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INTEGRATED SUSTAINABILITY ASSESSMENT USING BIM

Maria Teresa Henriques Alves Ferreira[a,*], António Aguiar Costa[b], José Dinis Silvestre[a]

[a] *University of Lisbon, Instituto Superior Técnico, Civil Engineering, CERIS, Av. Rovisco Pais 1, 1049-001, Lisbon, Portugal*

[b] *BUILT Colab, Collaborative Laboratory for the Digital Built Environment, Rua de Álvares Cabral 306, 4050-041 Oporto, Portugal*

[*] corresponding author: teresaferreira@tecnico.ulisboa.pt

Abstract. The construction industry is responsible for 40 % of the energy consumption and 36 % of the CO_2 emissions, and buildings are responsible for a significant part of energy consumption in Europe.

Thus, a growing concern regarding environmental impacts in the construction sector is in place. Reducing these impacts and optimise the design process is a major priority, and technology needs to be integrated along with the design to allow for better buildings performance. Building Information Modelling (BIM) methodology is one of the technologies that is revolutionising how the supply chain delivers the construction projects, allowing for an overview of the whole life cycle, keeping track of the data along the process, and potentiating more advanced simulations and supported decisions.

The tool proposed in this paper aims to integrate different types of sustainability analysis, namely Streamlined Life Cycle Assessment (LCA), Carbon Footprint, Life Cycle Cost (LCC) and Level(s) framework with BIM. This involves defining adequate Product Data Templates (PDT) and a database structure for BIM objects, including the necessary parameters to enable designers to do holistic and dynamic assessments from early design stages to a complete LCA. Also, considering the importance of using BIM to visualise different scenarios, a graphical interface will be developed to show the key sustainability indicators and support decision-making for more sustainable buildings. The results achieved show that technology must be taken to meet Climate most ambition targets and reduce the impact of construction.

Keywords: Building Information Modelling, sustainability, technology, Life Cycle Assessment, Life Cycle Cost.

1. Introduction

In line with the most ambitious targets established in Paris Agreement in 2015, EU Green Deal has an ambition of reducing carbon emissions by 55 % or more until 2030 and for Europe to be a climate-neutral continent by 2050 [1, 2]. Construction and retrofit of buildings cause substantial environmental impacts [3] due to their significant consumption of energy (40 %) and materials and energy-related greenhouse gas emissions (36 %) [4].

The application of environmental (LCA, including Global Warming Potential impact category) and economic (or Life Cycle Cost – LCC) Life Cycle Assessment (LCA) [5] to Construction are methodologies that: are recognized and standardized at the European level [6, 7], are becoming more and more important, and which are being increasingly used in this sector by experts and researchers. The Life Cycle (LC) paradigm emerges, and construction materials and buildings now represent the sum of all impacts and costs in the respective LC (no longer seen as individual impact and cost).

The construction industry plays a major role in the decarbonization process [3]. However, the lack of interoperability between EU targets for sustainability assessment and supply chain tools is a major issue in archive such important goals on climate issues.

In Figure 1 is shown a diagram of Circular Economy principles as a circle of interaction covering all LC stages of its analysis.

Applying Circular Economy principles (Figure 1), current research aims to use Sustainability indicators established in Level(s) Framework in a new construction case study. This is made by using a BIM Environment to complete both Economic and Environmental Assessment analyses.

Circular Economy principles and BIM (Figure 2) have a common ground in their Full LC approach, and this is seen by the authors as a huge advantage that should be merged contributing to digitalization and circularity development.

Level(s) is a common framework for sustainable buildings assessment across Europe, that has a whole LC approach. It considers measurement and improvement from design to end-of-life, covering both renovation and new construction [8].

Level(s) framework provides a common methodol-

Figure 1. Circular Economy Principles.

