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LCA Analysis of Three Types of Interior Partition Walls Used in Buildings †

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Abstract: Numerous studies have been done with the purpose of identify and try to reduce the impact generated by the construction industry, mainly focused on the use stage in the search to increase the energy efficiency. However, as these stage has been improved and the impact produced has been reduced, it has become evident the need to focus the research on the elements and life cycle stages that follow on the affectation scale. Therefore, the present research analyzes the importance of the embodied energy and the affectation generated by the materials with a LCA perspective, comparing one square meter of three different systems used as interior partition walls: hollow clay brick (HB), hollow concrete block (CB) and gypsum board (GB). The analyzed stages are from production of the materials to the building construction (stages A1–A5), using the Eco-invent database with the LCA manager software. The results of the analysis indicate the values of the environmental affectations and the consumptions made by each element during the analyzed stages. The comparison allowed to find that the constructive solution with mayor environmental affectation in the analyzed categories is the GB wall, and that is mostly done in the production stage (A1–A3).

Keywords: LCA; construction; partition walls; sustainable construction; materials

1. Introduction

The construction industry is a sector in constant development and growth, thus the consumption of resources used for this purpose and the associated environmental impacts are continuous. In Europe, this sector represents a third of the water consumption and the waste generated, as well as half of the extracted raw materials and energy used [1]. With the purpose of reduce the affectation of the sector, several actions and strategies have been implemented, to identify and try to reduce the impact generated. Between those strategies is the Life Cycle Assessment (LCA), which allows to determinate the consumptions made by an activity or process during all the Life Cycle Stages (LC) and quantifies their environmental impact, stablishing an objective evaluation and identifying the opportunity areas for improvement in the process.

LCA started at the end of the sixties [2] and is until 1997, that the International Standard Organization (ISO) and the Society of Environmental Toxicology and Chemistry (SETAC) developed the standardization of the methodology in the ISO 14000 series. In them, the concept of LCA is defined as a methodology that studies the inputs, outputs and environmental impacts of a system during its LC. Also, it stablishes four main phases: (1) Goal and Scope definition; (2) Inventory analysis (LCI); (3) Impact assessment (LCIA) and (4) Interpretation [3,4]. The LCA study in the construction sector has been done from different approaches, although it is based on a standard methodology, the studies responds to different needs, which translates into a variation of the analyzed parameters (functional unit, LC stages, methodology, etc.). However, common trends can be found during the comparison of different studies and their results. For example, numerous studies focused on the use stage of the building and the operation energy consumption can be found. They concluded that this phase has the highest consumption (90–95% of the total energy consumption) [5,6], and highlights the need to increase the energy efficiency of HVAC systems and the correct selection of materials used as the building envelope and insulation. Among these kind of studies, can be find the analysis of different constructive systems applied to an element [7–10], comparative analysis between traditional construction systems and ecologic materials [11,12] and some other analysis study the incorporation of recycled materials [13–16].

Considering the complexity involved in the evaluation of the environmental behavior of the construction, and in order to have a global perspective of the effects, it is necessary that the approach is not limited to the analysis of energy used during one single stage, but it requires an analysis of all the elements involved. And as the energy efficiency has increased and the consumption during the use stage has reduced, other stages and elements gain importance, such as the embodied energy of materials and the constructive elements used in the interior of buildings [17,18], which are studied in the present investigation. Studies focused on interior elements can be found [19–21], where it is shown that the difference between the affectations are usually related to the origin of the material [22]. Specific analysis of interior walls can also be found, for being one of the elements with the higher volume presence in buildings [23,24], and therefore with an important contribution in the affectations made to the environment. It should be noted that the impact categories and the analysis scopes are variated, which allows to observe the singularity of each study and that the development of more analysis can complement the existing information.

The present research takes in consideration the importance of the embodied energy, starting from the hypothesis that due to the nature and the process involving the elements of the different constructive systems of interior walls, during the stages of production to construction (A1–A5), different levels of affectation and consumption will be found. The main purpose of this paper is to obtain information about the affectation and consumptions generated by the selected materials; allowing to compare those elements and also provide information to designers and builders in the decision-making process for the design and selection of building elements (but with a perspective with environmental considerations).

