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Smart and Healthy within the 2-degree Limit

Integration of LCA tools in BIM toward a regenerative design.

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ABSTRACT

In the case of regenerative processes, design can receive significant benefits from information that can be obtained by applying the life cycle assessment methodology. The LCA (life cycle assessment) approach can be implemented both for a single building material and for the whole building. An effective and efficient real application of this methodology requires the integration of LCA databases and analysis routines in commonly used simulation tools such as energy performance simulation and Building Information Modelling (BIM). The integration of LCA tool significantly impacts the design efficacy especially in reducing environmental impact of the construction industry. This paper reviews the integrated LCA tools in simulation software currently available for BIM platforms and will explore the possibilities given to restorative design informed by LCA analysis, through a test on two construction typologies for a case study.

INTRODUCTION

This paper presents a preliminary overview of interoperability and application of LCA and BIM software within the activities of the EU-funded RESTORE (REthinking Sustainability TOwards a Regenerative Economy) COST Action [1]: this project aims to affect a paradigm shift towards restorative sustainability for new and existing buildings across Europe.

The literature on regenerative design defines ‘sustainability’ as a transitional stage between ‘green design’ on the one hand, and ‘regenerative design’ on the other [2,3]. The paradigm shift envisioned by the RESTORE project is aimed to move from the ‘green design’, which is essentially focused on doing ‘less bad’, and the ‘sustainability’, which implicates a ‘neutral’ state where the ideal performance is ‘zero’ (meaning nearly zero energy and low emissions building), towards an approach that permits regenerative capabilities to evolve, a net-positive restorative sustainability to incrementally do ‘more good’ [4,5].

The main challenges for implementing regenerative development are focused on the current lack of an integrated approach and on the scarcity of comprehensive examples providing quantifiable evidence of the benefits of regenerative built environments. In the long term, a regenerative approach to the built environment that integrates with ecosystems will increase the chances of a continuous suitable environment for humans. Although this may be difficult to test currently, development that aims to repair and integrate with ecosystems is more conducive to positive healthy outcomes than that which only slows the rate of degradation [6].

Although, the real strategies and design tools for evaluating the environmental impacts are not yet standardized for the regenerative design and developed for Regenerative design. The growing sensibility to the ecological aspects and the emergency due to the economic crisis pushed the architectural, engineering and construction communities to realize a negative environmental impact of the built environment. Buildings are responsible for 40% of carbon emission, 14% of water consumption and 60% of waste production worldwide [7]. According to the European Union Directive, land is the scarcest resource on earth, making land development one of the fundamental components in effective sustainable building practice [8,9]. Over 50% of the world's population live in cities. Environmental damage caused by urban sprawl and building construction is severe and we are developing building construction and human facilities at a speed that the earth cannot compensate [10]. Buildings affect ecosystems in different ways and their extension increasingly overtake agricultural lands and wetlands or bodies of water compromising existing wildlife. Energy is the building resource that has gained the most attention within the built environment research community. Moreover, building materials are another limited resource within a building’s life cycle [6].

Regenerative design could be one of the most important strategies in reducing the environmental impacts of the building sector. There are several tools and methods to help the implementation of sustainable development into the built environment. Life Cycle Assessment (LCA) is widely considered as a comprehensive method to assess the environmental sustainability of a building over its life cycle; and has growing importance in the scientific community. Several studies highlight the importance of improving and simplifying LCA application to buildings. Thus, it is recognized that the integration of BIM (Building Information Modeling) with LCA can reduce and optimize LCA application [11].

Regenerative theories propose to examine the historical, cultural and technological nuances, beside the elaboration of identification signs, focusing on design strategies linked to the place, the context and communities [12].

Since the design stage does not allow to make predictions on future regenerative performances of the building, the regenerative design involves the stakeholders of the project since from the very beginning. The proper way to implement a regenerative intervention suggests an alternative to change the present model of intervention on the context, advancing connections among constituent elements, coevolution of man and nature and the needs for adaptation and flexibility more than the economic income.