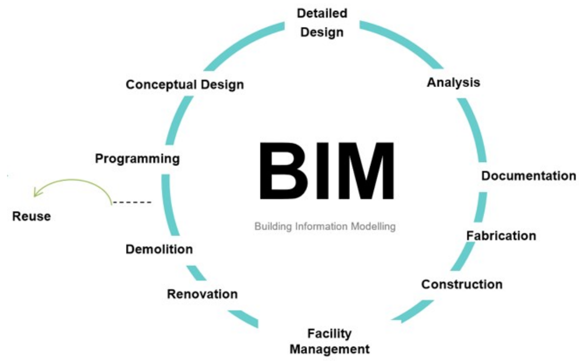

Figure 2. BIM – Full Life Cycle approach.

ogy for assessing the sustainability of buildings based on six macro-objectives. It contributes therefore to achieving EU and Member States policy goals in energy, material use and waste, water, and indoor air quality in an LC perspective [8].

Intending to bring buildings into the Circular Economy, Level(s) comprises a set of indicators, scenario tools, a data collection tool, checklists, and rating systems that allow professionals and project actors to measure buildings' performance [9].

The aim of this research is to aggregate green ambitions with technology by using Building Information Modelling (BIM) software to perform building environmental impacts and help supply chains to make their decisions through the full LC of the building, covering from early design stages decisions to the end of life. This was done by developing an LCA plugin for Revit software to perform LCA and LCC calculations, the plugin creates a set of parameters, each one representing an environmental or economic indicator, and does the calculation using the information and quantities from the BIM model.

2. Materials and Methods

In order to answer research questions and meet the defined goals, the plugin proposed integrates with BIM different types of sustainability analysis in its functionalities, namely Streamlined LCA, Carbon Footprint, and LCA in Level(s) framework. Economic analysis is also important and the parameter to measure LCC is also integrated into the plugin. To do so, it was necessary to develop an adequate Product Data Template (PDT) for BIM objects and construction elements, including the necessary parameters to enable designers to do holistic and dynamic assessments from early design stages to a complete LCA at the end of the design process. The objective is to give the user a set of options to perform environmental and economic calculations, nowadays there are different ways to archive so, the aim is to give the user different functionalities that correspond to different ways to get the LCA results for the user to choose the best one that fits its project objectives.

To perform an LCA based on Level(s) framework analysis, the corresponding indicators were studied to find which ones can be read within a BIM Environment, in BIM Object or elements, and possibly converted into parameters of analysis in the scope of LCA studies.

From the six Level(s) Macro objectives, the ones necessary for an LCA analysis were selected: objective 1 – Greenhouse gas emissions along building life cycle, covering LC Global Warming Potential; and objective 6, Optimized LCC and value. From the analysis of these macro-objectives, the following indicator was considered to do Level(s) LCA: Global Warming Potential (GWP) measuring the CO_2 emissions. To go further on the cradle to grave LCA analysis as recommended by EU [10] on the standard EN15804:2012+A2:2019 [11], the following indicators were also addressed: Abiotic Depletion Potential for fossil fuels (ADPE), Abiotic Depletion Potential of Materials (ADPM), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP), Water (user) deprivation potential, deprivation-weighted water consumption (WDP). To reach macro-objective 6 Optimized Life Cycle Cost and Value indicator, product and construction stages, use stage, and end of life stage, containing parameters for initial costs, annual costs, and periodic costs, were considered to measure LCC.

2.1. Plugin Functionalities

Mentioned indicators are read in the construction BIM elements/objects and can be analyzed directly within a BIM software. The BIM-based environment chosen to apply the plugin was Autodesk Revit.

Plugin functionalities were divided into four main topics, following the areas of research;

(I) Streamlined LCA;

(II) Carbon Footprint;

(III) Level(s) LCA;

(IV) Cost.

