A workflow to integrate operational and embodied aspects when implementing Life Cycle Sustainability Assessment in Building Information Modelling

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Abstract. The existing environmental crisis demands increased efforts to design more sustainable buildings, which means the simultaneous balance between environmental preservation, economic growth, and social well-being. This challenging objective requires holistic methods that enable a comprehensive, multi-dimension, and quantitative approach such as allows the Life Cycle Sustainability Assessment (LCSA). In addition, the existing context of digital transformation in the construction and building sector is increasing the use of digital tools based on the BIM methodology to support the assessment process and integrating more dimensions to guide decision-making. The present work presents a workflow that enables the calculation of the LCSA including operational and embodied aspects. The workflow proposes the building elements that should be included in the BIM model to enable the exchange of information. The workflow is focused on the Spanish context and includes the use of Revit (as BIM modeler), Dynamo (as LCSA tool), Cypetherm (as the energy demand calculator). The proposed workflow enables us to compare different design options and building materials without much effort. The study includes findings and recommendations to reduce the effort when implementing the LCSA at the early design stages.

1 Introduction

During the last decades, several national building design regulations (for example, in Spanish [1]) and sustainable systems certification (such as LEED [2]) have focused on reducing operational energy consumption during the building design process. However, current challenging objectives such as the UN Sustainable Development Agenda [3] and the decarbonisation objectives [4] require integrating other aspects and impacts such as the embodied environmental impact and other dimensions such as economic and social. To overcome these objectives, the Life Cycle Sustainability Assessment (LCSA) is proposed as a framework that simultaneously integrates environmental, economic, and social assessments. Promoted by the Life Cycle Initiative [5–7], the LCSA is defined as the sum of

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the Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (S–LCA). Conceived as a combination of different techniques with different levels of maturity and data availability [8], the application of LCSA to complex products can be difficult. Buildings as complex products present several limitations. Therefore, the application of LCSA in the construction sector during the design stages and integrated into the design tools is still scarce [9]. However, its implementation to assess the embodied aspects using Building Information Modelling (BIM) models has been validated [10,11], but the evaluation of operational aspects and the definition of workflows that comply with the current Spanish energy assessment regulation has not been addressed in the literature.

1.1 Goal of the study

The study proposes a BIM-based workflow that integrates the information and modelling requirements (input and outputs) to simultaneously perform the assessment of the embodied and operational aspects of a building envelope using a Life Cycle Sustainability Assessment (LCSA) method based on an element approach [12].

2 Workflow Description

2.1 Description of the method

To achieve this objective, a framework is proposed to be used in the building design process. It definition is based on previous studies in this field [13–15], integrating three main modules: background data, modelling, and calculation. Using a BIM model and a combination of different software to conduct the LCSA calculation, four steps are proposed, including the input information to define the building geometry, to conduct the LCSA calculation, and to obtain the LCSA results.

The design of this framework focuses on the envelope design, where assessing the balance between the operational and embodied aspects is significant [16]. The methodological framework to implement the LCSA in BIM bases on previous studies in this filed [9–11]. The system boundaries of the LCC, LCA and S-LCA includes the product and construction stages (A1-A3 and A5). It focuses on providing a harmonised framework to simultaneously conduct the triple dimension assessment, considering harmonised data sources for that purpose. However, due to the data availability there are slight differences in the system boundaries of them, which is consistent with previous studies [6,9].

Step 1: Input information to define the building

The BIM model (building project), is developed in the Autodesk 2021 REVIT BIM software [17], and integrates the geometry modelling of the building systems to be analysed: the structure (including columns, beams, slabs, foundations), the envelope (including walls, roof, slabs, windows, doors, and internal walls in a 200 LOD (Level of Development) [18]. Moreover, the BIM model definition includes the definition of zones, including tags, and their function in the building (e.g., kitchen, living room).