The Regenerative design process can also receive significant benefits from information and data given by the application of the LCA methodology toward the construction process [13]. LCA is a tool already used to analyse the environmental impacts of a product, an activity or a process along all the phases of the life cycle, through the quantification of the use of resources ("inputs" such as energy, raw materials, water) and emissions into the environment ("emissions" into the air, in water and soil), proposing also the best solution to be adopted in terms of environmental impacts.

In this context, the role of BIM appears as a building tool that facilitates the application of LCA in the construction sector: the use of BIM at the early stage of designing construction projects empowers the decision-making process in the construction sector [14]. BIM provides designers, architects, and engineers with data required to evaluate energy consumption and environmental impacts in the construction sector throughout the entire lifecycle of building materials. It can be really considered that BIM harmonizes both the information of building materials and the evaluation of their environmental impacts [15].

METHODOLOGY

This paper analyses how could be integrated BIM and LCA processes in a practical way for evaluating the environmental impacts of building materials in the construction sector.

The first step of the research is focused on the investigation of the state-of-the-art about the more used available LCA software: the analysis was developed according to the typology of tools (stand alone, plugin, suite tool) and their main characteristic in terms of database, products, data availability, obtaining the selection of: Caala [16], One Click LCA™ [17], Primus LCA [18], SIMAPRO [19], Open LCA [20], Tally® [21], Impact Compliant [22], Umberto Lca Soft [23], GaBi Soft [24].

The second step is to select the tools that could be implemented on BIM software: in this specific case Autodesk® Revit® [25] is analysed to conduct the 3D modelling and to apply the inventory database of building materials, in relation to the characteristic of the local climate, the building site and the local material production and supply.

After the quantification of building materials in the construction components, the environmental impacts are evaluated and discussed by a comparison of database and solutions.

Among the listed tools, this study focuses on the evaluation on those with a direct connection or plugin for BIM models: Tally® and One Click LCA™.

Tally® is a plugin application for Autodesk® Revit® software, developed by Kieran Timberlake and PE International, that allows users to quantify the environmental impact of building materials for whole building analysis as well as comparative analyses of design options.

This study adopted the educational licence, Version 2017.06.15.01 (6/18/2017): Tally® analysis accounts for the full cradle-to-grave life cycle according to the EN 15978 and utilizes a custom-designed LCA database developed in GaBi 6 and using GaBi databases, consistent with LCA standards ISO 14040-14044.

One Click LCA™, developed by Bionova®, is a LCA and LCC (Life-Cycle Costing) software that allows to design greener building, to create Environmental Product Declarations (EPD) for building materials and to earn valuable certification credits, including LEED v4's MRc1 Building Life-Cycle Impact Reduction, BREEAM Mat 01 Life cycle impacts.

The tool works as a plugin by importing data from Revit or BIM model, gbXML Energy model, Excel, or use the manual import within the cloud software itself and obtain a ready-made report.

This study adopted the educational licence, Version 1.0.2 (13/10/2017): the tool is also third-party verified for EN 15978, ISO 21931-1, ISO 21929-1 and for input data for ISO 14040/44 and EN 15804 standards; One Click LCA™ disposes of an own database for generic construction materials and a wide list of available databases, among the most used in the world (such as Environdec and other national version of EPD system).

Other software have been tested and evaluated, but their application is not proposed in this study because the absence of a direct link or plugin with BIM model: so data, values and geometry need to be implemented as spreadsheet and then inserted into the LCA tools.

APPLICATION - CASE STUDY

Further step proposed in this paper is a test on different tools and database using the same case study for comparing the results.

BUILDING

a = b = 10 m
h = 3 m
WWR= 10%
P = 2(a+b) = 40 m
Sfloor = Sceiling = ab = 100 m^2
Swall = 4ah = 120 m^2
Swind = 0,1 Swall = 12 m^2
Sdisp = Sfloor + Sceiling + Swall
= 2ab + 4ah = 320 m^2
V = abh = 300 m^3
S/V = Sdisp / V = 1.07

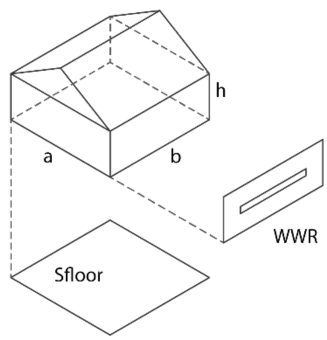


Figure 1 - Case study characteristics

The proposed case study (Figure 1) concerns a small residential building, which could be built with two different kind of structure: a masonry envelope and a wooden one. The envelope energy performances were defined in the technological and thermal characteristics according to the Italian law D.M. 26/06/2015 [26]. The building is located in Venice area (Italian Climate Zone E), according to the Italian law (Table 1).