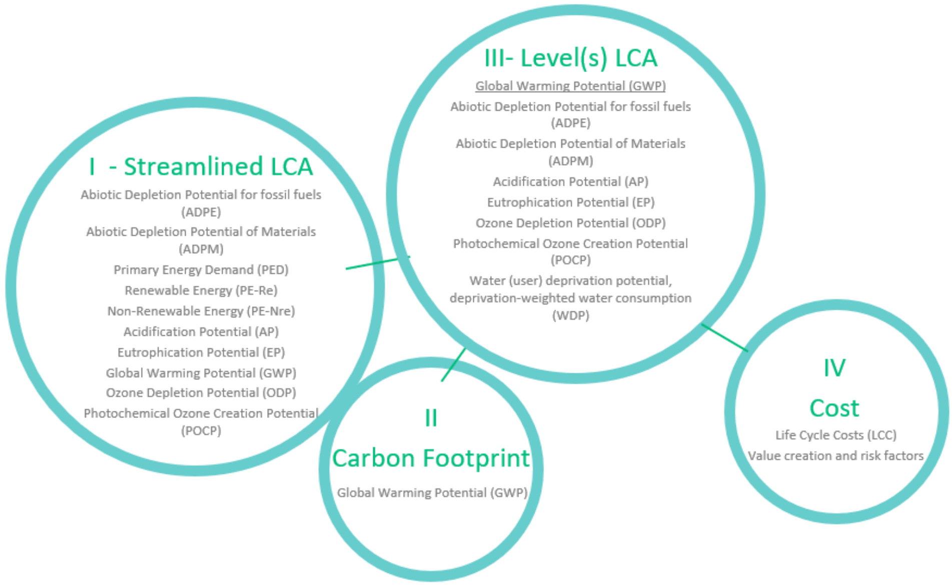

Figure 3. Plugin Functionalities with indicators.

In Figure 3 is possible to find core indicators per category of analysis. Those indicators will be converted to parameters to be read by Revit shared parameters.

2.2. Parametrization and Product Data Template (PDT)

The definition of an adequate PDT [12] structure for BIM objects was necessary to correctly convert indicators to parameters to be read in a BIM environment. Table 1 shows the proposed PDT including the new shared parameters with the objective of allocating the data need to perform the LCA calculations and analysis.

2.3. Framework for BIM LCA LCC Analysis

Tables 2–4 show LC stages for Production, Construction, Use and End of Life from A to D Modules.

The analytical calculation of the environmental impacts of the project on the production and construction phase (A1–A5 modules) is presented in Equation (1) [13]:

$$EI_x^{MC} = \overbrace{\sum_{a=1}^{i}(Q_a^M \times EI_a^M)}^{\text{Streamlined LCA A1–A3}} + \overbrace{\overbrace{\sum_{b=1}^{j}(D_b^V \times n \times EI_b^V)}^{\text{A4}} + \overbrace{\sum_{c=1}^{k}(Q_c^{Con} \times EI_c^{Con}) + L \times [A1 - A3]}^{\text{A5}}}^{\text{Complete LCA}}, \quad (1)$$

EI_x^{MC} environmental impact of category x resulting from the manufacturing and construction phase (A1–A5 modules);

i, j, k number of existing materials i, transportation j, and construction utilities k;

Q_a^M quantity of material a;

EI_a^M environmental impact (of category x) of material a;

D_b^V distance from the supplier to the construction site, multiplied by the number of travels (n);

EI_b^V environmental impact (of category x) of transportation b;

Q_c^{Con} consumption of utility c throughout the construction (e.g., electricity [kWh], gas [MJ], water [m^3]);

EI_c^{Con} environmental impact (of category x) of utility c;

L percentage of wasted materials during the construction phase.

The analytic calculation of the economic impacts of the project, on the production and construction phase

Indicator/ Parameter Name	Stream-lined LCA	Complete LCA	Level(s) LCA	Carbon Foot-print	Level(s) LCC	BIM Objects/ Elements	Project Details	Units
ADPE	x	x	x	-	-	x	-	MJ
ADPM	x	x	x	-	-	x	-	kg Sb eq
PE-Re	x	x	-	-	-	x	-	MJ
PE-NRe	x	x	-	-	-	x	-	MJ
AP	x	x	x	-	-	x	-	kg SO_2 eq
EP	x	x	x	-	-	x	-	kg PO_4^{3-} eq
ODP	x	x	x	-	-	x	-	kg R-11 eq
POCP	x	x	x	-	-	x	-	kg C_2H_4
WDP	-	-	x	-	-	x	-	m^3 world eq deprived
GWP	x	x	x	x	-	x	-	kg CO_2 eq
LCC-IC	-	-	-	-	x	x	-	€/m^2/yr
LCC-AC	-	-	-	-	x	x	-	€/m^2/yr
LCC-PC	-	-	-	-	x	x	-	€/m^2/yr
LCC-EoL	-	-	-	-	x	x	-	€/m^2/yr
Durability	-	x	-	-	-	x	-	yr
Density	-	x	-	-	-	x	-	$\rho = m/V$
Building's Service Life	-	x	-	-	-	-	x	yr
Transportation Type	-	x	-	-	-	-	x	
Transportation Distance	-	x	-	-	-	-	x	km
Utilities used	-	x	x	-	-	-	x	
Waste generated	-	x	x	-	-	-	x	

