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LCA Analysis Through a Visual Programming Tool: Workflow on a BIM Model Case Study

KEYWORDS: LCA, BIM, Visual Programming, Environmental Impact, Building Materials

BIM tools also allow to conduct various impact analysis and, with regard to the growing concern about environmental issues, they embody a valuable mean to analyse buildings process consequences thus guiding designers towards better and more aware choices.

The capacity of BIM applications to evaluate environmental issues would be enhanced if integrated with Life- Cycle Assessment (LCA) tools considered among the most suitable methods for evaluating such impacts.

However, a typical barrier in performing LCA during the early design stages, i.e. the moment that influence the most the project outputs, is the lack of project information. Usually, this implies LCA to be performed after the design phase, when all the significant decisions are already taken.

The implementation of LCA within the early stages of the design process, possibly through an automated method, can enhance the control of environmental variables hence, the integration of BIM and LCA, appears to be a suitable opportunity.

The parametric approach allows BIM-based software to collect data and connect them with model elements. In order to avoid manual compilation of complex records, Visual Programming tools can cooperate with the authoring BIM software and interrelate the model with external sources such as materials environmental impact databases. Moreover, they can be configured to perform complex LCA calculation and automatically update the outcomes when something in the model changes.

The goal of this paper is to propose a sample workflow applied to a case study, in order to provide AEC stakeholders with a simplified BIM-based method for easily detecting the potential consequence of undertaking certain design choices at initial project stages or, at least, at those phases when definitive materials and products selection occurs.

INTRODUCTION

Constructions today represent one of the minor sustainable sectors: buildings are considered responsible for the consumption of almost 50% of energy, 50% of fresh water, the depletion of around 80% of agricultural soil and 60% of materials for buildings and infrastructures (by bulk) (Edwards, 2014). Manufacturing building materials, indeed, accounts for 10% of all global energy end-use (United Nations Environment Programme, 2011).

Furthermore, buildings contribution to global pollution is estimated to reach nearly 50% in GHG emission, 40% in drinking water pollution and 50% in landfill waste and ozone depletion (Edwards, 2014).

Aiming at minimizing the impact related to building sector, several Sustainable Development strategies have been undertaken in the last decades (Ortiz et al., 2009). Policies, regulations together with tools and methods were developed to implement sustainability in the built environment (Kang, 2015).

For a long period, main attention has been given to the improvement of buildings operation, thus to energy performance, in particular with respect to heating and cooling aspects (Röck et al., 2018).

In order to ascertain the actual level of buildings sustainability and to achieve better sustainable performance, several approaches and technologies have been adopted (Chong et al., 2009) with the goal to perform assessments and comparisons.

Such tools should evaluate buildings attributes from different perspective, relying on various criteria and, from the assessment outcomes, provide effective information to be implemented in the design process allowing the comparison between different alternatives. Among the already existing tools and methodologies two in particular are able to enhance these kinds of evaluation: Building Information Modelling (BIM) and Life-Cycle Assessment (LCA).

The combined use of these two approaches, however, is still scarce: despite specific tools have reached a good level of maturity, several practice experiences of assessing the environmental impacts related to construction materials and products as part of the design process, highlight that further developments are needed to empower an optimized integration (Najjar et al., 2017).

The workflow proposed in this paper was developed (with the support of Open Project s.r.l., an engineering and architecture firm located in Bologna), as part of a PhD research in architecture technology at the University of Bologna, with the aim of promoting the environmental assessment of buildings within the common design practice, trying to overcome some critical issues that still hinder a widespread LCA application.

Although LCA is a current issue, considering both the recent European regulations on construction materials (CPR 305/2011, Directives 2014/23/EU, 2014/24/EU and 2014/25/EU) (Pachego-Torgal, 2014), and the requirements of many green building rating systems such as LEED, BREEAM and DGNB, still many practitioners do not consider environmental analysis during the design process.

The reasons usually concern the high level of expertise required, and the significant cost of some applications that, despite the capability of interoperating with BIM applications in a simplified way, do not motivate the investment.

The proposed workflow, although in a pretty simplified way, aims at providing a basis for a streamlined and convenient implementation of the LCA analysis starting from the early design stages as a guide for making more aware design choices.

LCA FOR BUILDINGS

The Life Cycle Assessment (LCA) method is considered a valuable means to evaluate the environmental impact related to buildings from extraction of raw materials, to production, assembling, refurbishment and to possible end of life scenarios. The literature recognizes it as a strategy to reduce environmental impacts and energy consumption related to the AEC industry (Ortiz et al., 2009).

LCA is usually employed in order to report several impacts throughout a selection of environmental issues involving air, water and soil quality, thus including toxicity to human

life and to ecosystem, climate alterations and the depletion of resource (renewable and non-renewable),

water and energy (Anderson and Thornback, 2012).

Standardized with the ISO 14040 and ISO 14044, LCA framework is composed by four phases: goal and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation.

Especially for the building sector, LCA is considered a data intensive methodology, requiring a great amount of information, in particular those associated with embodied impacts of buildings materials. In the early design stages, the use of LCA is limited by uncertainties regarding the definitive list of components and the actual service life of elements (Röck et al., 2018).

For this reason, Life-Cycle Assessment are usually performed at the end of the process, sometime just for certification purposes, once the building is close to completion (when extra changes would result in significant additional costs) and all the required information are accessible. In this way, LCA cannot provide relevant feedbacks able to guide the design process and the improvement of the sustainable aspects (Basbagill et al, 2013).

Despite being more challenging, the implementation of sustainable design has to occur in the early phases when the most influencing decisions for the environmental aspects of the project are taken, having the caution of considering, at the same time, the entire buildings life cycle (Antón and Diaz, 2014).

Anyway, LCA analysis can be performed following different levels of detail and complexity. The EeB Guide Handbook (2012), for instance, identifies three type of study: screening, simplified and complete. A screening LCA may be considered for an initial overview of the environmental impacts of a building or a product, a simplified one can be performed for a quick assessment, while the complete LCA fully reflects the ISO 14040/14044 approach. The Goal and Scope definition becomes much more inclusive as the level of the study approaches the complete method.

