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**BIM-LCA Construction Project****Spanish Case Study Report: LCA of a Single-family house.**

## Summary

1 – Aims .....	2
2 – Description of the case study .....	2
2.1.- Starting data for the study:.....	3
2.1.1. Localization of the single-family house. ....	3
2.1.2. Characteristics of the house.....	4
2.2.- Example of Master Thesis offered .....	8
3 – State of the art use of BIM and LCA to assess the sustainability of a building. ....	10
4 – Regulations and standards.....	13
5 – Case study methodology.....	13
6 – Development of the case study.....	15
6.1.- BIM models.....	15
6.2.- LCA Analysis.....	18
6.2.1. Objectives and scope of the LCA in the case study. ....	19
6.2.2. General inventory Analysis.....	19
6.2.3. Impact Assessment. ....	20
6.2.4. Interpretation of the results.....	24
7 – Analysis of the different alternatives studied. ....	25
8 – Conclusions and recommendations. ....	28
9 –References .....	29
Annex 1. LCA with Excel app of a single-family house concrete and bricks.....	30
Annex 2. LCA with Excel app of a single-family house in steel and bricks .....	31
Annex 3. LCA with Excel app of a single-family house in timber .....	32

## 1 – Aims

UPCT and CTCON developed the case study "**Construction products life cycle analysis (LCA) using a Building Information Modelling (BIM) model of a single-family house**".

Its main goal is to develop a didactic methodology for teaching and learning concepts related to the circular economy and the LCA in construction, through the study of several alternatives in the construction of a single-family home.

## 2 – Description of the case study

The Spanish case study of this Project has focused on studying several solutions to build a single-family house and perform a life cycle analysis (LCA) of each alternative using the BIM models created. The objective of this LCA assessment is to compare the sustainability of each solution.

- **Solution 1: Single-family house with concrete structures and brick envelope.**



Figure 1. House with concrete structure.

- **Solution 2: Single family house with steel structure and brick envelope**



Figure 2. House with steel structure.

- **Solution 3: Singel family house with structure and envelope in timber.**



Figure 3. House with timber structure and timber envelope

## 2.1.- Starting data for the study:

### 2.1.1. Localization of the single-family house.

The single-family house is located in Cartagena municipality, in an area on the outskirts of this port city that belongs to the Province of Murcia in Spain. The construction zone of the project has been specifically defined as a normal accessibility zone, with minimum slopes.



Figure 4. Project Location.

The surface of the plot is estimated at an area close to 700 square meters, while the total built area is believed to be close to 360 m<sup>2</sup>.

### 2.1.2. Characteristics of the house

It is a detached house of two floors above ground, with two parking spaces on its main façade south of the location of the house, with large patio on the rear façade, common areas and a toilet on the lower floor, and three bedrooms and three bathrooms on the upper floor. With flat and sloping roof areas.