Table 1. Proposed PDT.

	Raw Material Supply	Transport	Manufacturing	Construction installation
Production	A1	A2	A3	-
Construction	-	A4	-	A5

Table 2. LC stages A Modules/Production & Construction Stages.

	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use
Use stage	B1	B2	B3	B4	B5	B6	B7

Table 3. LC stages B Modules/Use Stage.

	Deconstruction, demolition	Transport	Waste Processing	Disposal	Reuse, Recycling, or energy recovery potentials
End of Life stage	C1	C2	C3	C4	D

Table 4. LC stages C/D Modules / End of Life.

(A1–A5 modules) is presented in Equation (2):

$$C^{MC} = \overbrace{\underbrace{}_{}\sum_{a=1}^{i}(Q_a^M \times AC_a^M)}^{\text{Streamlined LCC A1–A3}} + \overbrace{\overbrace{\sum_{b=1}^{j}(Q_b^M \times C_b^{C2B}) + \sum_{c=1}^{k}(Q_c^{Con} \times C_c^{Con}) + L \times [A1 - A3]}^{\text{A5}}}^{\text{Complete LCC}}, \quad (2)$$

C^{MC} costs resulting from the manufacturing and construction phase (A1–A5 modules);

i, j, k number of existing materials i, j and construction utilities k;

Q_a^M, Q_b^M quantity of materials a or b used in the construction;

AC_a^M the acquisition cost of material a;

C_b^{C2B} cost to build/assemble construction elements (e.g., cost to apply $1\,\mathrm{m}^2$ of mortar);

Q_c^{Con} consumption of utility c throughout the construction;

C_c^{Con} cost of utility c;

L percentage of wasted materials during the construction phase.

3. Results

In this article was developed an innovative approach for a Level(s) LCA methodology analysis and its integration into a BIM Plugin.

In this way, Designers are enabled to perform a holistic and dynamic assessment from early design stages to a complete LCA, and rapidly visualize different scenarios, using core sustainability indicators.

The innovative nature of the approach of the current plugin is that Level(s) LCA framework is integrated into BIM and gives the users the possibility to choose which type of analysis they will want to perform, including Streamlined LCA, Carbon Footprint, Level(s) LCA and Cost (LCC) (Figure 4).

Also, considering the importance of using BIM to visualize different scenarios, a graphical interface was developed to show the key sustainability indicators and support decision-making for more sustainable buildings.

3.1. Buildings Assessment Information

An example of environmental information read in Revit regarding exterior double brick walls with insulation is illustrated in Figure 5. It is possible to see the shared parameters for the LCA analysis inserted in Revit. Figure 7 explains the workflow of the LCA plugin, per analysis, and shows the connections, once one analysis is finalized, to go further/ deeper in the LCA analysis.

Using the case study of a new family swelling, the authors ran the plugin for exterior walls. According to the workflow in Figure 7, the first step is to choose the stage of the project development, either Conceptual Design (Level 1) or Detail Design (Level 2) stages. If level 2 is chosen, then the user is asked which functionality of the plugin he would like to perform (Figure 4). If he chooses, for example, Level(s) LCA, the shared parameters corresponding to the environmental indicator of analysis, Table 1, are loaded into the BIM Model and the data from the database is loaded to the project to be assembled to the correspondent elements, for example, a wall, Figure 5. The environmental data is stored in the properties of the BIM family and read also in the plugin. The next step is to perform the corresponding calculations, which are done automatically by the plugin following analytic models presented in Section 2.3; for this example Equation (1) is being used. Results can be exported both to excel and 3D visualization with a colour scheme, as presented in Figure 6 for the exterior walls sample.