Table 1 - Thermal Transmittance for each technological component of the two different structures of case study.

	Thermal Transmittance U [Wm^{-2}K^{-1}]	
	Case 1, masonry building	Case 2, wooden building
Basement	0.21	0.21
Wall	0.17	0.21
Flat Floor	0.18	0.19
Roof	0.19	0.18
Window	0.99	0.99

SYSTEM BOUNDARIES AND DELIMITATIONS

The analysis accounts for a full Cradle-to-Grave life cycle of the design process, including material manufacturing, maintenance and replacement, eventual end-of-life. The lifespan is considered for 50 years.

The two buildings are described with two different construction typologies, so the environmental assessment recognizes Revit categories, technological components, materials and energy used across all life cycle stages. The Life Cycle Stages are presented and analysed according to EN 15804 and EN 15978, as described in Table 2.

Table 2 - Life Cycle Stages according to EN 15804.

Life Cycle Stages	Sections	Data references
Product Stage	A1: Raw material supply	Quantity Take-off by Revit abacus of materials and integration with database, GaBi US (Tally®) and Ecoinvent (One Click LCA™).
	A2: Transport	
	A3: Manufacturing	
Construction Process Stage	A4: Transport to building site	Stage not evaluated
	A5: Installation into building	Data taken by database, GaBi (Tally®) and Ecoinvent (One Click LCA™)
Use Stage	B1: Use / application	Stage not evaluated
	B2: Maintenance	Life span of the building as in case study is estimated 50 years.
	B3: Repair	
	B4: Replacement	
End of Life Stage	C1: Deconstruction / demolition	Calculation database, GaBi (Tally®) and Ecoinvent (One Click LCA™)
	C2: Transport	
	C3: Waste processing	
	C4: Disposal	
Benefit and Loads beyond the System Boundary	D: Recycling	

ASSESSMENT RESULTS AND DISCUSSION

In order to understand the role of BIM and LCA integration in the evaluation of environmental impacts of building materials, this research a preliminary application of LCA tools on Autodesk® Revit® that aims to calculate the environmental impacts of the selected building materials.

Both Tally® and One Click LCA™ allow to investigate the direct impact of each materials to identify which ones are causing the highest environmental impact in any given category.

The identification of materials is the most important stage in the plugin use because it depends on the database quality, the availability, the congruence of information, the presence of specific products. Even if the quantity of available materials is restricted, Tally® interface presents an organized structure, an easily research filters and also it presents a very detailed characterization of materials (thermal properties, density, take-off method, service life).

The results of environmental impact given by the analyses are selected and discussed with reference to the Global Warming Potential (GWP) [kg CO_2 eq] and the

Primary Energy Demand (PED) [MJ]: the selection of these environmental impacts is still the object of study in the research activities of RESTORE Cost Action and the requirements described in the Materials Petal Handbook [27] for the achievement of the Living Building Challenge certification.

The GWP is a measure of greenhouse gas emissions, such as carbon dioxide and methane. These gases increase the absorption of radiation emitted by the earth. This may in turn have adverse impacts on ecosystem, human health, and material welfare [28]. The PED is a measure of the total amount of primary energy extracted from the earth: PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.

The results of both alternatives of case study are presented and discussed (Table 3, Table 4).

Impact results are quite different due to the adoption of databases: in Tally® the GaBi data are intended to represent the United States region and the year 2013, while in One Click LCA™ this research adopted Ecoinvent with a selection of France market data, due the not available collection for Italy. In fact, during the workflow of materials analysis, the connection from Revit abacus to LCA database is developed by a selection the available list of materials, by a choice among those with similar characteristics and by the conversion of service life.