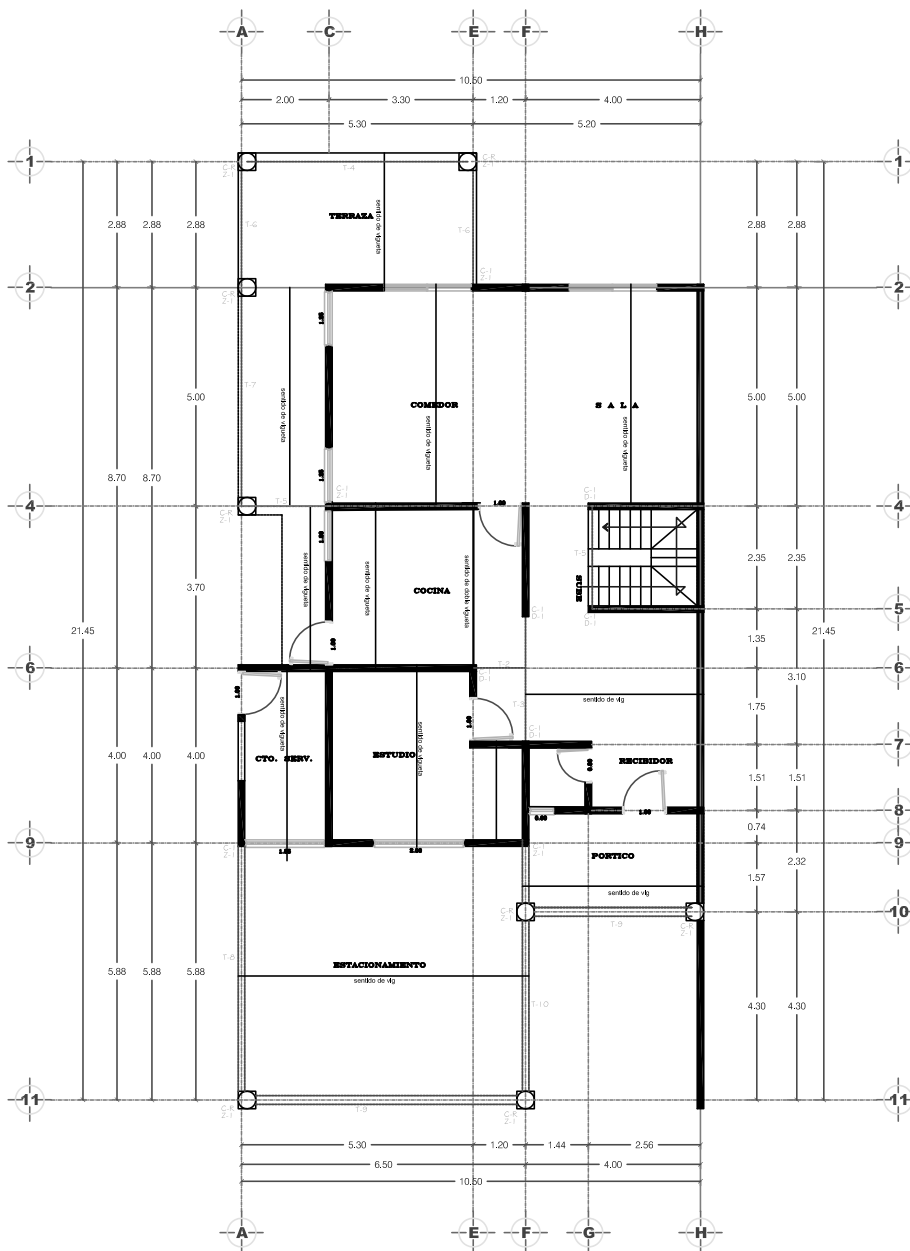


Figure 5. Plan of ground floor.