2. Materials and Methods

Goal and Scope definition: The goal of the study is to identify and compare the environmental impacts produced by three constructive systems, from different materials, used as interior partition walls in Spain. Therefore, the location selected for the analysis is the city of Barcelona, for its European representativeness [25]. The information obtained pretends to offer relevant data, from an environmental approach, which complements the criteria of selection and design of materials, as well as to identify areas of opportunity to improve the processes. The scope of the analysis includes the module from cradle to gate with options (Stages A1–A5) [3]. The methodology used for the elaboration of the LCA is the established in the ISO 14040-44 [4], and with the stipulations of UNE EN-15804 [3]. The functional unit is one square meter of each interior partition wall system, the selected unit responds to the needs of comparability between the characteristics and properties of the samples, as it is a commonly used value in the construction sector and its regulations.

The interior partition walls are those constructive elements that separate the interior of a building. These can be load-bearing or non-load-bearing, the three samples comply the Spanish regulations [26], which establish that they must be able to support themselves and provide soundproofing to the enclosures they separate [27]. As shown in Figure 1, the selected samples are: Hollow clay brick wall (HB), concrete block wall (CB) and gypsum plasterboard wall (GB); each of the samples have a total thickness of 10 cm and the layers are as following:

1. Gypsum plasterboard wall (GB): drywall consisting on a galvanized cold formed Steel frame, with a ceiling channel of 7 × 3 × 3 cm and vertical studs of 6.9 × 3.8 × 3.6 cm every 60 cm; with a

gypsum plasterboard of 1.5 cm at both sides, the inner field with an insulation of a rigid panel of volcanic Rockwool of 7 cm and joined by steel screws.

2. Concrete block wall (CB): hollow concrete block of 40 × 20 × 8 cm, received with cement mortar (cement and sand ratio 1:8) and coated with 1 cm of gypsum plaster in both sides.
3. Hollow clay brick wall (HB): hollow clay brick block of 50 × 20 × 7 cm, received with cement mortar (cement and sand ratio 1:8) and coated with 1.5 cm of gypsum plaster in both sides.

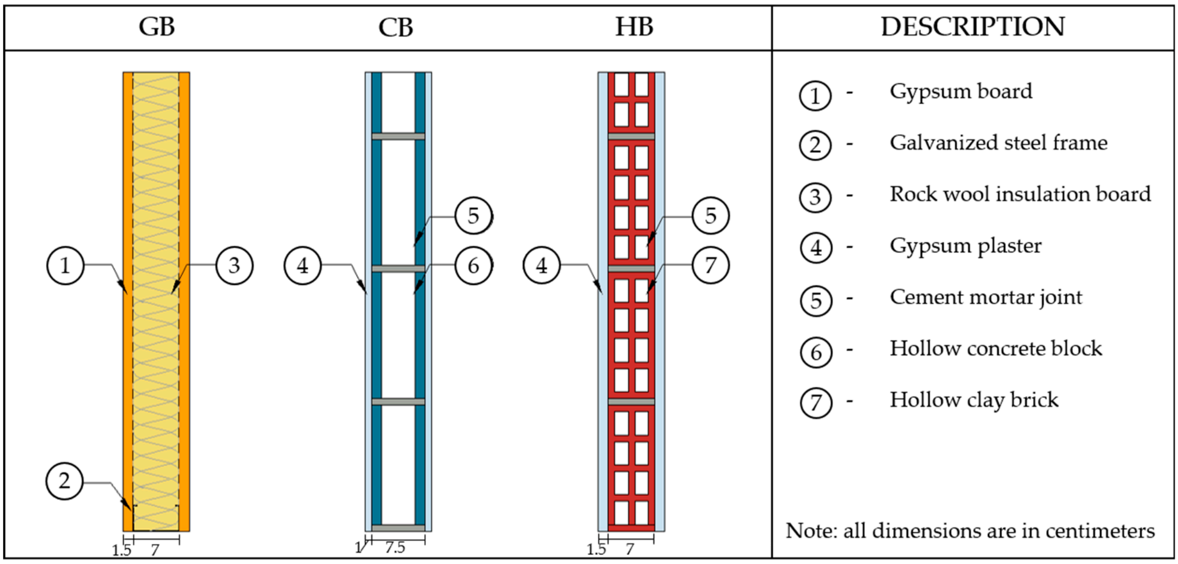

Figure 1. Constructive details and description of samples.