BUILDING INFORMATION MODELLING (BIM)

The AEC sector has witnessed, over the last decades, crucial changes in the design and management approaches as a result of the development of computer-aided design (CAD) software and, lately, after the introduction of building information modelling (BIM) platforms. According to the US National Building Information Model Standard Project Committee, BIM is defined as “a digital representation of physical and functional characteristics of a facility” and represent “a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle” (nationalbimstandard.org, retrieved December 2017). Wong and Zhou (2015) defined this technology as a set of interrelating policies, processes and technologies able to endorse a systematic approach to the management of projects crucial information in a digital format, during the whole life cycle of a building. Similarly, the European Committee for Standardization (CEN) defines it as the “use of a shared digital representation of a built object…to facilitate design, construction and operation processes to form a reliable basis for decisions” (EN ISO 29481-1:2017).

When employed to achieve sustainable purposes in buildings projects, this technology meets the definition of Green BIM: “a model-based process of generating and managing coordinated and consistent building data during its project lifecycle that enhance building energy-efficiency performance and facilitate the accomplishment of established sustainability goals” (Wong and Zhou, 2015).

As for energy aspects, for which BIM platforms can enable the integration of energy efficiency design with energy consumption assessment over the building’s life cycle (Yuan and Yuan, 2011), connecting BIM model to sustainability indicators and metrics, can enhance detailed sustainability trade-off analysis in order to undertake more aware decisions in the early projects phases. At the same time, this approach can stimulate similar decisions also for operation, maintenance and end of life scenarios (Wong and Zhou, 2015).

BIM processes are capable of bringing gather the diverse sets of information used in construction into a common information environment (EN ISO 29481-2:2016) thus potentially proving the overall information flow, encouraging transparency and interoperability between the stakeholders thus enhancing communication and reducing waste and errors (MacGraw Hill Construction, 2010).

BIM tools, therefore, involves the production of a digital 3D model of the building that includes a variety of physical and functional data of materials and components. In order to define the entity and the quantity of the information, some institutions, such as the American Institute of Architecture (AIA), have developed a specification reference for enabling practitioners to clearly specify and articulate the content and the consistency of Building Information Models, called Level of Development (LOD) (bimforum.org, retrieved July 2018).

LOD, hence, “describes the minimum dimensional, spatial, quantitative, qualitative, and other data included in a Model Element" and, taking as reference the AIA guide, it is possible to identify five levels, from LOD 100 to LOD 500, characterized by increasing accuracy in describing the model content (AIA, 2013).

BIM AND LCA INTEGRATION

Due to the complex structure of constructions, made up of a wide variety of products, composed in turn of different materials, performing an environmental assessment of a whole building becomes a complicated task.

Each product, in fact, has its own attributes and service life, resulting in heterogeneous environmental profiles. Beside the scarcity of products information in the early design stage, LCA is also affected from uncertainty about operating performance and decommissioning circumstances along with transportation issues (characterized by a relevant impact on the environment) thus growing the level of initial assessments inaccuracy (Buyle et al., 2013).

Nevertheless, Life-Cycle Assessment tools, are still considered among the most suitable methods for evaluating such impacts (Röck et al., 2018) but, in the majority of cases, the assessment is performed at the end of the process.

Anyway, as previously stated, the stages with the biggest influence on the project are the early ones, when the project development is more flexible and it is easier to analyze different alternatives for improving the performance. As a matter of fact, manual management of project information through LCA tools represents a key issue as it involves redundant and potentially error-ridden activities (Antón and Diaz, 2014).

Furthermore, the employment of the LCA method for a building cannot be performed with the same precision and accuracy as for other sectors (EeB Guide Project, 2012).

For these reasons, integration between BIM and LCA is considered a possible solution, since the LCA tools would have direct access to the BIM data.

For this purpose, BIM has been mainly employed for extracting quantities in order to compile Life Cycle Inventories (LCI) for LCA (Antón and Diaz, 2014) since BIM models can contain and provide all the necessary information sorted per building materials, components or assemblies.

The importance of running simplified LCA applications for buildings has been recognized in the literature (Kellenberger and Althaus, 2009) and the integration of BIM and LCA has been identified as a possible and valuable optimization for carrying out environmental assessments (Soust-Verdaguer et al., 2016).

In this direction, it is possible to find some example of integration, such as "Tally", an Autodesk Revit extension that enables LCA calculation of the BIM model but, currently, this software is adapted to the US context.

The BIM-LCA integration, still rises some perplexities regarding the verification of the future scenarios since it involves assumptions about materials and products end of life, indicating the inconveniency of including all the life cycle phases and conducting complete "cradle-to-cradle" BIM-based analysis (Peng, 2016).

SCOPE OF THE APPLICATION ON A CASE STUDY

The BIM-based environmental assessment techniques currently available, in the majority of cases need external tools, which can hinder a fluent interoperability, especially when a lack of data compatibility occurs, thus resulting in a time-consuming format conversion (Lee et al., 2015).

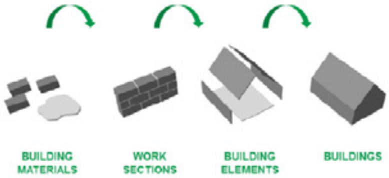
In order to overcome this issue, giving to users, at the same time, the freedom to customize the boundaries of the applications, this paper provides a simplified workflow of a BIM-based LCA analysis, that relies on a Visual Programming tool, namely Autodesk Dynamo, which can interoperate between an authoring BIM software, such as Autodesk Revit, and an external source of information (LCA dataset) enclosed in a spreadsheet (e.g. Microsoft Excel).

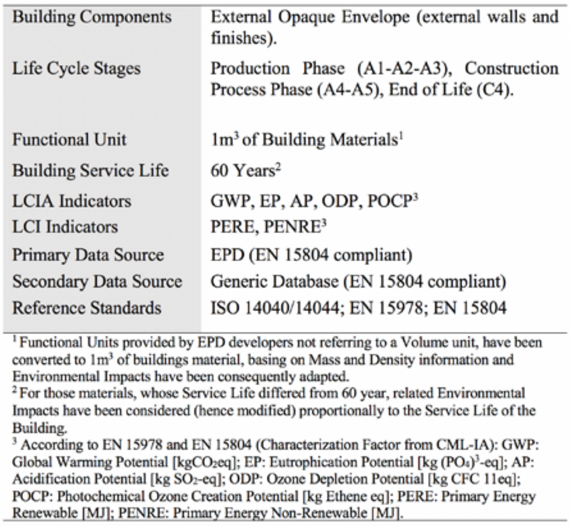
In this way, the analysis can be carried out directly within the BIM platform, through a customized set of parameters related to buildings materials.

The goal of this paper is to propose a sample workflow applied to a case study, in order to provide AEC stakeholders with a simplified BIM-based method for easily detecting the potential consequence of undertaking certain design choices at initial project stages or, at least, at those phases when definitive materials and products selection occurs.

