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EcoHestia: A comprehensive building environmental assessment scheme, based on Life Cycle Assessment

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Abstract

The sustainability assessment of building materials presents a major challenge the building physics community must approach, in order to establish justified sustainable solutions for the built environment. This study introduces EcoHestia, a comprehensive environmental building assessment tool, whose operation is based on a standardized, transparent, verifiable and internationally recognized approach life cycle approach (ISO 14040 series). The methodology as well as the rationale of EcoHestia is presented in detail. The major parameters which are considered, and the required assumptions for the development and establishment of the proposed building materials sustainability scheme are introduced and discussed in detail. A case study concerning the sustainability assessment of two buildings with the use of EcoHestia is presented and discussed.

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Keywords: Building material; Life Cycle Assessment; EcoHestia; Sustainability

1. Introduction

The construction and use of buildings in the EU account for about half of all our extracted materials [1] and energy consumption [2] and about a third of EU's water consumption [3]. The sector also generates about one third of all waste [4] and is associated with environmental pressures that arise at different stages of a building's life-cycle including the manufacturing of construction products, building construction, use, renovation and the management of building waste

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[5]. To enable professionals, decision makers and investors throughout the EU to use life-cycle aspects, they need empirical based, reliable, transparent and comparable data, which in turn will have to be based on clear indicators for building performance which combine the objectives of different public and private requirements [6]. The most widely employed methodology for addressing the sustainability performance of products and processes, including building materials, is the Life Cycle Assessment (LCA). LCA is a technique which enables the assessment of the environmental impacts associated with all the stages of a product's life from cradle to grave. LCA is based on a standardized, transparent, verifiable and internationally recognized approach life cycle approach (ISO 14040 series)[7].

The most established building materials databases currently available are the database of the Athena Sustainable Materials Institute [8] and the Green Guide of the Building Research Establishment (BRE) [9].

- The Athena Institute offers the only LCA-based tools in North America for whole buildings and assemblies. Athena has the most in-depth, complete and robust LCA databases for North American construction materials. Athena provides a user-friendly mechanism for designers to access the LCA databases and quickly estimate footprint of a building assembly or a whole building in terms of the following Impact Category Indicators: Global Warming Potential, Acidification Potential, Eutrophication Potential, Ozone Depletion Potential, Human Health Respiratory Effects Potential, Fossil Fuel Depletion and Photochemical Ozone Creation.
- The Green Guide is part of BREEAM (BRE Environmental Assessment Method) an accredited environmental rating scheme for buildings developed in the UK. The Green Guide contains more than 1500 specifications used in various types of building. Green Guide uses its own ranking system from A+ to E, where A+ represents the best environmental performance and E the most environmental impact. The Green Guide considers the following Impact Category Indicators: Climate change, Water extraction, Mineral resource extraction, Stratospheric ozone depletion, Human toxicity, Ecotoxicity to Freshwater, Nuclear waste (higher level), Ecotoxicity to land, Waste disposal, Fossil fuel depletion, Eutrophication, Photochemical ozone creation, Acidification.

The purpose of this study is to introduce EcoHestia. a comprehensive environmental building assessment tool, whose operation is based on a standardized, transparent, verifiable and internationally recognized approach life cycle approach (ISO 14040 series). In Section 2 a brief introduction of EcoHestia is provided. Section 3 focuses on the methodology used to develop EcoHestia and in Section 4 the environmental impact of two buildings, assessed with the use of EcoHestia, is presented and discussed.

2. EcoHestia: A comprehensive building environmental assessment scheme, based on Life Cycle Assessment

EcoHestia is a building materials Life Cycle Assessment (LCA) database developed by the Sustainable Energy Research Group [10]. EcoHestia enables the implementation of whole- building cradle to site Life Cycle Assessment, considering all the inputs and outputs, including materials, energy and waste, associated with the construction of the building. EcoHestia is based on a standardized, transparent, verifiable and internationally recognized approach - the ISO 14040 series.

The main features of EcoHestia are the following:

- it delivers the environmental performance and the level of sustainability of any building.
- it enables comparison of different building designs, from an environmental perspective.
- it enables assessment of the energy efficiency of buildings
- it supports stakeholders environmental based decision- making

Currently the following building materials are included in the EcoHestia database.