4. Discussion

The potential of disruptive technologies, such as Building Information Modelling (BIM), changes how the assessment of its sustainability is conducted [14].

LC existing tools/platforms for BIM available in the market that integrate sustainability analysis for building Design were already analyzed by the authors, i.e. Tally and One Click LCA. From that analysis, several gaps, lack of interoperability between tools, limited parameters of analysis, limited databases, and lack of BIM libraries were found.

Regarding the Digitalization of Construction, the development of the proposed methodology and tool is fundamental to supporting the performance-driven architectural design of buildings [15]. Following the results presented, the authors believe that a user-friendly tool to make simulations of different sustainability analyses helps Designers and supply chains to make choices with lower environmental impact. The time and effort of Level(s) LCA are reduced, and a graphic user interface would provide the decision-making support for the design of sustainable buildings.

For future research, the idea is to build a plugin that is flexible enough to address new indicators and analysis in its functionalities and also remove the

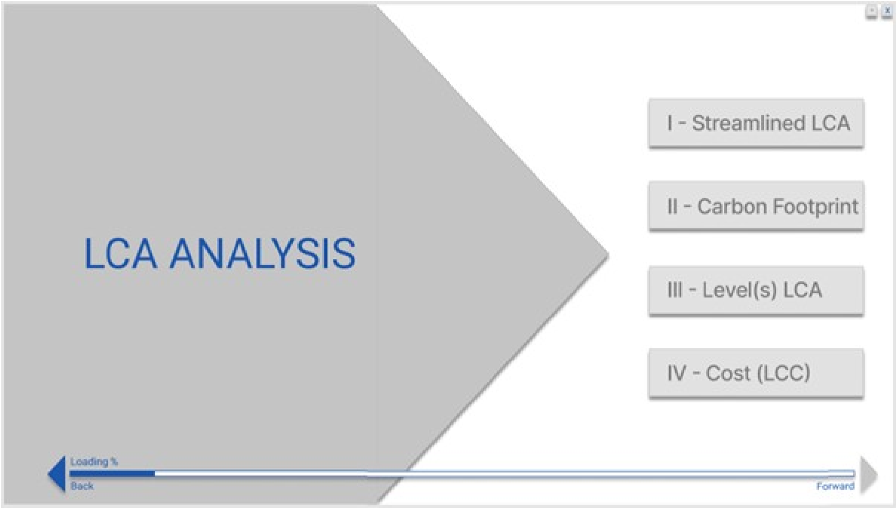

Figure 4. Plugin functionalities options.