LCA: In order to make the LCI, data collection and quantification of energy input-output were required; as well as the affectation made by the analyzed systems. The database used for the LCI was Ecoinvent V3.0 [28], which is of recognized use in various European investigations due to its representativeness, evaluation transparency and accuracy of the data [9,13,29–31]. The Swiss Federal Offices and the ETH Zurich developed this database, which has a global level, and contains a wide spectrum of activities and systems; its selection for this research is because the information available in the Spanish field is limited or null. Thus, a local adaptation was made for the transport evaluation.

For the LCI in the stages A1–A3, an analysis and inventory of the materials, needed for each sample per functional unit, was required. The BEDEC database was used for establish the quantification of materials [32], the standard values in the database were corroborated manually (approximation and local technology). Since Ecoinvent uses different units for the evaluation (in function of the analyzed material or product), a calculation of the weight of each material was needed. The transport distances of materials were quantified (from factory to construction site), by the traveled kilometers by the material needed to build one square meter of each sample. For the above, the location of the factories and distributors, found in less than 100 km around of the selected construction site, were considered and the distances were averaged (the distances were measured with the Google Earth software) [33]. A truck of maximum 18 tons was considered for the transportation, with diesel fuel and a lifetime of 54,000 km/vehicle; this type of vehicle satisfies all the specifications for mobility of materials [34]. For the stage A4–A5, the need of lift the materials was considered, using a tower crane with twenty-six meters high, thirty-three meters jib and a lifetime of 10,000 h, to be used in a building with a high of 20.75 m according to the regulations in the city of Barcelona [35]. Finally, for the construction of the interior walls, it's required a range of manual techniques and not the use of specialized or with high impact machines; therefore the values derived of the use of minor tools were not considered in the analysis.

LCIA: The LCIA was established with the quantifications made in the LCI and with the software LCA Manager 1.3 (SIMPPLE, Tarragona, Spain). In this software, all the LCI data was added to evaluate the magnitude and importance of the environmental impacts of each of the analyzed systems. The LCA Manager software, developed by SIMPPLE, performs an environmental evaluation quantifying the environmental profile of process and products along all the LC; it is based on the ISO 14040/44:2006 methodology, which has six stages for its calculation: characterization, inventory, indicators, impacts, results and graphics [36]. For the environmental evaluation, the impact categories selected were the described by Eco-indicator 99 methodology [37]; which from an approach in function of the damage, expressed by eco-points, presents in numeric units a relation between the impact and the affectation caused for a process or material based on the LCA data. It includes three types of damages that are of interest for the present research: Human Health (HH) (climate change, ozone layer depletion, carcinogenic effects, respiratory effects and ionizing radiation); Ecosystem Quality (EQ) (ecotoxicity, acidification, eutrophication and land-use); and Resources (R) (which is the natural resources consumption, the energy needed to extract resources and the depletion of agricultural and bulk resources).

3. Results

After the characterization of materials and the modelling of the data in LCA Manager software (sustained by Ecoinvent data), the matrix of environmental impact were generated and produced according to Eco-indicator 99, which are necessary for obtaining the LCA results. The analysis allow to obtain the environmental profile of each of the samples and to identify which one of them causes a minor affectation—as in which of the analyzed stages is intensified or the impact is mayor.

In Figure 2 the results obtained by stage of LC are analyzed; it can be observed that for the three samples the stage in which a greater impact is generated is during A1–A3. In the case of GB, 1.98 points of affectation are generated, which is 1.24 more than the points obtained by CB and 1.09 more points than HB. The analysis of the impacts by LC stages, allows to identify that the production of the materials used in GB are those that require the improvement in their processing, which could be in the production of volcanic rock wool insulation, the metal studs and in the gypsum plasterboard [31,38].