- Aluminium, PVC, Float Flat Glass
- Brick, Plasterboard, Tiles
- Cement, Plaster
- Concrete (C10/ C15, C16, C20/ C25, C35)
- Thermal Insulating Materials (EPS, Mineral wool)
- Paint (exterior, interior), Waterproofing, Polyethylene film
- Plywood
- Steel

The straightforwardness and user- friendliness operation of the environmental building assessment tool EcoHestia provides the users with several options for the utilization of the generated results. The results generated by EcoHestia predict values for the environmental performance of a building, and they address the potential environmental impacts caused by the construction of the building. The EcoHestia impact results, which are calculated on a Key Performance Indicators (KPIs) basis, enable the objective assessment of the sustainability level and the environmental performance of different buildings or building designs by quantitative indicating which performs better. The environmental building assessment tool also facilitates the evaluation of the energy efficiency of buildings which share similar designs characteristics but incorporate different insulating materials. Through the most efficient use of resources or energy and by allowing the identification of alternative options, EcoHestia also achieves the lowering of the overall construction costs, as well as contributes to the cost savings. Furthermore, EcoHestia may also supports decision- making based on the key objectives of the project and the involved stakeholders.

Taking into consideration the numerous benefits of EcoHestia, possible applications include

- the industry, including civil engineers, quantity surveyors (QS), and environmental building design experts, employs EcoHestia for the assessment of alternative technical building design options and systems for the realization of the most sustainable building projects.
- research, as a reference point for the research community on the application of LCA in the construction industry. EcoHestia supports researchers in the implementation of whole- building LCA through the exploitation of the generated results or through providing validation to the results of their study.
- policy- making. Governmental and regulative bodies can exploit EcoHestia in a policy making context, as quantitative data can be used for the development of strategies on building designs and decisions about introducing subsidies for construction materials and building systems.

3. EcoHestia Methodology

3.1. EcoHestia Databases

EcoHestia performs 'cradle- to- site' LCA, taking into consideration the pre- utilization phase of the building, comprised of the following stages:

- Extraction/ acquiring of the raw materials
- Transportation of the raw materials to the manufacturing/ processing plant
- Transformation or manufacturing of the raw materials into the final product (construction materials or building element)
- Transportation of the final product to the construction site

The operation of EcoHestia is conducted according to the principles described in the ISO 14040 series on Life Cycle Assessment [7], providing transparency and reliability of its generated results. It employs the Life Cycle Impact Assessment (LCIA) - CML 2001 methodology [11]. CML is the methodology of the Centre for Environmental Studies of the University of Leiden, whose results are expressed in terms of emissions to the environment on a series of environmental impact categories. Accordingly, EcoHestia generates the impact of the investigated building on the following impact categories, also described in detail in Table 1:

- Global Warming Potential (GWP 100 years)
- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Ozone layer Depletion Potential (ODP, steady state)
- Abiotic Depletion Potential of elements and fossils (ADP Elements and ADP Fossils)
- Human Toxicity Potential (HTP)
- Photochemical Ozone Creation Potential (POCP)

Additionally, EcoHestia also generates the following:

- Building' s embodied energy
- Building' s carbon footprint.

Table 1. Impact categories indicators generated by EcoHestia

Impact Category Indicators	Characterization Model	Unit
Global Warming Potential (GWP)	This value deals with all greenhouse gases (arises from emissions of CO_2, and *methane*) that may cause the earth's temperature to rise and have negative effect on the ecosystem, human health and material welfare.	*kg CO_2- Eq.*
Acidification Potential (AP)	This impact is caused by deposition of acidifying pollutant on soil, water, organisms, ecosystems & materials such as *sulphur* and *nitrogen*.	*kg SO_2- Eq.*
Eutrophication Potential (EP)	This category cover all impacts of high environmental levels of macronutrients (*phosphorous* and *nitrogen*) causing high biomass production in aquatic and terrestrial ecosystems. For example air pollutants, wastewater etc.	*Kg phosphate-Eq.*
Ozone Depletion Potential (OZP)	This impact arises with the increased ultraviolet radiation from the sun which depletes the ozone layer when *CFCs* and *HCFCs* reach the stratosphere.	*kg R11- Eq.*
Abiotic Depletion Elements (ADP Elements)	This category describes the reduction of the global amount of non-renewable raw materials. It covers the availability of natural elements in general.	*kg Sb-Eq.*
Abiotic Depletion Fossil (ADP Fossil)	This category indicator is related to the use of fossil fuels (oil, coal and natural gas) lost from reserves.	*MJ*
Human Toxicity Potential (HTP)	This category covers the impact on human health of all toxic substances emitted to air, water and soil.	*kg DCB-Eq.*
Photochemical Ozone Creation Potential (POCP)	This impact is caused by releases of hydrocarbons to atmosphere where produce ozone and can arise at any stage of the life cycle.	*kg Ethene- Eq.*

The reliability of the EcoHestia results originates from the fact that its database is based on the characteristics of the local construction industry and on primary data provided by local product manufacturers. Additionally, the impact from the energy consumed for the manufacturing of the building materials is also representative of the country's energy mix, whereas the fuel required for the transportation of the materials is also according to the country's specifics.

