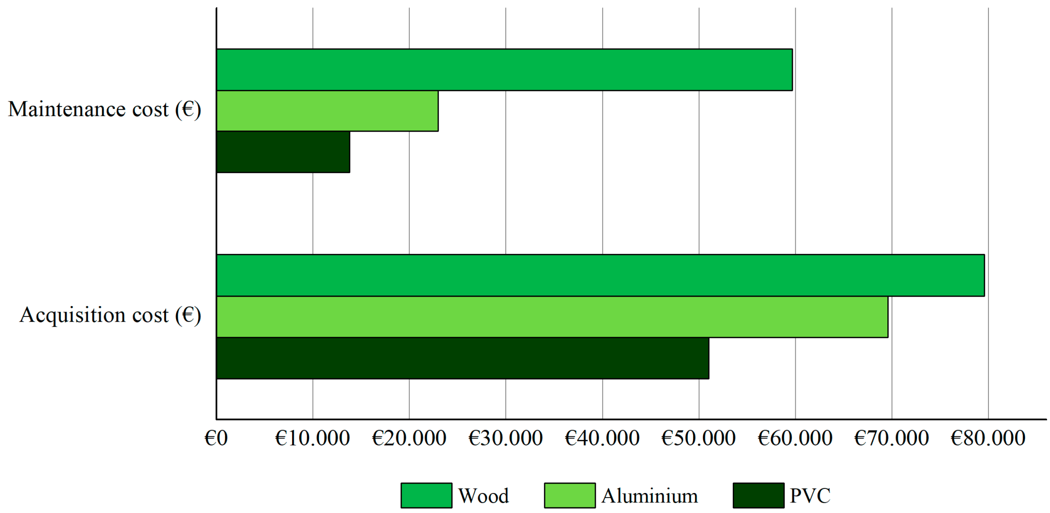


Figure 4. Economic assessment of different window frame solutions.

Therefore, it is clear that decision-making in this and other analyses can heavily rely on the relative importance that designers will attribute to environmental and economic performance. The new version of the tool includes a final overall assessment covering the environmental and economic dimensions, allowing the user to introduce weighting factors that reflect their relative importance. In this analysis, equal factors were assigned to environmental impacts (25%) and non-renewable resource consumption (25%), with their total equaling the factor attributed to the sum of acquisition and maintenance cost (50%).

The results shown in Table 10 suggest PVC window frames as the best solution among those considered for the CTA building renovation project due to their low associated costs and environmental performance that is comparable to wood frame windows. It should be noted that such an outcome could be modified if the user assigns considerably different weighting factors to the examined economic or environments aspects.

Table 10. Global performance indicators of different window frame solutions.

Parameters	Weighting Factors	Window Frame Materials		
Code		A11	A22	A33
Material/Solution		PVC	Aluminium	Wood
Acquisition & Maintenance costs	50%	0.47	0.66	1.00
Environmental impacts	25%	0.74	1.00	0.76
Non-renewable resources consumption	25%	0.32	1.00	0.26
Total classification	100%	23%	41%	35%

3.2. Communication with BIM

The communication or articulation of the eco-design tool output with BIM was engineered through a visual programming software application (Dynamo) of the BIM family. A routine was created to import information consisting of interconnections between predefined nodes existing in the software, represented by black boxes in Figure 5. Each node has connections, represented by lines, that allow data to be transferred. The nodes are divided either as "inputs" and "outputs", and the connection can only be established if the data are comparable. In Figure 5, five groups of nodes are represented by color, and each group is responsible for different tasks: (i) blue group: communication with the Excel tool; (ii) orange group: material category in BIM; (iii) pink group: communication of the code entered into the BIM; (iv) grey group: the values to be searched in Excel and BIM; and (v) green group: parameters to be filled in the BIM.