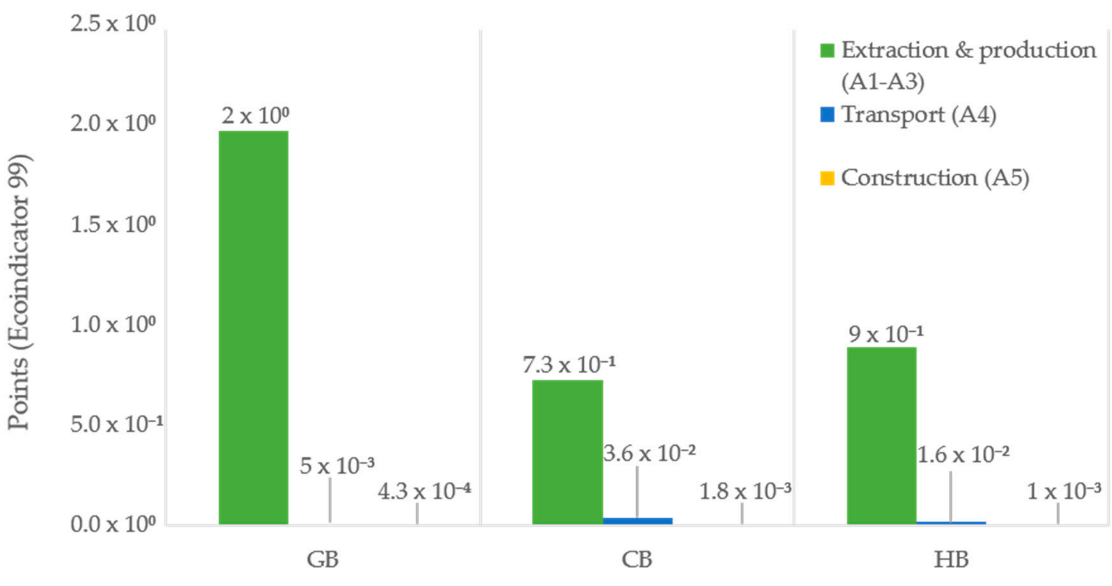

Figure 2. Resume of Eco-indicators by LC stages.

Figure 3 shows the resume of the points obtained by each sample in the three analyzed categories (HH, EQ and R) and also the indicators that compose them. Analyzing the main categories, can be seen that GB causes an average of 2.81 times more impact on the environment, than CB and HB. In addition, analyzing each sample is observed that GB gets twice as points in HH than in R, while in EQ gets just 0.15 points. HB and CB, have the same amount of points of affectation in HH (0.43 points) and in EQ, the affectation has minimum differences (obtaining 0.05 and 0.03 points respectively). Finally, HB has 60% more consumption of R than CB.