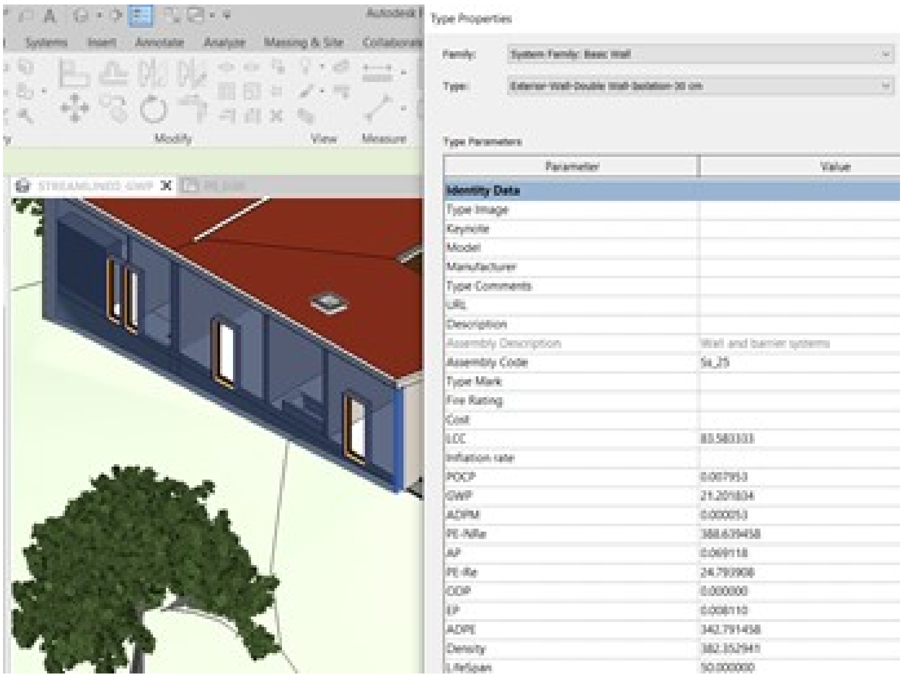

Figure 5. Environmental Impacts incorporated in shared parameters of a wall in Revit.

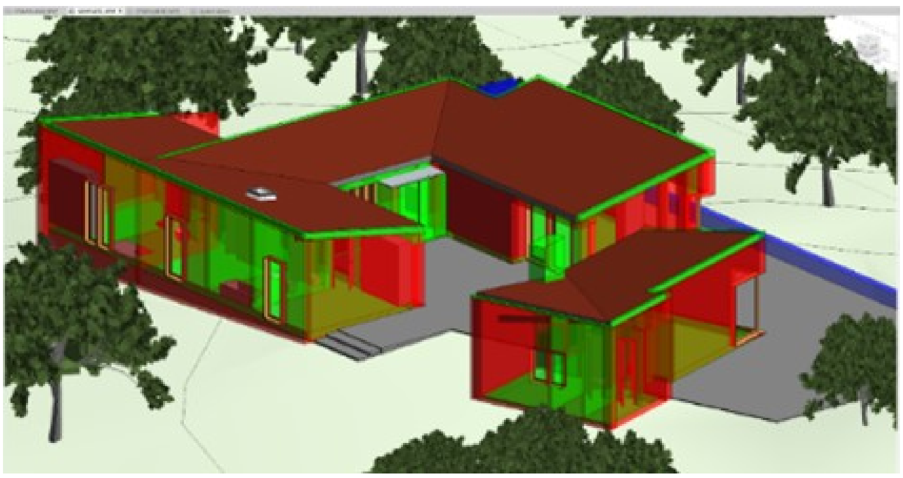

Figure 6. Level(GWP) analysis complete 3D results for a wall.

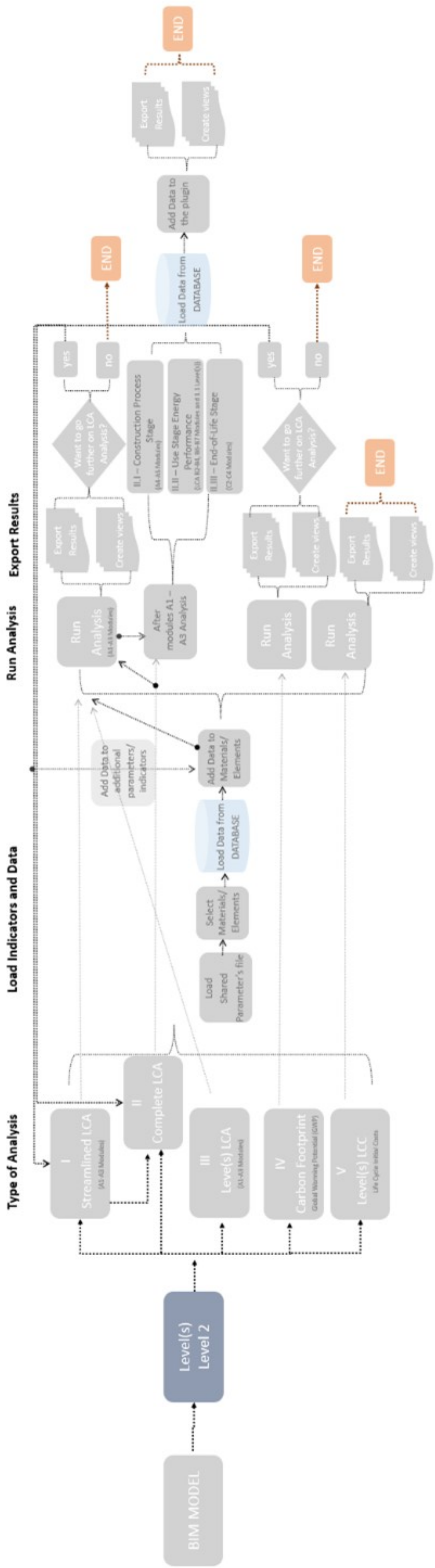

Figure 7. Workflow scheme of the LCA Plugin.