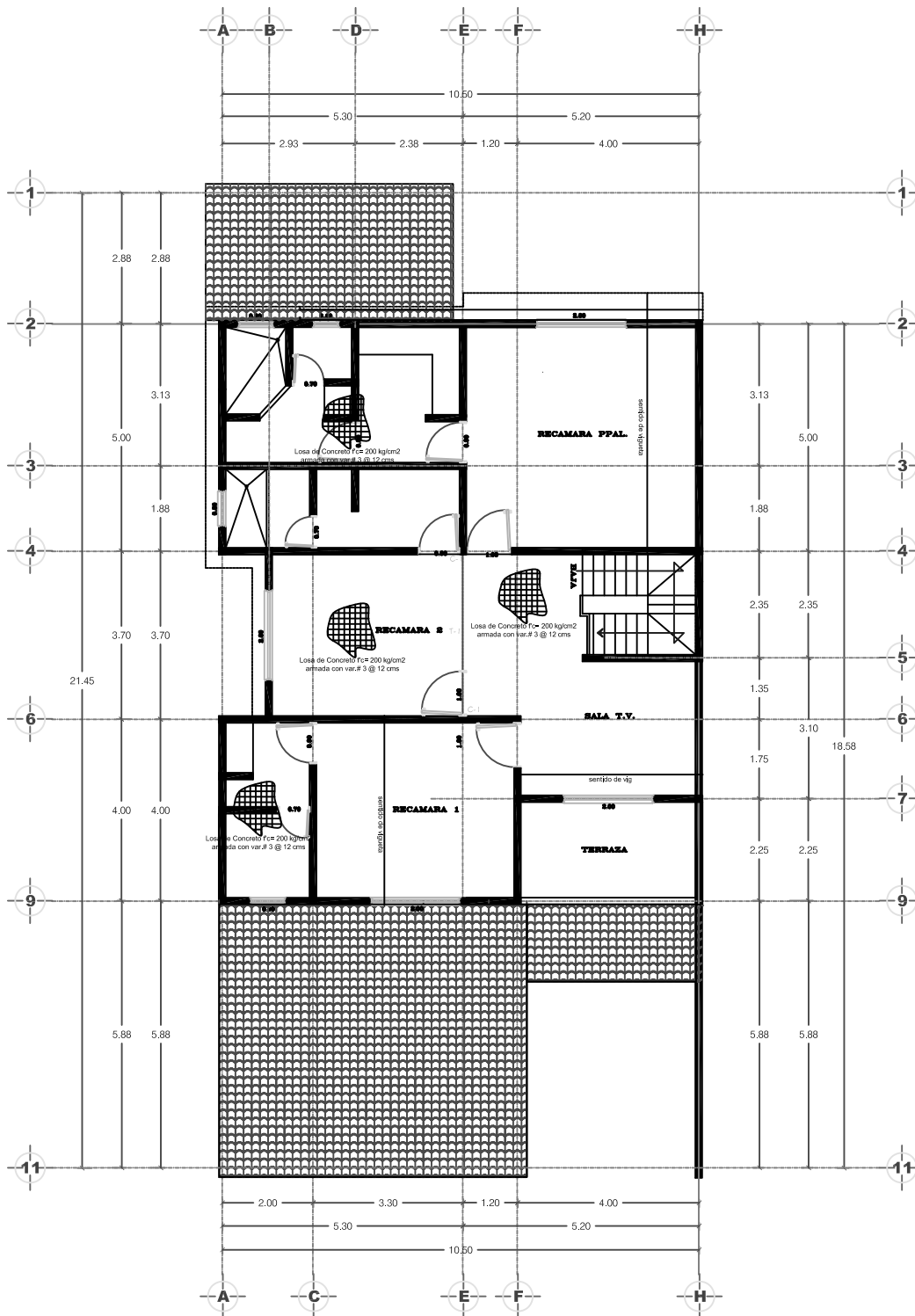


Figure 6. Plan of first floor.