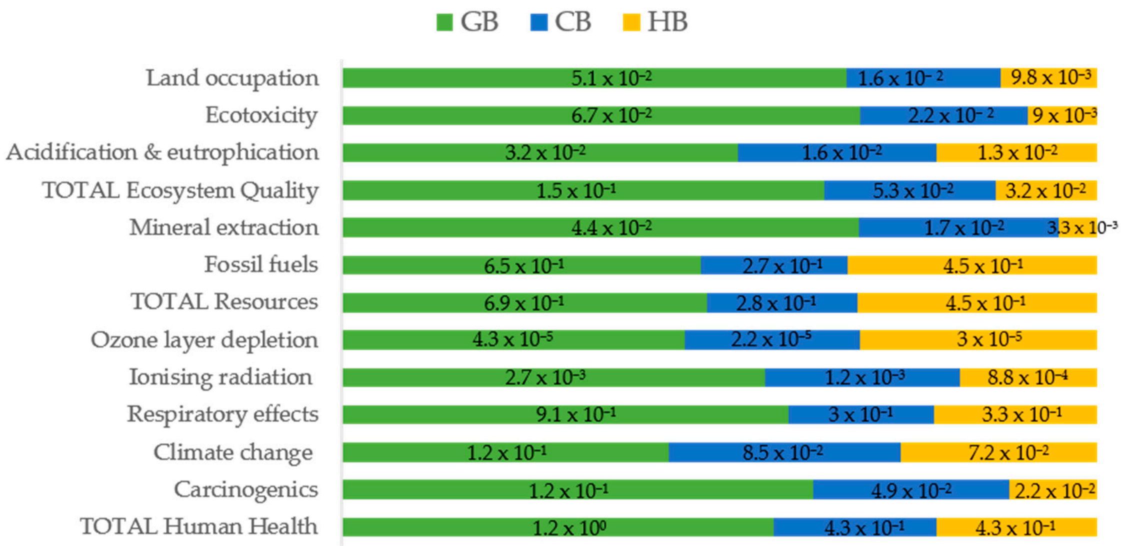

Figure 3. Resume of main Eco-indicators for each sample.

In order to perform a comparative analysis of the three samples, with a better understanding of the Figure 3, a description in detail of each indicator contained in the main categories is made:

- Land occupation: GB has three times more points than CB and five more than HB.
- Ecotoxicity: GB has three times more points than CB, and seven times more than HB.
- Acidification and eutrophication: GB has twice points than CB and HB.
- Mineral extraction: GB has 0.04 more points than HB, and 0.02 more points than CB.
- Fossil fuels: GB has 0.20 points more than HB and 0.38 more than CB.
- Respiratory effects: GB has 2.73 times more points than HB and 3 times more than CB.
- Climate change: GB has 0.04 points more than HB and 0.03 more than CB.
- Carcinogenic: GB has 0.09 more points than HB and 0.068 more than CB.
- Ozone layer depletion and Ionizing radiation are the indicators than generate the less impacts.

It can be seen that the GB sample is the one with the higher impact in almost all the categories; this is related to the nature and composition of the materials in the samples. GB sample has three main components that made the higher affections to the environment: gypsum plasterboard, steel stud and insulation[31–38]. While HB and CB samples has only one central component that makes the affectation, in the CB sample the principal contributor is the cement used in the block [39] and in the HB sample, the higher contribution is done by the production of the clay bricks [40].

4. Discussion and Conclusions

Through the realization of the ACV of the three systems used as interior partition walls in buildings and following the methodology established by the regulations, the impact generated by each of the samples is obtained, fulfilling the main objective. The results indicate that GB sample is the system with the mayor affectation in the three categories (HH, EQ, R), being HH the category with the higher score. Likewise, HB is identified as the system with lower impact in the categories. In addition, it was established that the extraction and production, is the stage that has the higher impact for the three samples, this is due to the processes necessary to obtain the raw materials and the production of elements [39]. In several studies described in the introduction, it has been concluded that the affectations generated by each material are linked to the nature and manufacturing process of the materials. In the present research, it is shown that these stages (A1–A3) are the ones that generated the higher affectation. It is observed that the production of the GB sample materials, gypsum plasterboard, insulation and steel studs, are the main contributors of affectation.

The results of the research provide information to professionals in the construction sector that will allow them to consider an environmental approach in the decision—making process (in addition to the economic factor), thus fulfilling the second objective of the research. Finally, in the analysis is not considered the incorporation of recycled materials in the manufacture of any of the products used in the samples, if such incorporation is considered, it might be presented as a study perspective of more environmental value and interest, where the reduction of the affectations could be exposed trough the implementation of this measure.