ones that with the following developments will be made redundant. It is also possible to expand the proposed methodology to assess other methods such as LEED, BREAM, WELLS, or others but some of them have methods of analysis not quantitative and that is a limitation to where this plugin can automatically grow and specified engineering consultants is required to fulfill all the requirements of specified schemes.

5. Conclusion

The application of BIM can simplify Level(s) implementation by systematizing the approach and accelerating access to data.

The integration of different types of sustainability analysis, namely Streamlined LCA, Carbon Footprint, LCC, LCA/ Level(s) framework, and LCC with BIM enable Designers and the Construction industry to easily integrate and see the environmental impacts of their buildings, and possible study better alternatives and actively collaborate to reduce the impact of the construction industry on the important Climate Change issues.

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References

[1] EC. Communication from the European Commission: A renovation wave for Europe – Greening our buildings, creating jobs, improving lives, 2020. COM(2020)662. Brussels, Belgium.

[2] EC. Renovation wave, 2021. [2021-03-11]. https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

[3] EC. Communication from the European Commission: The European Green Deal, 2019. COM (2019) 640, Brussels, Belgium.

[4] EC. Energy efficiency – Revision of the Energy Performance of Buildings Directive, 2010. [2020-03-11]. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12910-Revision-of-the-Energy-Performance-of-Buildings-Directive-2010-31-EU

[5] R. Santos, A. A. Costa, J. D. Silvestre, et al. BIM-based life cycle assessment and life cycle costing of an office building in Western Europe. *Building and Environment* **169**:106568, 2020. https://doi.org/10.1016/j.buildenv.2019.106568

[6] CEN. Sustainability of construction works – Assessment of buildings - Part 2: Framework for the assessment of environmental performance. EN 15643-2., 2011. Comité Européen de Normalisation, Brussels, Belgium.

[7] CEN. Sustainability of construction works – Assessment of buildings - Part 4: Framework for the assessment of economic performance. EN 15643-4, 2012. Comité Européen de Normalisation, Brussels, Belgium.

[8] EC. *Level(s), Putting whole life carbon into practice.* Publications Office of the European Union, 2021. https://doi.org/10.2779/79139

[9] EC. *Level(s), Putting circularity into practice.* Publications Office of the European Union, 2021. https://doi.org/10.2779/19010

[10] N. Dodd, S. Donatello, M. Cordella. Level(s) indicator 1.2: Life cycle global warming potential user manual: overview, instructions and guidance (publication version 1.0), 2020.

[11] EN15804:2012+A2:2019, Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products.

[12] M. Signorini, S. Frigeni. *Development of a BIM-based product data template for sustainability.* Master's thesis, Politecnico di Milano, ARC I – Scuola di Architettura Urbanistica Ingegneria delle Costruzioni, 2018. http://hdl.handle.net/10589/143041

[13] R. Santos, A. A. Costa, J. D. Silvestre, L. Pyl. Integration of LCA and LCC analysis within a BIM-based environment. *Automation in Construction* **103**:127–149, 2019. https://doi.org/10.1016/j.autcon.2019.02.011

[14] R. Santos, A. A. Costa, J. D. Silvestre, L. Pyl. Informetric analysis and review of literature on the role of BIM in sustainable construction. *Automation in Construction* **103**:221–234, 2019. https://doi.org/10.1016/j.autcon.2019.02.022

[15] X. Shi, W. Yang. Performance-driven architectural design and optimization technique from a perspective of architects. *Automation in Construction* **32**:125–135, 2013. https://doi.org/10.1016/j.autcon.2013.01.015