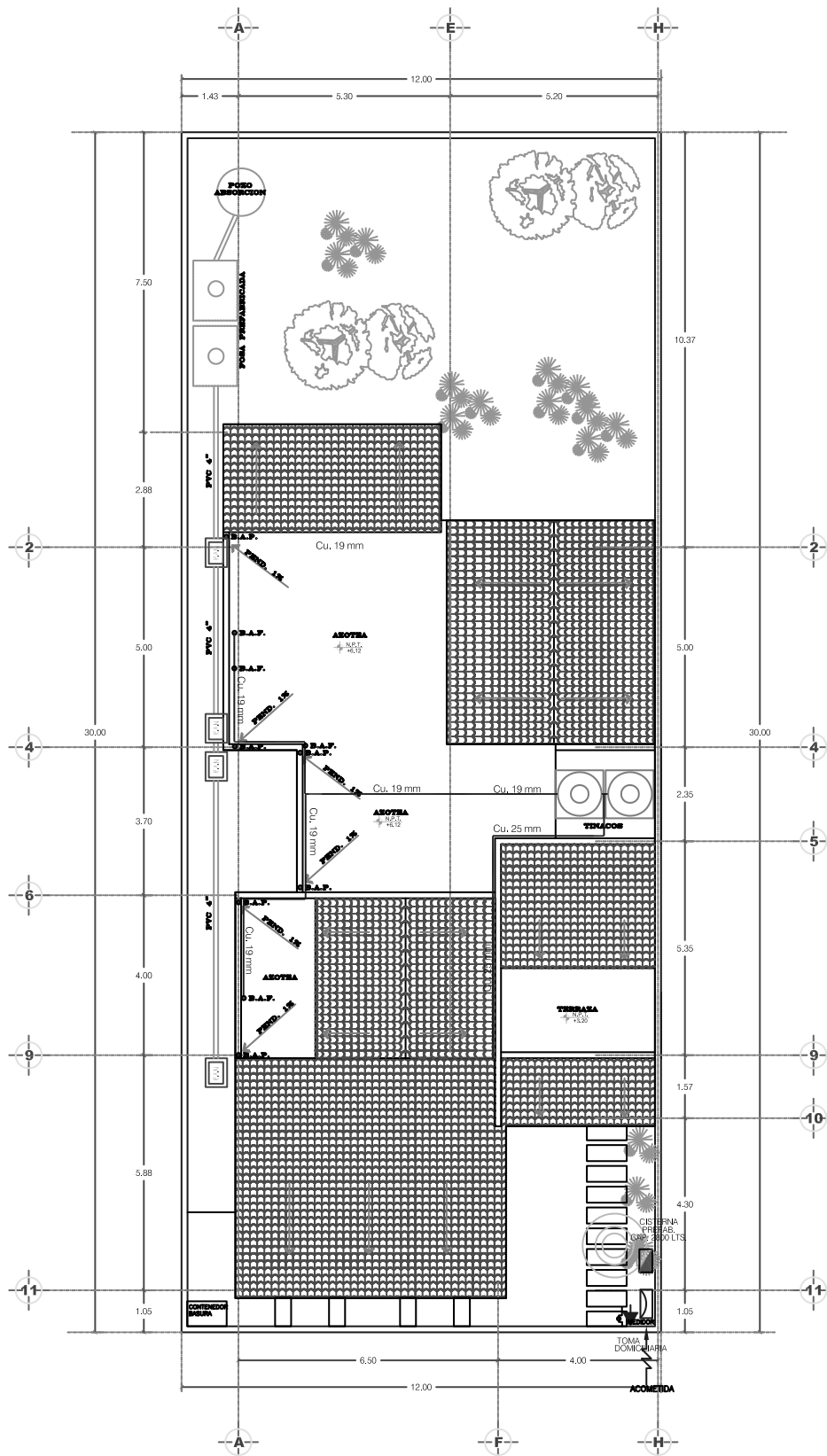


Figure 7. Overall plan

It is estimated that the construction area is 360 m<sup>2</sup>, The terrain on which the house sits is a semi-hard clay soil.

Each of the mentioned solutions to be studied in this case of study of the BIM-LCA Construction Project, has been offered as a master's thesis or final degree project to Civil Engineering students of the UPCT.

The following section shows one of the offers made to students.

## 2.2.- Example of Master Thesis offered

**Title in English:** Timber structure design and life cycle analysis of a single-family house using BIM and LCA tools.

**Objectives:** The aim of this study is to carry out the design of the timber structure of a single-family house following Eurocode 5, and an analysis of the environmental impact produced by this construction throughout its life cycle following the EN ISO 15978:2012 standard. In order to carry out the analysis of the life cycle of the single-family house, a BIM model will be built as a preliminary step, from which the measurements of the materials used and other parameters will be obtained. In the second part of this master thesis, a parametric study will be carried out to analyse the improvement for the environment caused by the use of other materials in the structure and thermal envelope and the change in the transport distances of the materials.

**Phases:** In this master's thesis the student will have to develop the following phases:

Phase 1: Choice of the type of foundation according to the geotechnical properties of the ground.

Phase 2: Choice of the enclosure and partitions of the dwelling. Several alternatives.

Phase 3: Determination of gravity loads (own weight, dead loads, service loads...) and horizontal loads (wind and earthquakes) acting on the building for its design.

Phase 4: Design of the structural system of the house. Pre-dimensioning of beams, columns and floors under gravity loads and service load.

Phase 5: Analysis to obtain internal forces and deformations in the structure after carrying out the appropriate combinations of actions.

Phase 7: Verification of the ultimate and serviceability limit states of both the foundation and the rest of the structural elements.

Phase 8: BIM modelling of the house with Cype Architecture.