If it is to be used effectively, it is also important to understand the limitations of EcoHestia. Primarily, the EcoHestia values reflect the fact that the impact category results are based on a relative approach and that they present potential environmental effects, rather than predict actual impacts. At the present phase, the database of EcoHestia is comprised of 21 LCAs of construction materials and building elements. These represent a very limited number of LCAs of building elements for the implementation of whole- building analysis, however additional LCAs of construction materials and building elements are anticipated to be developed and incorporated into EcoHestia.

3.2. EcoHestia Application

EcoHestia determines the level of sustainability of any building in a four step process:

1. Introduction of the construction materials' quantities (in kg) required for the construction of the whole building
2. Computation of the environmental impacts of the building by EcoHestia
3. Assessment of different technical building design options
4. Optimisation of building design according to the objectives

The methodology followed for the implementation of the LCA of a single building element for its incorporation in the EcoHestia database is presented for the case of clay brick. Table 2 presents the Life Cycle Inventory (LCI) for the production of 1 kg of clay brick (Functional unit). The LCI consists of a detailed tracking of all the in- and outflows of the system under investigation. Input flows typically consist of raw materials and energy in different forms, while the output flows may include useful products, solid and water- borne wastes, atmospheric emissions, and other waste streams. Figure 1 present the Sankey diagram indicating the processes involved in the manufacturing of clay brick, as well as the mass balance for the manufacturing of 1 kg of clay brick.

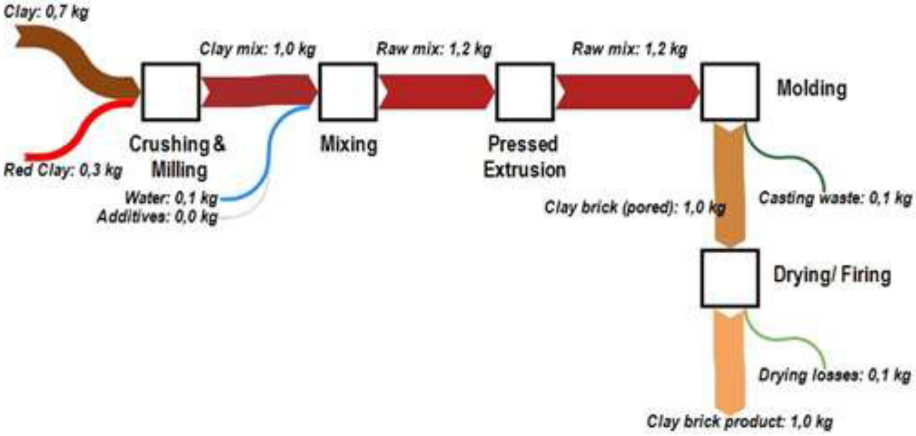

Fig. 1. Sankey diagram of the mass balances for the production of 1 kg of clay brick

Table 2. Data Inventory for the production of 1 kg of clay brick - Input

Inputs	Quantities	Units
Raw materials - Clay	0.740	kg
Raw materials - Red Clay	0.260	kg
Raw materials - Water	0.130	kg
Raw materials - Additives	0.020	kg
Energy - Electricity from HFO (KWh)	0.908	kWh
Energy - Diesel	0.00064	kg
Transport(ELCD) of Clay	4.75	km
Transport(ELCD) of Red Clay	18.20	km

Table 3. Data Inventory for the production of 1 kg of clay brick - Output

Outputs	Quantities	Units
	Materials	
Product (Brick)	1	kg
Emissions - Inorganic emissions to air		
Carbon dioxide (CO2)	0.373	kg
Carbon monoxide (CO)	1.2×10^{-4}	kg
Nitrogen oxides (NO_X) (eq. NO_2)	7.21×10^{-4}	kg
Nitrogen (atmospheric nitrogen)	4.29×10^{-6}	kg
Oxygen	2.99×10^{-5}	kg
Sulphur dioxide (SO_2)	0.00206	kg
Water vapour	0.482	kg
Water (evapotranspiration)	0.0833	kg
Emissions - Organic emission to air (group VOC)		
Methane (CH4)	3.61×10^{-4}	kg
Other emission to air		
Exhaust	1.47	kg
Particle to air		
Dust (PM2,5-PM10)	2.2×10^{-5}	kg
Dust (PM2,5)	3.95×10^{-5}	kg