The boundaries of the study are identified considering the following key aspects:

- The case study selected for the application of the workflow, a model floorplan of a multi-storey student residence, has been developed with LOD 300, by which the elements are usually detailed with specific assemblies and attributes such as quantity, size, shape, location and orientation are precisely identified. According to Soust-Verdaguer et al. (2016), this is the most suitable LOD for a correct management of the environmental implications at initial stages.
- This circumstance allows to focus particularly on the study of buildings materials and products alternatives, since preliminary characteristics have been already defined. For this reason, following the modular approach of aggregation proposed by Trigaux et al. (2014) (Fig.1), this study will consider the building materials and further aggregation as objects of the analysis, in order to produce outputs referred to the building elements. In particular, the investigation will be limited to the external opaque envelope, since it represents a key element in shaping thermal and energy performance and it covers a considerable portion of the total building surface (Azari, 2014).
- For the LCA analysis, taking as reference the classification suggested in the EeB Guide Handbook (EeB Guide Project, 2012), this study will reach an extent comparable to the "simplified" one, thus considering specific, quantitative environmental information on building elements, products, materials and components but not including all the ISO 14040/14044 and EN 15978 prescriptions. The simplified scheme adopted is shown in Table 1.
- European standards defining the environmental performance of buildings, such as EN 15978:2011, EN 15643-1:2010, EN 15643-2:2011 and EN 15804:2012, have been also taken as reference but, even if energy and water consumption during the use phase are listed as element to be included in the assessment, this study has been limited to the impacts associated with materials and products during buildings life cycle, as recognized by Malmqvist et al. (2010) as the simplest building-related application.





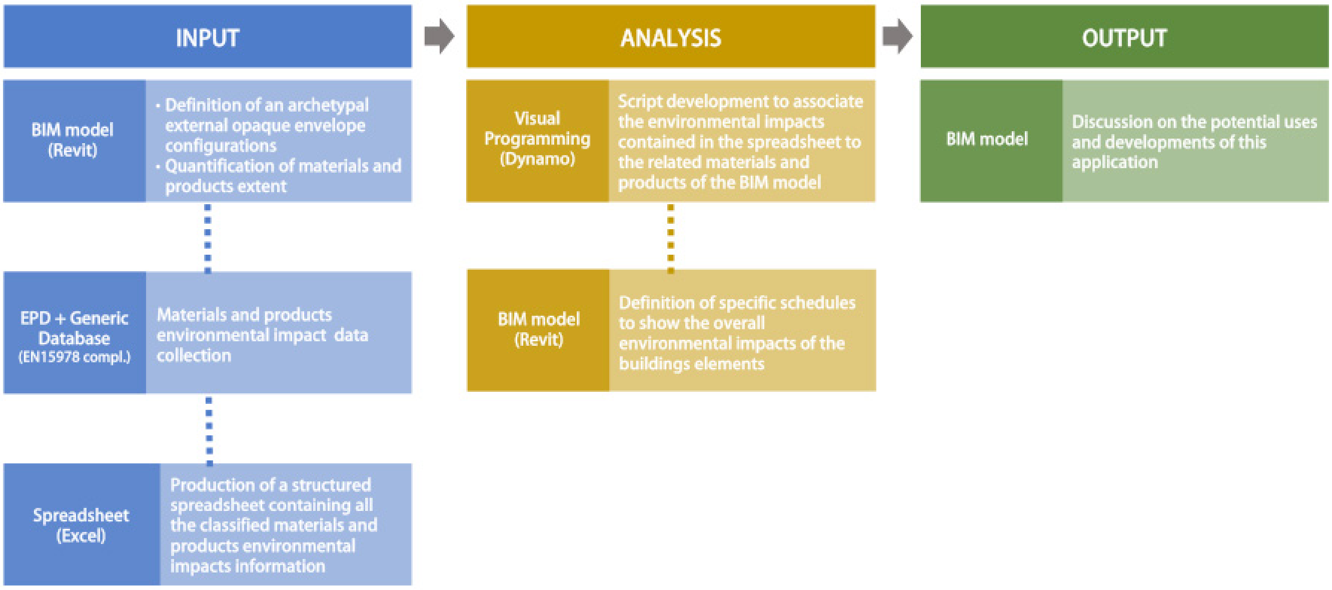
Building Components	External Opaque Envelope (external walls and finishes).
Life Cycle Stages	Production Phase (A1-A2-A3), Construction Process Phase (A4-A5), End of Life (C4).
Functional Unit	1m³ of Building Materials[1]
Building Service Life	60 Years[2]
LCIA Indicators	GWP, EP, AP, ODP, POCP[3]
LCI Indicators	PERE, PENRE[3]
Primary Data Source	EPD (EN 15804 compliant)
Secondary Data Source	Generic Database (EN 15804 compliant)
Reference Standards	ISO 14040/14044; EN 15978; EN 15804

[1] Functional Units provided by EPD developers not referring to a Volume unit, have been converted to $1m^3$ of buildings material, basing on Mass and Density information and Environmental Impacts have been consequently adapted.

[2] For those materials, whose Service Life differed from 60 year, related Environmental Impacts have been considered (hence modified) proportionally to the Service Life of the Building.

[3] According to EN 15978 and EN 15804 (Characterization Factor from CML-IA): GWP: Global Warming Potential [kgCO_2eq]; EP: Eutrophication Potential [kg $(PO_4)^3$-eq]; AP: Acidification Potential [kg SO_2-eq]; ODP: Ozone Depletion Potential [kg CFC 11eq]; POCP: Photochemical Ozone Creation Potential [kg Ethene eq]; PERE: Primary Energy Renewable [MJ]; PENRE: Primary Energy Non-Renewable [MJ].