Step 2: Input information to conduct the LCSA (Embodied and Operational aspects)

Step 2.1: Input_Operational Impact Calculation

The operational impact calculation is conducted based on the building energy demand. To this end, the BIM model defined in Step 1 is exported to the IFC format using the IFC file export-import platform, BIMserver.centre [19]. The platform is linked to the CYPETHERM
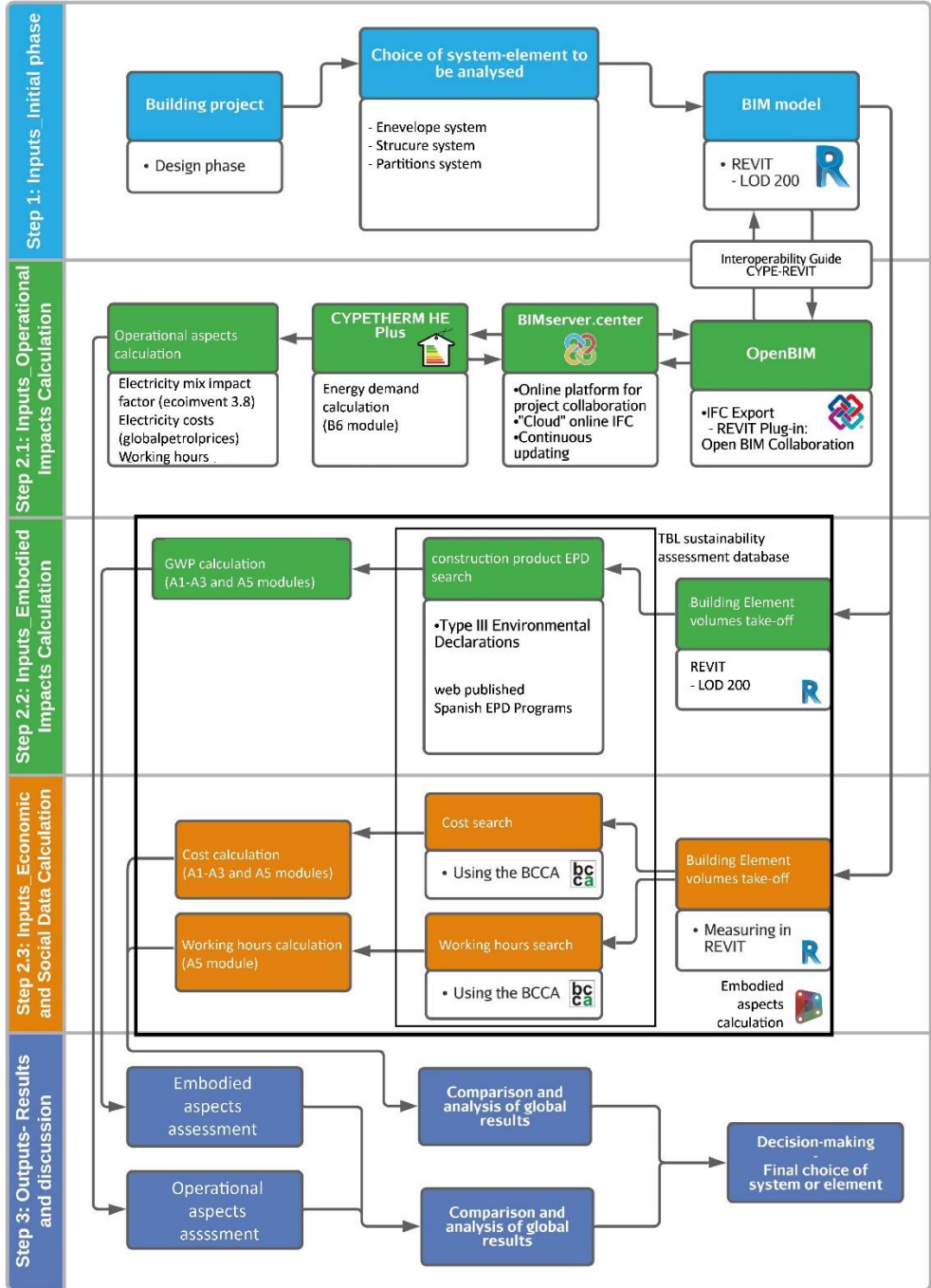
Figure 1. Schematic of the workflow and information requirements.

HE Plus calculation software to obtain the annual operational energy demand. The software automatically extracts geometry information from the IFC model (about the walls, roof, slabs, windows, doors, internal walls, and zones). Nevertheless, the detailed information about the building materials and the building usage profile are manually inserted by the user. The operational environmental impacts are calculated using the energy demand multiplied by the electricity production factor extracted for Spain (extracted from ecoinvent 3.8 [20]). The operational cost is calculated using the electricity cost from official sources [21].