4. EcoHestia Application – Case Studies

Provided as examples of the effectiveness and usefulness of the environmental building assessment tool EcoHestia, a case studies of whole- building LCAs is presented. The case study concerns the LCA of a level- ground, two- storey residential building located in Paralimni, Cyprus was implemented using EcoHestia. The total useful floor area of the building is 374 m^2, including both covered and uncovered areas, while the total height of the building is 7.5 m. According to the Bill of Quantities (BoQ), the main construction consists of concrete, brickwork, and plaster. Polystyrene was employed for building insulation purposes, and plasterboard was used between the internal walls. Also, the building has a flat roof with asphalt membrane polyester. The EcoHestia generated results for the case study building 1 are presented in Table 4. The table indicates the life- cycle impact of each of the building's element for the selected impact categories, based on the quantities provided by the user and the KPIs of the tool.

5. Conclusions

The key objective of this study was to introduce the building environmental assessment tool EcoHestia, a comprehensive building material LCA library, which allows the implementation of the whole-building LCA. This study presented the fundamentals of the EcoHestia LCA library, and introduced to the rationale of the total environmental analysis of building units. The bill of quantities of a case study building was evaluated against the EcoHestia KPIs on the environmental impact of each construction material. The effectiveness of adopting life cycle approaches for the environmental evaluation of buildings is highlighted in this work; nevertheless building environmental assessment tools and/ or databases embracing national or regional data have yet to be developed for a worldwide employment.

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Table 4. EcoHestia Whole Building Life-Cycle-Assessment

A/A	Description	Quantity	Unit	GWP [kg CO2-Equiv.]	AP [kg SO2-Eq.]	EP [kg Phosphate-Eq.]	ODP [kg R11-Eq.]	ADP Elements [kg Sb-Eq.]	ADP Fossils [MJ]	HTP [kg DCB-Eq.]	POCP [kg Ethene- Eq.]
A	**Concrete Works**										
	C20-25 (p=2400)	173	m^3	3.43E+05	2.80E+06	9.96E+05	1.66E+06	1.33E+05	4.24E+06	3.50E+04	1.49E+06
	C30-35 (p=2400)	100	m^3	2.02E+05	1.65E+06	5.88E+05	9.55E+05	7.73E+04	2.50E+06	2.07E+04	8.76E+05
B	**Reinforcement**	21807	kg	4.23E+04	2.51E+02	1.13E+05	2.03E+05	5.71E+04	8.22E+05	3.10E+03	1.44E+05
C	**Brickwork**										
	Brick 30cm thermal /14.20kg	148	m^2	9.03E+03	6.69E+04	8.61E+03	1.77E+05	2.74E+04	1.12E+05	9.33E+02	3.67E+04
	Brick 25cm thermal / 13.90kg	39	m^2	2.78E+03	2.06E+04	2.66E+03	5.46E+04	8.44E+03	3.47E+04	2.88E+02	1.13E+04
	Brick 20cm / 5.45kg	122	m^2	4.28E+03	3.17E+04	4.08E+03	8.39E+04	1.30E+04	5.33E+04	4.42E+02	1.74E+04
D	**Plasterboard (10cm)**	10.20	m^2	1.11E+04	9.14E+01	3.12E+03	5.12E+03	8.93E+02	1.39E+05	1.15E+03	4.88E+03
E	**Insulation**										
	Polystyrene (5cm)	519	m^2	6.38E+04	1.34E+05	1.35E+05	4.17E+04	1.84E+05	2.51E+06	2.71E+03	2.44E+05
F	**Plaster**	1013	m^2	5.93E+03	3.29E+04	1.25E+05	1.28E+05	1.62E+03	5.45E+04	4.13E+02	1.75E+04
G	**Interior Painting**	717	m^2	3.69E+01	1.03E+02	1.29E+02	1.08E+02	1.17E+02	1.16E+03	1.53E+00	2.03E+02
H	**Exterior Painting**	388	m^2	3.37E+01	8.85E+01	1.18E+02	1.04E+02	1.16E+02	1.08E+03	1.33E+00	1.86E+02
I	**Windows**	47.5	m^2	1.72E+03	8.27E+03	6.60E+03	2.29E+03	7.14E+03	2.30E+04	8.83E+01	5.59E+03
J	**PVC**	93	m^2	2.57E+01	6.62E+01	6.61E+01	1.23E+02	1.00E+02	5.30E+02	1.19E+00	8.09E+01
	TOTAL			6.85E+05	4.74E+06	1.98E+06	3.32E+06	5.10E+05	1.05E+07	6.48E+04	2.84E+06