Table 3 - Environmental impact for masonry building

	GWP [kgCO_2eq]		PED [MJ]	
Stage	Tally®	One Click LCA™	Tally®	One Click LCA™
A1-A3	82’280	50’960	1’074’010	966’797
B1-B6	339’268	330’289	5’678’943	5’695’184
C1-C4, D	7’303	6’227	111’898	105’442
Total	428’851	388’676	6’864’851	6’767’423
		-9.4%		*-1.4%*

Table 4 - Environmental impact for wooden building

	GWP [kgCO_2eq]		PED [MJ]	
Stage	Tally®	One Click LCA™	Tally®	One Click LCA™
A1-A3	41’928	44’428	913’590	1'142’400
B1-B6	349’223	323’562	5’752’942	5'555’106
C1-C4, D	21’093	953	109’350	16’661
Total	412’244	368’944	6’557’182	6’714’166
		-10.5%		*2.4%*

Moreover, Tally® and One Click LCA™ present different materials selection and calculations; while One Click LCA™ considers all materials separately, in Tally® the default procedure gives the possibility to choose how to consider a component: for example, a masonry wall could be treated as a single whole impact, or as sum of different layers, so the mortar and the finishing are considered as distinct materials. This is a positive plus for Tally®, but also it needs more attention into the construction of the building model in both tools.

The same situation is given for other materials: for example, in case of reinforced concrete component, Tally® requires to specify the quantity of concrete and steel in the same label; One Click LCA™ interface need to insert a new layer in BIM model linked to the reinforcement and then to choose the proper code “reinforced steel for concrete structures” in the database. In this case the user had to make more attention and to alter the BIM model in order to consider all the layers for the LCA; this is the reason why the research has ignored the quantity of mortar in Tally®, in such a way to conform the quantity as in One Click LCA™.

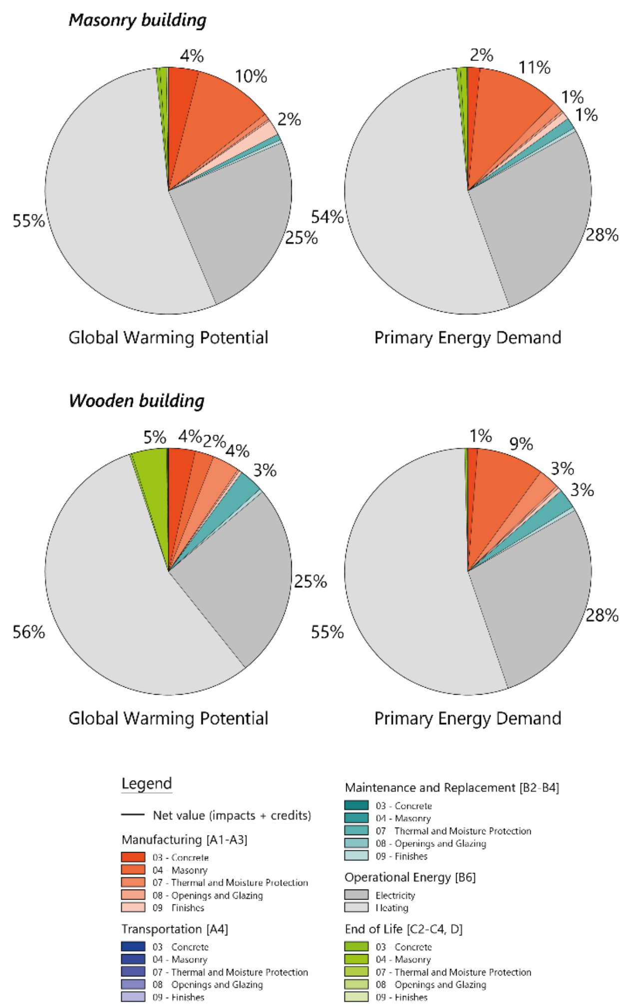


Figure 2 - Environmental impact by Tally® calculation for masonry and wooden building

The results of LCA are given in a descriptive report, spreadsheet file, or graphical dashboards (Figure 2, Figure 3) that provides a summary of all energy, construction, transportation, and materials inputs in the study.