Table 1: Boundaries of the LCA framework adopted in the study



WORKFLOW DEVELOPMENT AND IMPLEMENTATION

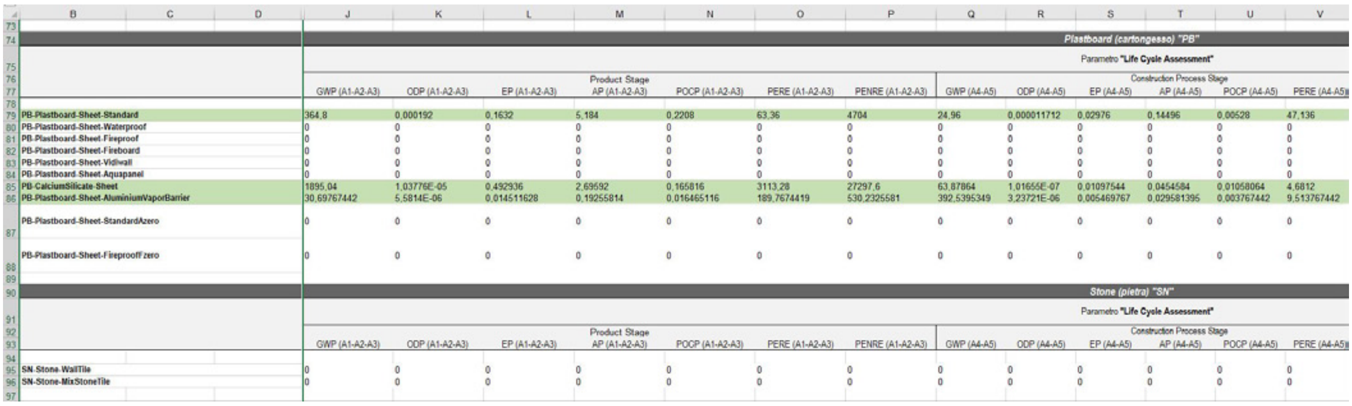
Data acquisition is the most conspicuous issue since buildings contain great quantities of different materials and the availability of reliable data is limited. In order to simplify the LCA process, it is important to select the most representative data related to few characteristic life cycle stages (Malmqvist et al. ,2010).

In order to manage the data in an optimized and replicable manner, a "common language" based on data structure and classification convention, is one of the first task of the workflow development. This convention is necessary to interrelate LCA database with the BIM model (Röck et al., 2018).

Inspired by the essential steps of LCA Design illustrated by Seo et al. (2007), who proposed an information flow divided into: "Input", "Analysis" and "Solution", this study relies on a similar structure (Fig.2) in which:

- the Input step includes: the definition of an archetypal external envelope configuration compliant with the national thermal performance regulation, the quantification of the envelope materials and products extent through Autodesk Revit, the collection of the LCA data from EPDs and generic database, the production of a structured spreadsheet containing all the classified materials and products environmental impacts information;
- the Analysis step involves: the evelopment of a script with the Autodesk Dynamo visual programming tool, able to associate the environmental impacts contained in the spreadsheet to the related materials and products of the BIM model, the definition of specific schedules in the BIM platform, able to show the overall environmental impacts, organized per indicator and life cycle phase and sorted per singular material or per aggregate components;
- the Output (Solution) step consists in: the discussion of the potential uses and developments of this application.

Figure 1: Modular approach of aggregation for LCA data processing (Trigaux et al., 2014)
Figure 2: Steps of BIM-based LCA Design (adapted from Seo et al., 2007



Plastboard (cartongesso) "PB"

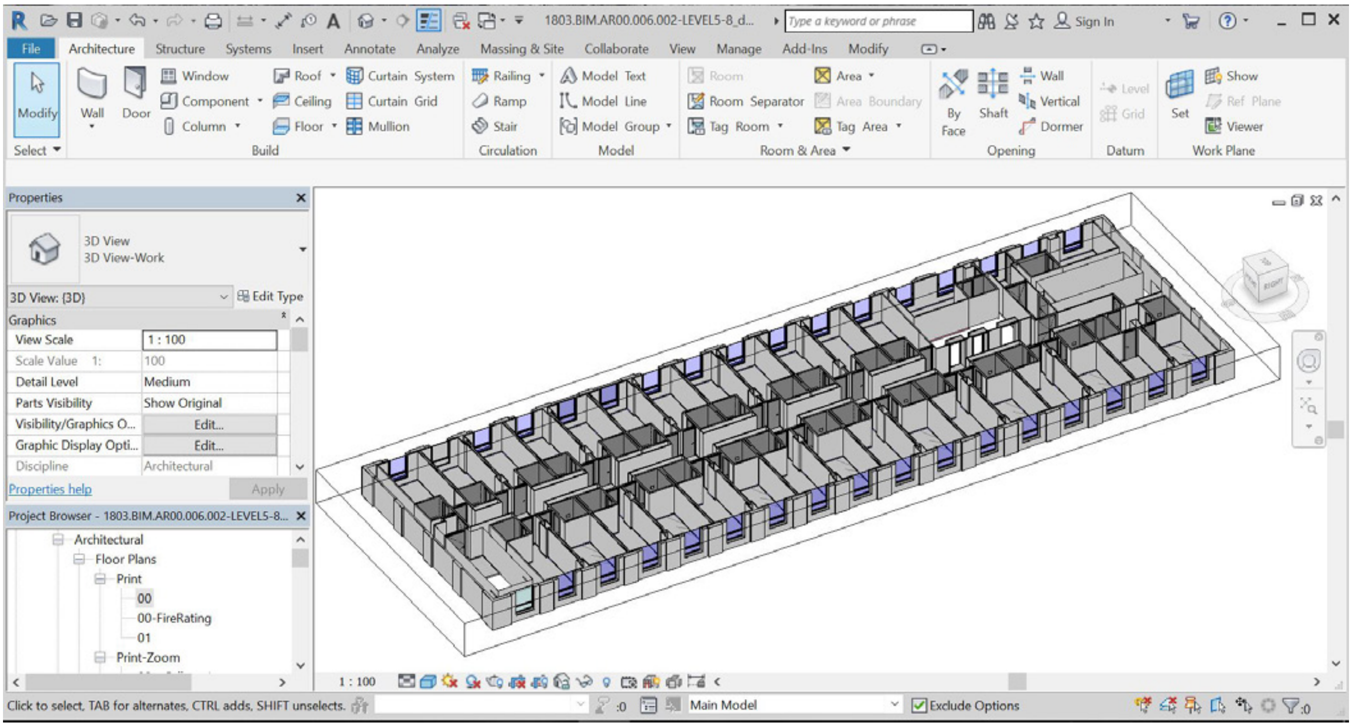
Parametro "Life Cycle Assessment"