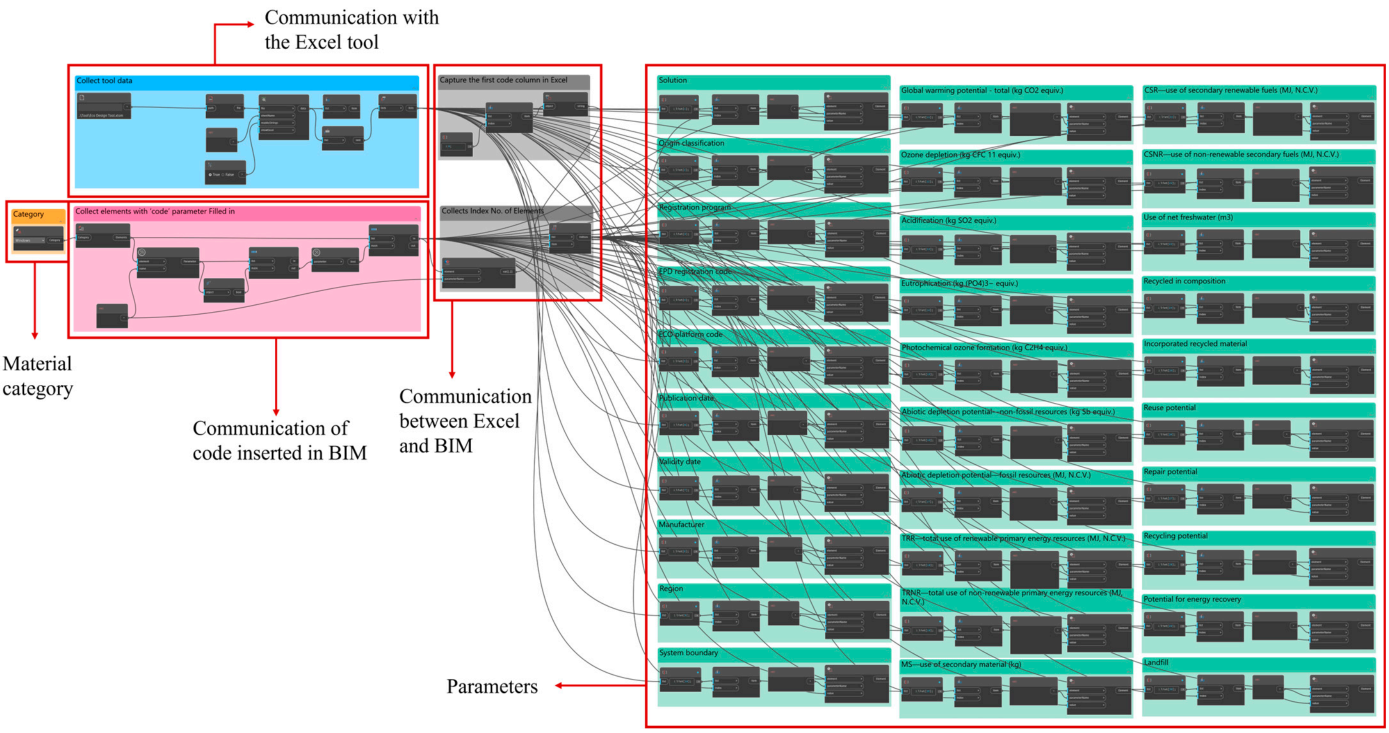


Figure 5. Dynamo routine structure.

To enhance communication, a summary spreadsheet was introduced in the tool to filter the most relevant parameters from the EPDs (Table 11). After selecting the preferred building solution, the user simply enters the associated code, and the information is automatically imported to BIM. Only two additional items must be indicated by the user prior to data import: the material category in the BIM (orange box) and the spreadsheet location (blue box). The material category must be modified according to the material being evaluated. The same parameters are then created in BIM as "Shared parameters", generating a "*.txt" file that can be easily related to any type of project or material in BIM (Figure 6a).

Table 11. List of parameters considered when connecting the UAveiroGreenBuilding project eco-design tool with BIM.

Parameter	Material
Code	-
Material/solution	-
Origin classification	-
Registration program	-
EPD registration code	-
ECO platform code	-
Publication date	-
Validity date	-
Manufacturer	-
Region	-
System boundary	-
Global warming potential—total (kg CO_2 equiv.)	-
Ozone depletion (kg CFC 11 equiv.)	-
Acidification (kg SO_2 equiv.)	-
Eutrophication (kg $(PO_4)^{3-}$ equiv.)	-
Photochemical ozone formation (kg C_2H_4 equiv.)	-
Abiotic depletion potential—non-fossil resources (kg Sb equiv.)	-
Abiotic depletion potential—fossil resources (MJ, N.C.V.)	-
TRR—total use of renewable primary energy resources (MJ, N.C.V.)	-
TRNR—total use of non-renewable primary energy resources (MJ, N.C.V.)	-
MS—use of secondary material (kg)	-
CSR—use of secondary renewable fuels (MJ, N.C.V.)	-
CSNR—use of non-renewable secondary fuels (MJ, N.C.V.)	-
Use of net freshwater (m^3)	-
Recycled in composition	-
Incorporated recycled material	-
Reuse potential	-
Repair potential	-
Recycling potential	-
Potential for energy recovery	-
Landfill	-