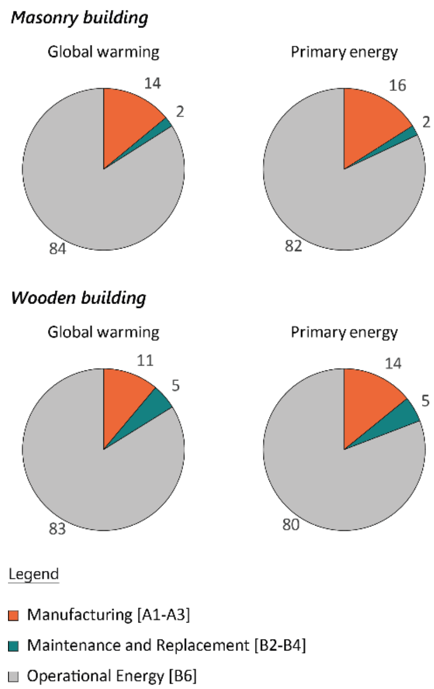
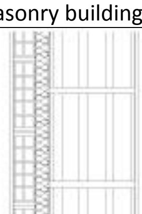


Figure 3 - Environmental impact by One Click LCA™ calculation for masonry and wooden building

The chosen of database is more evident in case of comparation of tool, as shown in the results for masonry external wall (Table 5). In Tally®, the database doesn't list type of hollow brick, so the analysis was conducted using a generic brick, even if with a higher impact than hollow brick. So, for comparing the outputs, the solid brick was selected in both software, even though the One Click database gives data for hollow brick.

Table 5 - Environmental impact for masonry external wall

Masonry building				
				
Materials	GWP [kgCO2eq]		PED [MJ]	
	Tally®	One click	Tally®	One click
Brick	31'2412	18'708	526'687	426'403
Mortar	7'849	4'253	45'584	108'819
EPS	795	1'045	23'524	17'260
Plaster	323	7'387	7'111	92'801
Total	40'209	31'392	602'906	645'283
		-22%		+7%

The high value of GWP in Tally® can be due to the absence of a materials with characteristics comparable to mortar plaster; as consequence cement data was selected, even if the higher impact than a lime mortar usually used as a finish for the walls.

CONCLUSIONS

The paper evaluates the interoperability of LCA tools a BIM software in order to evaluate environmental impacts in the construction sector throughout the entire lifecycle of building materials; in particular this study evaluates the available plugins for Autodesk® Revit®: Tally® and One Click LCA™.

In Tally® the user could define relationships between BIM elements and construction materials from the database, while working on a Revit model. The result is LCA on demand, and an important layer of decision-making information within the same time frame, pace, and environment that building designs are generated.

One Click LCA™ works with structural and architectural models and is able to adapt to material labelling practices. The cloud service to which the plugin connects detects the materials used in your model and calculates their environmental impacts automatically. Databases should be enhanced due to the difficulty in finding the specific products for the buildings within the respective country market and the environmental label of materials.

Some relevant notes are reported according to the workflow during the application.

The Tally® application works directly in Revit, while One Click LCA™ does the analysis in the cloud.

The tools present different procedure for materials selection and method of calculation; One Click LCA™ considers materials separately, and the list of products is organized by assessment method and by country source; Tally® allows to choose how to consider a component and the layer of inner materials with a strict connection and cohesion to Revit, even if the available list of products is quite delimited.

Both tools allow a comparison of construction technology and choice of materials, giving exhaustive reports, charts for evaluate the impacts of products, materials at each stage of life span, and also spreadsheets for further data elaboration (especially in One Click LCA™).

The outputs given by a test on the two type of buildings shows how the use of both tools gives similar values only for PED (about 1.5%), not for GWP (about 10%); the differences emerged using different databases, that get available not the same products, so the environmental impact of each material presents very different values (about 22% average). These issues could be solved with a deep knowledge of manufacturing process of materials, but first, in relation to the aim of this research, it needs an awareness of database content and the availability to modify and add database values to the tools, still precluded by software houses.

The next step of the research will regard the analysis and the achievement of environmental requirements according to Living Building Challenge, in term of embodied carbon footprint and full LCA calculation.

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