	Product Stage							Construction Process Stage					
	GWP (A1-A2-A3)	ODP (A1-A2-A3)	EP (A1-A2-A3)	AP (A1-A2-A3)	POCP (A1-A2-A3)	PERE (A1-A2-A3)	PENRE (A1-A2-A3)	GWP (A4-A5)	ODP (A4-A5)	EP (A4-A5)	AP (A4-A5)	POCP (A4-A5)	PERE (A4-A5)
PB-Plastboard-Sheet-Standard	364,8	0,000192	0,1632	5,184	0,2208	63,36	4704	24,96	0,000011712	0,02976	0,14496	0,00528	47,136
PB-Plastboard-Sheet-Waterproof	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-Plastboard-Sheet-Fireproof	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-Plastboard-Sheet-Fireboard	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-Plastboard-Sheet-Vidiwall	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-Plastboard-Sheet-Aquapanel	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-CalciumSilicate-Sheet	1895,04	1,03776E-05	0,492936	2,69592	0,165816	3113,28	27297,6	63,87864	1,01655E-07	0,01097544	0,0454584	0,01058064	4,6812
PB-Plastboard-Sheet-AluminiumVaporBarrier	30,69767442	5,5814E-06	0,014511628	0,19255814	0,016465116	189,7674419	530,2325581	392,5395349	3,23721E-06	0,005469767	0,029581395	0,003767442	9,513767442
PB-Plastboard-Sheet-StandardAzero	0	0	0	0	0	0	0	0	0	0	0	0	0
PB-Plastboard-Sheet-FireproofFzero	0	0	0	0	0	0	0	0	0	0	0	0	0

Stone (pietra) "SN"

Parametro "Life Cycle Assessment"

	Product Stage							Construction Process Stage					
	GWP (A1-A2-A3)	ODP (A1-A2-A3)	EP (A1-A2-A3)	AP (A1-A2-A3)	POCP (A1-A2-A3)	PERE (A1-A2-A3)	PENRE (A1-A2-A3)	GWP (A4-A5)	ODP (A4-A5)	EP (A4-A5)	AP (A4-A5)	POCP (A4-A5)	PERE (A4-A5)
SN-Stone-WallTile	0	0	0	0	0	0	0	0	0	0	0	0	0
SN-Stone-MixStoneTile	0	0	0	0	0	0	0	0	0	0	0	0	0



3D View: {3D}

Graphics

View Scale	1 : 100
Scale Value 1:	100
Detail Level	Medium
Parts Visibility	Show Original
Visibility/Graphics O...	Edit...
Graphic Display Opti...	Edit...
Discipline	Architectural

- Architectural
  - Floor Plans
    - Print
      - 00
      - 00-FireRating
      - 01
    - Print-Zoom

Click to select, TAB for alternates, CTRL adds, SHIFT unselects.

☑ Exclude Options

STEP 1: INPUT

The object of the study is the external opaque envelope (thus excluding windows) of a multi-storey student residence model floorplan, that will be located in Bologna (Italy). The building structure is a reinforced concrete frame, and the external walls are mostly composed by plasterboard structures insulated with different types of Rockwool panels, enclosed in calcium-silicate sheets and finished with skim-coat layers.

The external envelope has been designed in compliance with the Italian regulation on buildings thermal performance: D.M. 26.06.2015.

The BIM model of the building, at the time of the study, reached the LOD 300, hence including the definitive configuration of the envelope stratigraphy (Fig. 3).

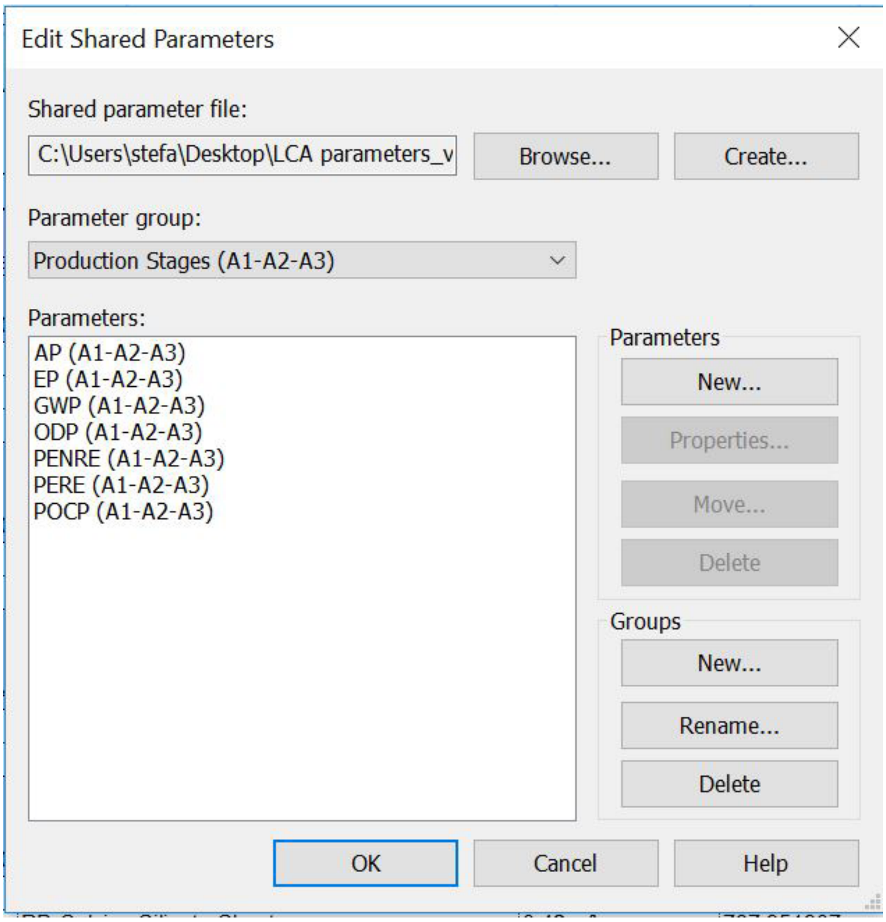
With Autodesk Revit, it was possible to compute the exact quantities of the building materials generating a “wall schedule”.

For the quantification of the environmental impacts, specific and local Environmental Product Declarations (EPD) EN 15804 compliant have been collected, thus assuming the consistency with the European context and with the latest environmental management standards. When the right EPD was not available, generic LCA databases (EN 15978 compliant) were used as a secondary data source.