Phase 9: Obtaining measurements of housing materials with Open BIM Quantities

Phase 10: Construction budget and Life Cycle Analysis of the building in stages A1-A5 with the Archimedes Cype tool. These stages are as follows:

- Product:A1-A3
  - Extraction of raw materials (A1)
  - Transport to factory (A2)
  - Manufacturing (A3)
- Construction process: A4 - A5
  - Transport of the product (A4)



### Product installation and construction process (A5)

Phase 11: Full life cycle analysis of the building with OneClick. Input: measurements and other parameters in Excel sheet. This analysis will be carried out according to the standard *UNE 15978:2012. Sustainability in construction. Assessment of the environmental performance of buildings. Calculation methods.*

In this analysis, in addition to steps A1-A5, the following steps will be considered:

- Stage of use, information modules related to the building structure.
  - B1: use or application of the installed product; - B2: maintenance;
  - B3: repair; - B4: replacement; - B5: rehabilitation.
- Stage of use, information modules related to the operation of the building.
  - B6: in-service energy use (e.g. operation of the heating system and other installed services linked to the building);
  - B7: in-service water use.
- End-of-life stage. The stage includes the supply and transport of all materials and products, and the associated energy and water use.
  - C1: deconstruction, demolition;
  - C3: treatment of waste for reuse, recovery and/or recycling;
  - C4: elimination.
- Benefits and burdens beyond system boundaries. The stage includes:
  - D: potential for reuse, recovery and/or recycling, expressed as net loads and benefits.

Phase 12: Comparison of the results of the analysis with the results of other case studies, other Master's Thesis, of single-family houses with concrete or steel structure and brick envelopes. The results of the life cycle analysis to be compared will be the corresponding indicators of environmental impact, use of resources and other indicators relating to waste generated, reusable materials.

Phase 13: Drafting of a tutorial guide for the use of BIM and LCA tools in this case study.

**Requirements:** Student of the Master's Degree in Civil Engineering.

**Abstract:** The assessment of the environmental impact of a building throughout its life cycle is a very useful tool to quantify the sustainability of building materials. This Master's Thesis aims to develop a life cycle analysis for a case study and compare the results with other cases already analysed. The design of a single-family house with timber structure with BIM tools will be the first step to carry out the life cycle analysis.

#### **Bibliography:**

UNE-EN ISO 14040: 2006. Environmental Management. Life Cycle Analysis. Principles and reference framework.  
UNE-EN ISO 14044: 2006. Environmental Management. Life Cycle Assessment. Requirements and guidelines.  
UNE-EN 15978:2012 Sustainability in construction. Assessment of the environmental performance of buildings. Calculation methods.  
UNE-EN 1995-1-1. Eurocode 5: Design of timber structures Part 1-1: General rules and building regulations.  
Spanish Technical Building Code.

**Competences:** Those included in the MUICCP Master's Thesis Teaching Guide. In addition: ability to use BIM and LCA tools to assess the sustainability of the materials used in the construction of a single-family house.

### 3 – State of the art use of BIM and LCA to assess the sustainability of a building.

The high environmental impact of residential buildings throughout their lifecycle has aroused growing and notable interest within the scientific community in recent decades, utilizing the methodology of Life Cycle Assessment (LCA).

Over time, various methodologies have been devised to assess environmental impact. The most internationally recognized methodology is Life Cycle Assessment (LCA), applied to construction sector products through the UNE-EN 15804 standard (2012) and to buildings through the UNE-EN 15978 standard (2012). Additionally, the LCA methodology also serves as a decision-making tool in the design and construction stages of the building, particularly in the selection of construction materials with a lower associated environmental impact.

From the review of the literature on LCA studies applied to the environmental assessment of buildings, it is concluded that the buildings most frequently analyzed are residential ones in the European continent, with the ultimate goal of evaluating newly constructed buildings. Within the scope, the lifecycle stages most frequently analyzed are product and construction, followed by end-of-life. The most commonly used functional unit is the total building area, considering its expected service life, which is generally assumed to be 50 years.

On the other hand, despite articles specifically addressing LCA in buildings, it should be noted that both inventory databases and software tools used are not typically specific to buildings. Most authors employ generic databases and software that could also be used for LCA of other types of products or systems. This indicates that there is still progress to be made in the development and use of building-specific software and databases that adapt to the specific conditions of each region.