To validate the communication between the eco-design tool and the BIM, PVC window frames were selected, as they demonstrated the best overall performance. In the present case-study, the "Windows" category and the "A11" code were selected, as pre-defined earlier. The routine created in Dynamo was executed and the data imported automatically (Figure 6b). The routine developed in Dynamo allowed effective communication between the eco-design tool and BIM, enabling environmental data storage in BIM models associated with the case study under analysis. It should be mentioned that the data entered are not intended for calculations but rather for future memory, facilitating access to the information throughout the building's life cycle. This data storage method can also be useful in design maintenance, rehabilitation, and demolition actions and serve as a reference point given the continuous evolution of standards, materials, and EPDs.

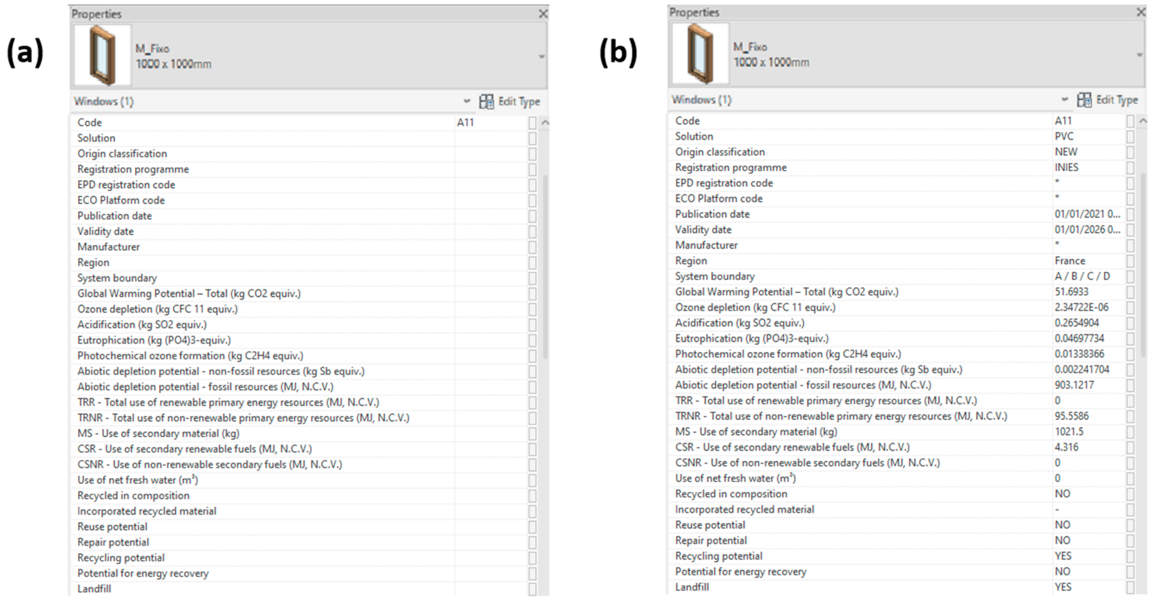


Figure 6. Parameters entered into BIM (**a**) and imported data after executing the developed Dynamo routine (**b**).

4. Conclusions

The aim of this work was to optimize, test, and validate an eco-design tool initially developed in the UAveiroGreenBuilding project. The tool is designed to incorporate eco-design concepts into decision-making for construction projects using information sourced from environmental product declarations (EPDs) and life cycle assessment (LCA) studies. The tool proved to be effective in processing data and providing easily interpretable outputs, enabling intuitive comparisons of the performance of competitive construction solutions.

Different window frame solutions considered in the rehabilitation of the Central Technical Area of the University of Aveiro were used as the case-study. PVC window frames were found to have the best overall performed due to their well-balanced environmental and economic profiles. However, the unavailability of Portuguese Environmental Product Declarations may limit the regional applicability of the gathered results, stressing the need for further incentives to publish EDP.

Communication with BIM was achieved via a Dynamo routine. The developed routine simplified and expedited the data transfer process, significantly improving the consistency and updating of BIM models while reducing manual labor and associated errors. Similar to BIM, the eco-design tool could be linked to digital product passports in the future, providing a comprehensive and detailed overview of the materials used in construction projects, as well as their environmental impacts and service performance throughout their life cycle. Continuing to develop the integration of digital tools in the building sector will further facilitate decision-making processes, increasing transparency and compliance with updated construction standards and ultimately contributing to a more efficient and sustainable construction sector.

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