Figure 3: 3D view of the case-study BIM model (designed with Autodesk Revit)
Figure 4: Portion of the spreadsheet containing materials environmental impacts

Eventually, a structured spreadsheet (Fig. 4) containing all the classified materials and products environmental impacts information has been produces following robust classification rules such as:

- organizing all the buildings materials per category and per type;
- codifying and indexing each material with specific type mark considering the previous organization;
- defining a number of columns equal to the number of environmental indicators included in the analysis for each Life Cycle phase considered for a total of 21[1] variables;
- assigning unique tags to each column in order not to create ambiguities with the Revit model codification;


Edit Shared Parameters

Shared parameter file: C:\Users\stefa\Desktop\LCA parameters_v

Parameter group: Production Stages (A1-A2-A3)

Parameters:
AP (A1-A2-A3)
EP (A1-A2-A3)
GWP (A1-A2-A3)
ODP (A1-A2-A3)
PENRE (A1-A2-A3)
PERE (A1-A2-A3)
POCP (A1-A2-A3)

STEP 2: ANALYSIS

The first part of the LCA analysis consisted in the generation, within the Revit file, of a number of custom parameters able to contain the environmental information to embody in the BIM model.
This was accomplished through the creation of specific "shared parameters" (Fig. 5) to associate with the project materials for a total of 21 (One for each indicator for all the Life Cycle phases).

The most delicate part of the analysis, besides, regarded the elaboration of a script through the visual programming tool Autodesk Dynamo, in order to relate the environmental information contained in the spreadsheet to the BIM model parameters, specifically customized to host such data.
The script (Fig. 6, 7) has been developed to accomplish the following task:

- Detecting the spreadsheet within a defined directory;


Run completed with warnings.

Figure 5: Autodesk Revit shared parameters for the environmental indicators
Figure 6: Autodesk Dynamo script view

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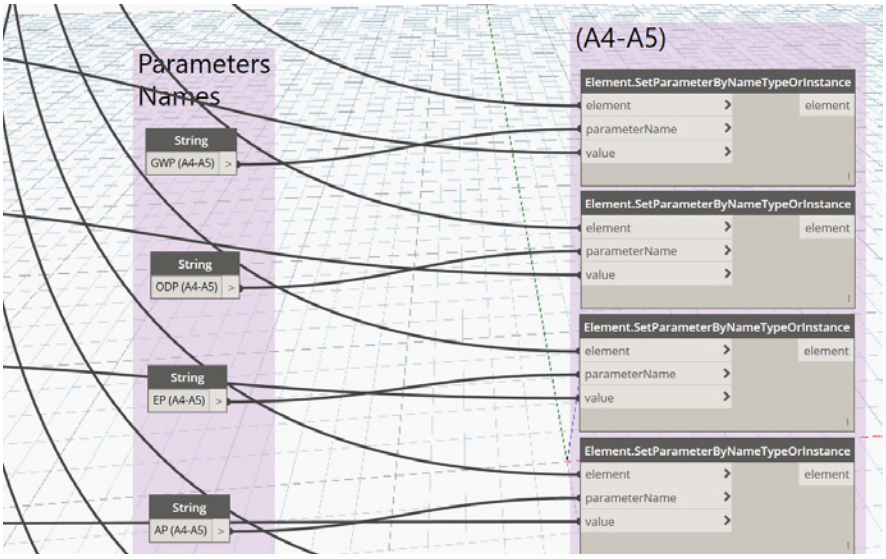
[1] The phases considered are three as the A1-A2-A3 and the A4-A5 phases have been aggregate.

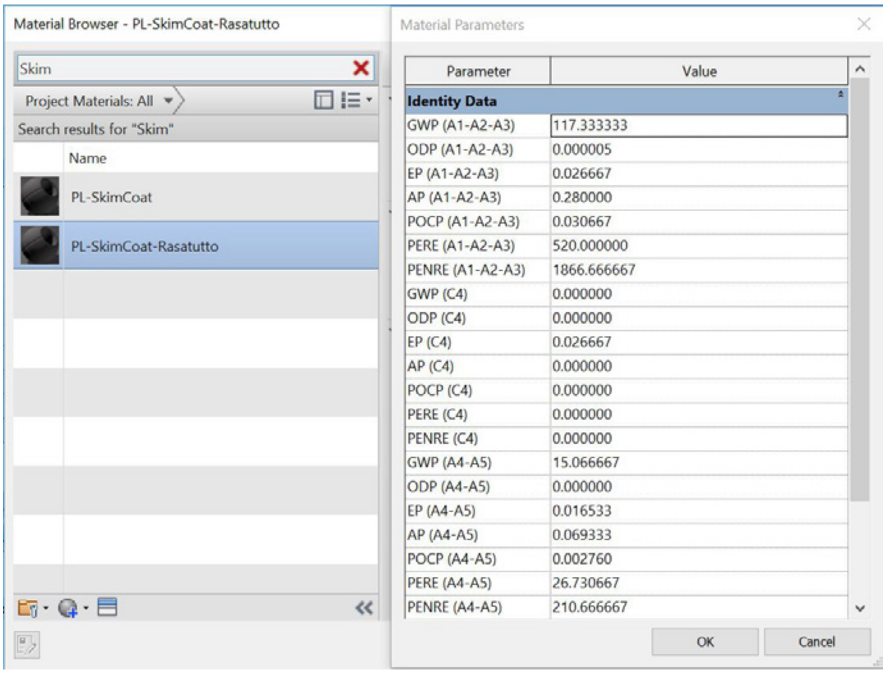
- Reading the content of the cells per column (excluding the headers) at specified positions (indexes) in the spreadsheet;
- Creating lists of elements filled with the content of the cells;
- Recognizing the Revit materials listed in the spreadsheet file with the same designation;
- Recognizing the Revit parameters (shared parameters) listed in the spreadsheet file with the same designation;
- Assigning the lists content incorporating the spreadsheet data, to Revit detected parameters for each specific material.
- An example of the correct run of the script for a material is shown in figure 8.

At this point it was possible to define specific schedules in Revit, in order to visualize the overall environmental impacts, organized per indicator and life cycle phase and sorted per singular material and per aggregate components. Revit schedules, actually, act as simplified spreadsheet, allowing to run easy operation between the cells. This attribute enabled the creation of other custom parameters intended to calculate the LCA outcomes by multiplying the unitary impacts for the actual materials quantities (Fig. 9, 10). Also the grand total of each impact indicator was calculated through the Revit schedules.