The potential of Building Information Modeling (BIM) tools in facilitating decision-making processes during Life Cycle Assessment (LCA) applications within the context of building construction has been widely acknowledged and documented in a number of academic review articles [1], [2]. For instance, Soust-Verdaguer et al. [3] conducted a comprehensive review of studies that explored the synergies between BIM and LCA, with a specific focus on how BIM can streamline data input and optimize the output of LCA tools. This review also put forth practical strategies for integrating BIM software and LCA tools, such as the development of templates and software plug-ins. It is

important to note, however, that this review predates 2018, and many recent publications on this subject have not been considered.

In particular, since 2018, a substantial number of research papers have emerged that investigate the integration of BIM and LCA through case studies. Eleftheriadis et al. [4], for instance, conducted an in-depth review that delved into the relationship between BIM and LCA in terms of enhancing energy efficiency (including embodied and operational energy) and engineering performance aspects (such as cost and safety) of structural systems. This review underscored the imperative of incorporating BIM in the decision-making process related to building structures and presented critical insights in both engineering and sustainable energy domains, along with proposing a set of research guidelines. However, it primarily emphasized a qualitative perspective, without thoroughly addressing the methodological barriers and quantitative aspects associated with BIM-integrated LCA.

Similarly, Llatas et al. [5] conducted a systematic literature review (SLR) with the aim of identifying opportunities for integrating LCA into the BIM process during the building design phase. Their review paper introduced an approach to assist in the implementation of BIM-integrated LCA; however, it analyzed only 36 case studies published in two specific journals.

Dalla Mora et al. [6], on the other hand, conducted an extensive review of BIM-integrated LCA studies published between 2007 and 2019, demonstrating how BIM could enhance data management in LCA applications. They also examined the influence of various parameters in this context and highlighted the notable absence of readily available LCA databases integrated into BIM tools as a significant challenge. Nevertheless, a systematic analysis of how these factors affect the BIM-integrated LCA application remains limited.

Seyis [7] conducted a comprehensive review that identified the advantages and disadvantages associated with BIM-based LCAs. The findings of this review pointed to laborious data input processes as a primary challenge in BIM-integrated LCA. A similar study was conducted by Obrecht et al. [8], which facilitated a comparative assessment of different types of BIM-integrated LCA methods, weighing their respective strengths and weaknesses.

Panteli et al. [9] focused their research on prior studies concerning the use of BIM for environmental assessments of buildings during the design phase. They emphasized the critical importance of data interoperability between BIM and LCA tools in this context.

In summary, while these previously published works have conducted reviews of the integration of BIM and LCA, there exists a compelling need for a more systematic and comprehensive review to provide a deeper understanding of these crucial aspects within the field of BIM-integrated LCA. In the work of Teng et al. [10] a systematic review of previous work on the integration of BIM and LCA is developed. The fig. 7 and table 1 show some results of this work.

Concerning the methodological aspects of software integration and data interchange, a pivotal undertaking revolves around the formulation of strategies for achieving seamless software integration and efficient data exchange between Building Information Modeling (BIM) software and Life Cycle Assessment (LCA) tools. Conventionally, LCA for buildings tends to be executed toward the latter stages of the design process, a juncture at which precise and comprehensive data become accessible. However, at this stage, influencing critical decisions may be impractical or too late in the development process. To ameliorate this challenge, various methodological approaches have been proposed with the aim of integrating BIM software and LCA tools more effectively.

Data exchange emerges as another significant hurdle when dealing with disparate data formats inherent to BIM software and specialized LCA tools. The paramount objectives in coupling BIM and LCA tools often encompass the exportation of Bill of Materials (BoM) and the establishment of building datasets, both of which represent intricate and time-intensive procedures. In this context, three distinct approaches have been identified by Teng et al. [10] to facilitate data transfer between BIM and LCA tools. These approaches encompass the integration of a process that amalgamates diverse data into a third-party application or tool (Type I), the importation of a BoM report generated from the BIM model into a dedicated LCA tool (Type II), and the utilization of plug-ins that incorporate LCA data into BIM software (Type III) (as illustrated in Figure 7). A comparative analysis of these three categories of approaches is delineated in Table 1.