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References

1. Comisión Europea. Oportunidades para un uso más eficiente de los recursos en el sector de la construcción. In *Estrés en el Trabajo: Un reto Colectivo*; OIT: Ginebra, Switzerland, 2014; 52014DC0445, ISBN 9789223306410.
2. Scientific Applications International Corporation (SAIC). *Life-Cycle Assessment: Principles and Practice*; National Risk Management Research Laboratory, Office of Research and Development, US Environmental Protection Agency: Cincinnati, OH, USA, 2006; pp. 4–5.
3. AENOR. AENOR: Norma UNE-EN 15804:2012+A1:2014. 2014. Available online: https://www.aenor.com/normas-y-libros/buscador-de-normas/UNE?c=N0052571 (accessed on 9 May 2018).
4. Gestión Ambiental—Análisis del Ciclo de Vida—Requisitos y Directrices. ISO 14044. ISO 14044:2006(es); 2006. Available online: https://www.iso.org/obp/ui/#iso:std:iso:14044:ed-1:v1:es (accessed on 27 February 2018).
5. Hallquist, A. Energy consumption: Manufacture of building materials and building construction. *Habitat Int.* **1978**, *3*, 551–557.
6. Sartori, I.; Hestnes, A.G. Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy Build.* **2007**, *39*, 249–257.
7. Citherlet, S.; Defaux, T. Energy and environmental comparison of three variants of a family house during its whole life span. *Build. Environ.* **2007**, *42*, 591–598.
8. Menoufi, K.; Castell, A.; Farid, M.M.; Boer, D.; Cabeza, L.F. Life Cycle Assessment of experimental cubicles including PCM manufactured from natural resources (esters): A theoretical study. *Renew. Energy* **2013**, *51*, 398–403.
9. Monteiro, H.; Freire, F. Life-cycle assessment of a house with alternative exterior walls: Comparison of three impact assessment methods. *Energy Build.* **2012**, *47*, 572–583.
10. Rincón, L.; Castell, A.; Pérez, G.; Solé, C.; Boer, D.; Luisa, F. Evaluation of the environmental impact of experimental buildings with different constructive solutions using Life Cycle Assessment and Material Flow Analysis. *Appl. Energy* **2013**, *109*, 544–552.
11. Rivela, B.; Cuerda, I.; Olivieri, F.; Bedoya, C.; Neila, J. Análisis de Ciclo de Vida para el ecodiseño del sistema Intemper TF de cubierta ecológica aljibe. *Mater. Constr.* **2013**, *63*, 131–145.
12. Saiz, S.; Kennedy, C.; Bass, B.; Pressnail, K. Comparative life cycle assessment of standard and green roofs. *Environ. Sci. Technol.* **2006**, *40*, 4312–4316.
13. Knoeri, C.; Sanyé-Mengual, E.; Althaus, H.J. Comparative LCA of recycled and conventional concrete for structural applications. *Int. J. Life Cycle Assess.* **2013**, *18*, 909–918.
14. Faleschini, F.; de Marzi, P.; Pellegrino, C. Recycled concrete containing EAF slag: Environmental assessment through LCA. *Eur. J. Environ. Civ. Eng.* **2014**, *18*, 1009–1024.
15. Turk, J.; Cotic, Z.; Mladenovic, A.; Sajna, A. Environmental evaluation of green concretes versus conventional concrete by means of LCA. *Waste Manag.* **2015**, *45*, 194–205.
16. Marinković, S.; Radonjanin, V.; Malešev, M.; Ignjatović, I. Comparative environmental assessment of natural and recycled aggregate concrete. *Waste Manag.* **2010**, *30*, 2255–2264.
17. Fay, R.; Treloar, G.; Iyer-Raniga, U. Life-cycle energy analysis of buildings: A case study. *Build. Res. Inf.* **2000**, *28*, 31–41.