STEP 3: OUTPUT

The application of a custom script with a Visual Programming tool such as Autodesk Dynamo in order to interrelate data contained in external spreadsheet with the BIM model elements, permits a full customization of the LCA analysis depending on the goal. It can be employed for design purposes in order to compare and select the materials with the lower environmental loads or it can be used to fulfil the requirements of those Sustainability Rating Tools including LCA credits, such as LEED,





Parameter	Value
Identity Data	
GWP (A1-A2-A3)	117.333333
ODP (A1-A2-A3)	0.000005
EP (A1-A2-A3)	0.026667
AP (A1-A2-A3)	0.280000
POCP (A1-A2-A3)	0.030667
PERE (A1-A2-A3)	520.000000
PENRE (A1-A2-A3)	1866.666667
GWP (C4)	0.000000
ODP (C4)	0.000000
EP (C4)	0.026667
AP (C4)	0.000000
POCP (C4)	0.000000
PERE (C4)	0.000000
PENRE (C4)	0.000000
GWP (A4-A5)	15.066667
ODP (A4-A5)	0.000000
EP (A4-A5)	0.016533
AP (A4-A5)	0.069333
POCP (A4-A5)	0.002760
PERE (A4-A5)	26.730667
PENRE (A4-A5)	210.666667

Figure 7: Portion of the script showing the nodes for assigning the values to the parameters
Figure 8: Filled parameters with LCA data for a material in Revit

DGNB or Green Star.

The schedules are customizable, allowing practitioners to visualize the information in the preferred way depending on the goal of the analysis.

Being a pilot study, the workflow still suffers from complexity in running some step, as it requires manual data entry for the spreadsheet and the manual creation of custom parameters in Revit to host the external data.

Further development could boost the convenience of such an approach, leading to innovative, comprehensive and reliable applications.

DISCUSSION

One of the crucial task of integrating LCA and BIM, is obtaining a convenient decision-making method suitable for the designers on a day-to-day basis without having a particular LCA expertise (Antón and Diaz, 2014). Performing LCA applications with reasonable effort is an ambition to provide design guidance while monitoring the consequences of design decisions (Röck et al., 2018).

Currently, several assessment tools for construction process are available and can be considered a reliable opportunity especially for the easy access provided to several environmental impact databases but, when data incompatibility between different tools occurs, they might not allow universal evaluations (Antón and Diaz, 2014), resulting in a time-consuming format conversion (Lee et al. (2015) with the risk of hindering the possibility of fair comparisons between building materials and products as well as between different design options.

In literature, it is likely to find a number of possible solutions in order to conduct reliable and, within certain circumstances, comparable assessments. In the majority of cases, these solutions imply simplified methods that facilitate data collection and analysis completion.

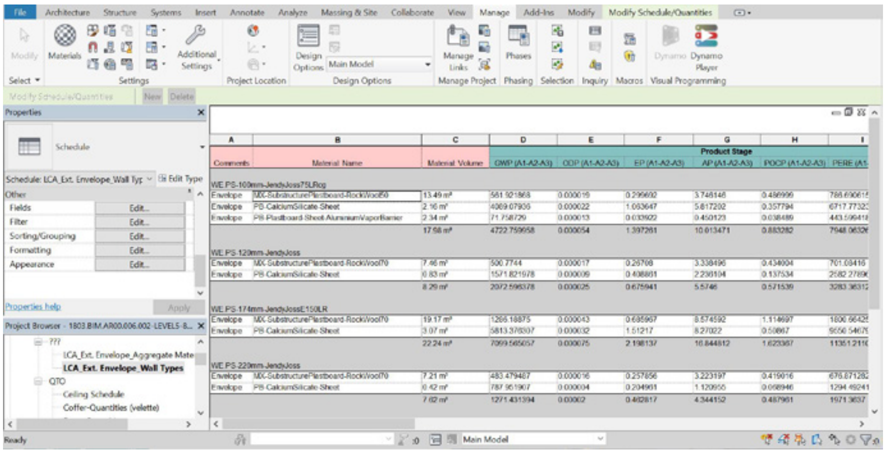
The use of BIM is spreading rapidly and, for designers and decision makers, this technology can represent a valid means to facilitate LCA analysis at different scales.

Even if at early design stages BIM models usually reach only a low Level of Development (LOD) thus not providing sufficient data to be used in a comprehensive LCA (Peng, 2016), as suggested by Röck et al., (2018), aggregating the environmental database at a building element level can allow to conduct reliable LCA also at initial phases.

Moreover, the capacity of BIM tools to easily produce (and provide access to) the bill of materials quantities, allows a continuous real-time update of the LCA evaluation, as the project acquires a greater level of details, hence a higher LOD.

In line with other experiences found in literature (Shadram and Mukkavaara, 2018) endorsing the use of visual scripting tools, the proposed workflow employed Autodesk Dynamo for the integration between the BIM software and the external data sources, thus allowing progressive assessment updates.

Other key aspects considered in order to obtain comparable assessments, were: setting a number of ground rules and conventions to adopt, both in the spreadsheet structure and in the BIM

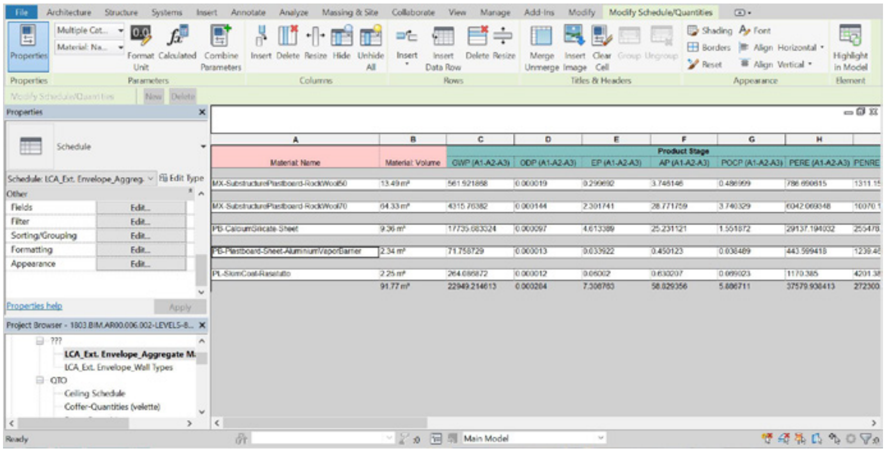


Schedule: LCA_Ext. Envelope_Wall Types

Project Browser - 1803.BIM.AR00.006.002-LEVELS-8...