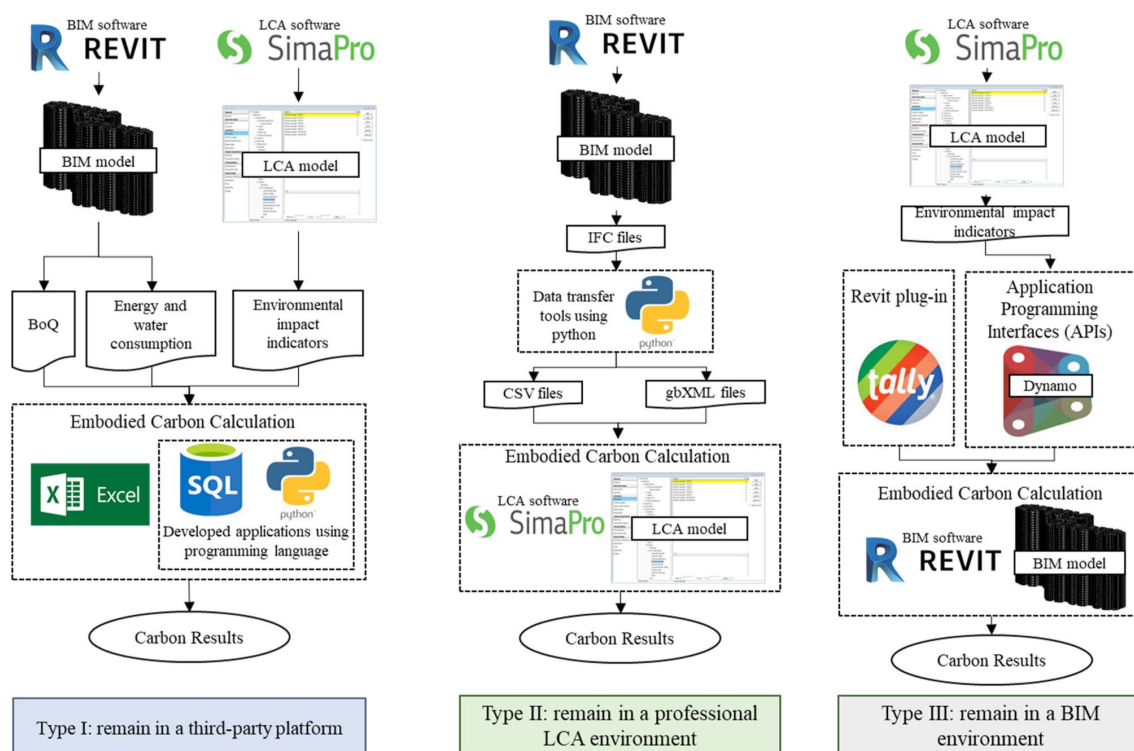


Figure 8. Three approaches for data exchange between BIM software and LCA tools. (Source: Teng et al. [10])

**Table 1:** Three types of data exchange approaches between BIM and LCA tools. (Source: Tend et al. [10])

Type	Data exchange approach	Calculation platform	Description	Advantage	Disadvantage
I	From BIM and LCA to a third party	Excel	Importing a BoQ report generated from the BIM model and corresponding emission factors provided by LCA tools into Excel	Simple and time-saving	Inefficient to handle a more complex calculation
		Self-developed application	Using programming language to achieve automatic data extraction and calculation between BIM and LCA tools	Automatic and clear calculation	Only numerical results can be obtained
II	From BIM to LCA	Professional LCA tools	Importing a BoQ report generated from the BIM model or BIM model into dedicated LCA tools	Professional, detailed and visualized analysis	Inconsistent data formats of material databases; Manually data mapping is needed
III	From LCA to BIM	BIM platform	Using a Revit plug-in to conduct LCA Importing LCA data into BIM objects or an in-built database through application programming interfaces (APIs)	Flexible data modification, integrated data storage, quick feedback, and intuitive visualization	Inaccuracy of the results Manual data mapping is needed

## 4 – Regulations and standards

### LCA regulations and standards:

- UNE-EN ISO 14040: 2006.Environmental Management. Life Cycle Analysis. Principles and reference framework.
- UNE-EN ISO 14044: 2006. Environmental Management. Life Cycle Assessment. Requirements and guidelines.
- UNE-EN 15978:2012 Sustainability in construction. Assessment of the environmental performance of buildings. Calculation methods.