Step 2.2: Inputs_Embodied Impact Calculation

The embodied aspects calculation is conducted using a visual programming language Dynamo (Autodesk Revit 2021) Script, which has been previously addressed to calculate embodied energy and embodied carbon [22]. The present work integrates the background information (including environmental, economic, and social indicators) with the BIM model building element volume quantity take-off. The environmental data on the building material are extracted from geographically representative construction products EPDs (Environmental Product Declaration), developed according to the EN 15804 [23] standard and web-published in Spanish EPD Programs (EPD International, DAPconstrucción and GlobalEPD). The economic and social data are extracted from the BCCA [24] (Andalusian Construction Cost Base). The information about the environmental impacts and economic cost has been collected and organized in a Triple Bottom Line Data Base (TBL) [9] that follows an element classification [12]. The Dynamo Script uses the TBL database as data input to enrich the BIM model information.
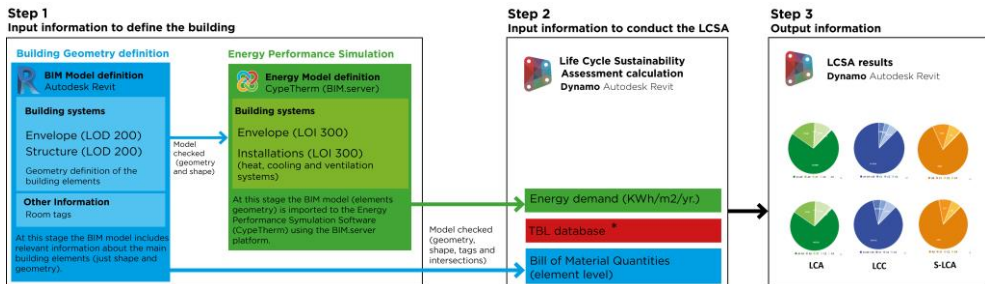

Figure 2. Schematic of the steps and main information.

Step 3: Output information

LCSA results (graphics) are shown in real time, integrating the embodied and operational aspects (see Figure 2). This step enables us to compare and identify the building design option that produces the lowest environmental impacts, costs, and social (footprint and handprint).

3 Conclusions

This paper presents a conceptual structure and demonstrates the utility of the BIM model to perform the LCSA, including embodied and operational aspects calculation in compliance with the current Spanish technical regulation. The paper shows the steps followed to simultaneously calculate and visualize the results of environmental, economic, and social assessments using two main software, Autodesk Revit (Dynamo) and CYPETHERM HE

Plus, and based on a 200 LOD BIM model (integrating the geometry definition of the envelope and structure). The BIM model can be automatically imported to the Energy Performance Simulation and re-imported to Autodesk Revit. The current study was limited to consider one indicator per dimension to demonstrate it feasibility. However, to enrich the indicators the same procedure could be used. New impact categories (environmental, economic and social) can be included the TBL database and linked them to BIM model element volumes using the Dynamo Script. Future research can focus on validating the workflow application in different case studies.

References

[1] CTE, Spanish Building Technical Code, Real Decreto 314/2006 17 Marzo. BOE 74 (2006) 11816–11831. doi:CTE-DB-SE.

[2] S. Kubba, LEED v4 Practices, Certification, and Accreditation Handbook: Second Edition, 2015. doi:10.1016/C2015-0-00887-5.

[3] UN - United Nations, The Sustainable Development Goals Report 2019, 2019.

[4] European Commission, European Parliament, The European Green Deal, Eur. Comm. (2019). doi:10.1017/CBO9781107415324.004.

[5] M. Finkbeiner, E.M. Schau, A. Lehmann, M. Traverso, Towards life cycle sustainability assessment, Sustainability. (2010). doi:10.3390/su2103309.

[6] Valdivia S, C. Ugaya, G. Sonnemann, J. Hildenbrand, (eds), Towards a Life Cycle Sustainability Assessment. Making informed choices on products., Paris, 2011.

[7] W. Kloepffer, Life cycle sustainability assessment of products (with Comments by Helias A. Udo de Haes, p. 95), in: Int. J. Life Cycle Assess., 2008. doi:10.1065/lca2008.02.376.