18. Buyle, M.; Braet, J.; Audenaert, A. Life cycle assessment in the construction sector: A review. *Renew. Sustain. Energy Rev.* **2013**, *26*, 379–388.
19. Nebel, B.; Zimmer, B.; Wegener, G. Life cycle assessment of wood floor coverings: A representative study for the German flooring industry. *Int. J. Life Cycle Assess.* **2006**, *11*, 172–182.
20. Bowyer, J. *Life Cycle Assessment of Flooring Materials: A Guide to Intelligent Selection*; Dovetail Partners Inc.: Minneapolis, MN, 2009; p. 10.
21. Jönsson, Å.; Tillman, A.-M.; Svensson, T. Life cycle assessment of flooring materials: Case study. *Build. Environ.* **1997**, *32*, 245–255.
22. Nicoletti, G.M.; Notarnicola, B.; Tassielli, G. Comparative Life Cycle Assessment of flooring materials: Ceramic versus marble tiles. *J. Clean. Prod.* **2002**, *10*, 283–296.
23. Mateus, R.; Neiva, S.; Bragança, L.; Mendonça, P.; Macieira, M. Sustainability assessment of an innovative lightweight building technology for partition walls—Comparison with conventional technologies. *Build. Environ.* **2013**, *67*, 147–159.
24. Broun, R.; Menzies, G.F. Life cycle energy and environmental analysis of partition wall systems in the UK. *Procedia Eng.* **2011**, *21*, 864–873.
25. Instituto de Estadística de Cataluña. Idescat. Indicadores de la Unión Europea. Available online: https://www.idescat.cat/indicadors/?id=ue&lang=es (accessed on 11 June 2018).
26. Ministerio de vivienda de España. *Código Técnico de la Edificación*; Real Decreto, 314. Marzo 2006. Madrid, Spain, 2006. Available online: https://www.codigotecnico.org/index.html.
27. Ministerio de vivienda de España. CTE-Documento básico de Protección frente al ruido (DB-HR). 2007; Available online: https://www.codigotecnico.org/index.php/menu-proteccion-frente-ruido.html.
28. E. Z. Swiss Federal Offices. Ecoinvent Database, V3.0. 2007. Available online: https://www.ecoinvent.org/database/database.html (accessed on 21 April 2018).
29. Gámez-García, D.C.; Gómez-Soberón, J.M.; Corral-Higuera, R.; Almaral-Sánchez, J.L.; Gómez-Soberón, M.C.; Gómez-Soberón, L.A. LCA as comparative tool for concrete columns and glulam columns. *J. Sustain. Archit. Civ. Eng.* **2015**, *11*, 21–31.
30. Ortiz, O.O.; Asqualino, J.P.; Castells, F. Evaluación ambiental basada en el análisis del ciclo de vida (ACV) en la fase de construcción de una edificación en Cataluña. *Afinidad* **2010**, *67*, 175–181.
31. Ferrández-García, A.; Ibáñez-Forés, V.; Bovea, M.D. Eco-efficiency analysis of the life cycle of interior partition walls: A comparison of alternative solutions. *J. Clean. Prod.* **2016**, *112*, 649–665.
32. Instituto de Tecnología de la Construcción. *Banco de Precios BEDEC ITeC*; ITEC: Barcelona, Spain, 2017.
33. Google. Google Earth. Available online: https://www.google.es/intl/es/earth/index.html (accessed on 21 May 2018).
34. Ministerio de Fomento de España. Vehículo a Motor de 2 ejes-Pesos (Vehículos de Motor)-Pesos-Pesos y Dimensiones-Inspección y Seguridad en el Transporte-Transporte Terrestre-Áreas de Actividad-Ministerio de Fomento. Available online: https://www.fomento.gob.es (accessed on 4 June 2018).
35. Administración Pública del Área Metropolitana de Barcelona. Secció 3a Zona de Densificació Urbana: Subzona I, Intensiva I Subzona II, Semiintensiva (13), Pub. L. No. 321–328, 173 (2004). Available online: www3.amb.cat/normaurb2004/Docs/Normes.htm (accessed on 17 May 2018).
36. Simpple Efficient Solutions., 2010. Manual de usuario LCA Manager Versión 1.3. Tarragona, España: Simpple. Available online: https://www.simpple.com/es/productes/lcamanager/ (accessed on 7 April 2018).
37. Pré Consultants., 2000. Eco-Indicator 99—Manual for Designers. In *Ministry of Housing, Spatial Planning and the Environment*. Available online: http://www.pre-sustainability.com/download/manuals/EI99_ Manual.pdf (accessed on 19 April 2018).
38. Bribián, I.Z.; Capilla, A.V.; Usón, A.A. Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. *Build. Environ.* **2011**, *46*, 1133–1140.
39. Monahan, J.; Powell, J.C. An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a LCA framework. *Energy Build.* **2011**, *43*, 179–188.
40. Koroneos, C.; Dompros, A. Environmental assessment of brick production in Greece. *Build. Environ.* **2007**, *42*, 2114–2123.