- ???
  - LCA_Ext. Envelope_Aggregate Mate
  - **LCA_Ext. Envelope_Wall Types**
- QTO
  - Ceiling Schedule
  - Coffer-Quantities (velette)

A	B	C	D	E	F	G	H	I
			Product Stage					
Comments	Material Name	Material Volume	GWP (A1-A2-A3)	ODP (A1-A2-A3)	EP (A1-A2-A3)	AP (A1-A2-A3)	POCP (A1-A2-A3)	PERE (A1-
WE.PS-100mm-JendyJoss75LRog								
Envelope	MX-SubstructurePlastboard-RockWool50	13.49 m³	561.921868	0.000019	0.299692	3.748146	0.486999	786.690615
Envelope	PB-CalciumSilicate-Sheet	2.16 m³	4069.07936	0.000022	1.063647	5.817202	0.357794	6717.7732
Envelope	PB-Plastboard-Sheet-AluminiumVaporBarrier	2.34 m³	71.758729	0.000013	0.033922	0.450123	0.038489	443.599418
		17.98 m³	4722.759958	0.000054	1.397261	10.013471	0.883282	7948.0632
WE.PS-120mm-JendyJoss								
Envelope	MX-SubstructurePlastboard-RockWool70	7.46 m³	500.7744	0.000017	0.26708	3.338496	0.434004	701.03416
Envelope	PB-CalciumSilicate-Sheet	0.83 m³	1571.821978	0.000009	0.408861	2.236104	0.137534	2582.2789
		8.29 m³	2072.596378	0.000025	0.675941	5.5746	0.571539	3283.3631
WE.PS-174mm-JendyJossE150LR								
Envelope	MX-SubstructurePlastboard-RockWool70	19.17 m³	1286.18875	0.000043	0.685967	8.574592	1.114697	1800.6642
Envelope	PB-CalciumSilicate-Sheet	3.07 m³	5813.376307	0.000032	1.51217	8.27022	0.50867	9550.5467
		22.24 m³	7099.565057	0.000075	2.198137	16.844812	1.623367	11351.211
WE.PS-220mm-JendyJoss								
Envelope	MX-SubstructurePlastboard-RockWool70	7.21 m³	483.479487	0.000016	0.257856	3.223197	0.419016	676.87128
Envelope	PB-CalciumSilicate-Sheet	0.42 m³	787.951907	0.000004	0.204961	1.120955	0.068946	1294.4924
		7.62 m³	1271.431394	0.00002	0.462817	4.344152	0.487961	1971.3637



Schedule: LCA_Ext. Envelope_Aggreg...

Project Browser - 1803.BIM.AR00.006.002-LEVELS-8...

- ???
  - **LCA_Ext. Envelope_Aggregate M...**
  - LCA_Ext. Envelope_Wall Types
- QTO
  - Ceiling Schedule
  - Coffer-Quantities (velette)

A	B	C	D	E	F	G	H	I
		Product Stage						
Material: Name	Material: Volume	GWP (A1-A2-A3)	ODP (A1-A2-A3)	EP (A1-A2-A3)	AP (A1-A2-A3)	POCP (A1-A2-A3)	PERE (A1-A2-A3)	PENRE
MX-SubstructurePlastboard-RockWool50	13.49 m³	561.921868	0.000019	0.299692	3.748146	0.486999	786.690615	1311.15
MX-SubstructurePlastboard-RockWool70	64.33 m³	4315.76382	0.000144	2.301741	28.771759	3.740329	6042.069348	10070.1
PB-CalciumSilicate-Sheet	9.36 m³	17735.683324	0.000097	4.613389	25.231121	1.551872	29137.194032	255478
PB-Plastboard-Sheet-AluminiumVaporBarrier	2.34 m³	71.758729	0.000013	0.033922	0.450123	0.038489	443.599418	1239.45
PL-SkimCoat-Rasatello	2.25 m³	264.068872	0.000012	0.06002	0.630207	0.069023	1170.385	4201.38
	91.77 m³	22949.214613	0.000284	7.308783	58.829356	5.886711	37579.938413	272300

Figure 9: Portion of Revit schedule indicating the LCA outputs for the external envelope wall types
Figure 10: Portion of Revit schedule indicating the LCA outputs for the materials composing the external envelope

tool, basing on the goal and scope of the analysis, and referring to the same standards and regulations depending on the context of the study.

The benefit of performing such an integration employing the proposed method are:

- easy access to the actual quantities and attributes of construction materials and products of the building, thus avoiding manual data entry;
- autonomy of adapting the assessment variables (e.g. study boundaries, environmental indicators) to different analysis scopes, depending on personal expertise and evaluation goals;
- opportunity of comparing different design alternatives, especially with regard to materials and products, resulting in an effective decision-making tool;
- capacity of real-time assessment as the project level of detail evolves: from the early design stages to the conclusive ones, without re-importing the BIM model into external LCA platform every time the model changes;
- opportunity of taking advantage of a structured spreadsheet for materials and product that can be updated with new elements and environmental information and, therefore, it can be re-employed in further analysis;

This paper also evidences certain inconveniencies such as:

- producing a spreadsheet implies a robust structure in naming and classifying materials and environmental impacts, resulting in an accurate but time-consuming manual data entry since is still not achievable to obtain an automatic data import from EPDs or other LCA databases into the BIM models;
- collecting reliable data from certified sources, such as EPDs, is still a delicate step since it depends on the availability of data for all the project materials and products;
- the accuracy in performing the LCA and the representativeness of the outcomes, depends greatly on the quality of the BIM model;
- the issue of calculating and automatically including aspects such as transportation information, construction techniques, materials and product maintenance, is still problematic due to the different features and locations of each project;

This sample workflow, even if applied on just one case study does not limit the validation of the method, since the ground procedures for the environmental data processing and its integration into the BIM environment do not depend on different buildings design process and different buildings typologies (Röck et al., 2018).

CONCLUSION

This paper proposed a sample workflow of a simplified BIM-LCA integration through the employment of a Visual Scripting tool, addressing some of the requirements expressed in the literature with reference to environmental assessment at initial stages and simplification approaches to LCA, aiming at providing a reliable overview of different materials and products alternatives.

Such an approach has shown to imply some benefits in performing LCA analysis within a BIM environment, with respect to operational feasibility and economic convenience, as well as some drawbacks resulting from unresolved LCA issues and methodological limitations.

In line with other experiences found in literature, dealing with existing methods and tools for effectively integrate BIM and LCA analysis (Antón and Diaz, 2014), this paper recognize that further developments are required in this field.

Interoperability between BIM models and LCA tools needs improvements and data exchange for automatic association of each building material and products with the unit processes during the life cycle is still a relevant challenge (Soust-Verdaguer et al., 2016).

Building Information Modelling (BIM) is providing a great improvement in the overall information management regarding every phase of the building process, fostering the achievement of better project performance and quality. Further developing the interoperability between BIM designs and LCA analysis, can concur to the improvement and the ease of integrated design which can be seen as a key factor in achieving sustainability (Antón and Diaz, 2014).

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