[8] S. Valdivia, · Jana, G. Backes, M. Traverso, · Guido Sonnemann, S. Cucurachi, J.B. Guinée, T. Schaubroeck, M. Finkbeiner, N. Leroy-Parmentier, · Cássia Ugaya, C. Peña, A. Zamagni, A. Inaba, M. Amaral, M. Berger, J. Dvarioniene, T. Vakhitova, C. Benoit-Norris, M. Prox, · Rajendra Foolmaun, · Mark Goedkoop, Principles for the application of life cycle sustainability assessment, Int. J. Life Cycle Assess. 26 (2021) 1900–1905. doi:10.1007/s11367-021-01958-2.

[9] C. Llatas, B. Soust-Verdaguer, A. Passer, Implementing Life Cycle Sustainability Assessment during design stages in Building Information Modelling: From systematic literature review to a methodological approach, Buiding Environ. 182 (2020). doi:10.1016/j.buildenv.2020.107164.

[10] C. Llatas, B. Soust-Verdaguer, A. Hollberg, E. Palumbo, R. Quiñones, Developing a BIM-based Life Cycle Sustainability Assessment application in the early design stages using Industry Foundation Classes, Autom. Constr. (Under Rev (2021).

[11] B. Soust-Verdaguer, I. Bernardino Galeana, C. Llatas, M. V. Montes, E. Hoxha, A. Passer, How to conduct consistent environmental, economic, and social assessment during the building design process. A BIM-based Life Cycle Sustainability Assessment method., J. Build. Eng. (2021).

[12] T. Lützkendorf, Application of "Element"-Method in Sustainability Assessment, in: Cent. Eur. Towar. Sustain. Build. 2019, 2019: pp. 1–8.

[13] B. Kiss, Z. Szalay, Modular approach to multi-objective environmental optimization of buildings, Autom. Constr. 111 (2020) 103044. doi:10.1016/j.autcon.2019.103044.

[14] B. Kiss, M. Röck, A. Passer, Z. Szalay, A cross-platform modular framework for building Life Cycle Assessment, in: Sustain. Built Environ. D-A-CH Conf. 2019, 2019: pp. 1–10.

[15] C. Llatas, R. Angulo Fornos, N. Bizcocho, I. Cortés Albalá, R. Falcón Ganfornina, I. Galeana, A. García-Martínez, J.C. Gómez de Cózar, S. Alonso López, P. Meda, J.M. Mercado Martínez, M. V Montes, R. Periañez Cristobal, R. Quiñones, T. Rojo, C. Rubio-Bellido, M. Ruiz Alfonsea, B. Soust-Verdaguer, Towards a Life Cycle Sustainability Assessment method for the quantification and reduction of impacts of buildings life cycle, IOP Conf. Ser. Earth Environ. Sci. 323012107. 323 (2019). doi:DOI: 10.1088/1755-1315/323/1/012107.

[16] M. Najjar, K. Figueiredo, A.W.A. Hammad, A. Haddad, Integrated optimization with building information modeling and life cycle assessment for generating energy efficient buildings, Appl. Energy. 250 (2019) 1366–1382. doi:10.1016/j.apenergy.2019.05.101.

[17] A. Revit, Autodesk Revit, Architecture. 1 (2021) About Revit Architecture. http://usa.autodesk.com/adsk/servlet/pc/index?id=17801984&siteID=123112&s_tnt=31959:0:0.

[18] BIM Forum, Level Of Development (LOD) Specification Part I & Commentary, 2020.

[19] BIMserver.center. BIM en la nube., (n.d.). https://bimserver.center/es (accessed October 31, 2021).

[20] ecoinvent, ecoinvent, (2020). https://www.ecoinvent.org/ (accessed December 30, 2020).

[21] Global Petrol Prices, (2021). www.globalpetrolprices.com.

[22] S. Giaveno, A. Osello, D. Garuf, D. Santamaria Razo, Embodied Carbon and Embodied Energy Scenarios in the Built Environment. Computational Design Meets EPDs ., Sustain. 13 (2021). 10.3390/su132111974.

[23] EN, EN 15804:2012 + A2:2019 - Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products, Int. Stand. (2012) 70.

[24] Andalusian Government, BCCA. Base de Costes de la Construcción de Andalucía. Clasificación Sistemática de Precios Básicos, Auxiliares y Unitarios, 2017.