### BIM regulations and standards:

- UNE-EN ISO 16739-1: Data exchange in the construction industry and in property management using IFC (Industry Foundation Classes).
- UNE-EN ISO 19650-1: Organization and digitization of information in building and civil engineering works that use BIM (Building Information Modelling).

## 5 – Case study methodology.

In the Spanish Case Study of this BIM-LCA project, Cype's Open BIM software package has been used (see next Figure):

- With them we design the structure of the house (using CypeCad) and its corresponding Open BIM model, that is, its BIM model in IFC format. We upload this BIM model of the housing structure to a server (BIMServerCenter).
- Then we use another software (**Cype Architecture**) to create the BIM model of the architectural part of the house.
- Next, we enrich the BIM model of the house by incorporating information about the housing envelope with **Open BIM Construction Systems**.
- And finally, we use the **Open BIM Quantities** and **Arquimedes** software to build the Bill of Quantities of the construction, from the measurements that the software makes in the elements of the BIM model. Arquimedes is able to print the LCA report that has been made by adding impacts of each of the budget items using the Cype LCA database.

This LCA only contains stages A1 to A5. Next Figure shows the workflow and data exchange in the Spanish Case Study using Cype software and BIMServerCenter. In this workflow each software exchanges information with the OpenBIM model of the house that is stored in a BIMServerCenter Project.

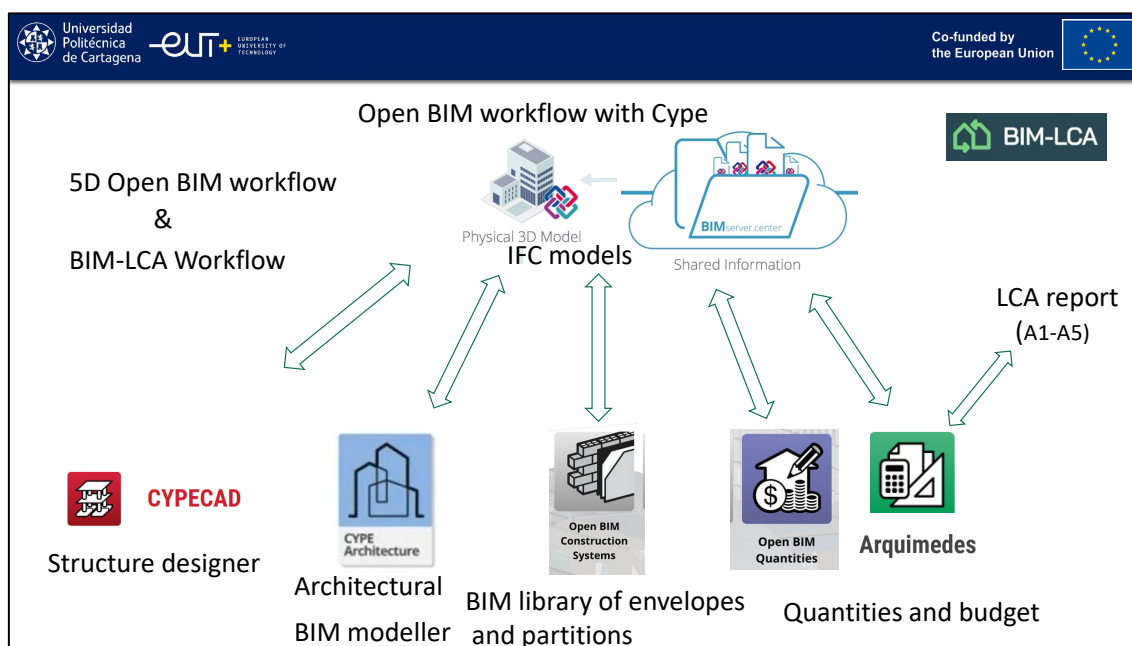


Figure 9. Workflow in the Spanish Case Study using OneClick LCA.

With the workflow followed to develop the Spanish case study, the integration between the BIM model and the LCA assessment is perfect since the same database that serves to build the Bill of Quantities serves to perform the Construction Life Cycle Analysis.



The Cype Architecture software is explained in a tutorial of this BIM-LCA Construction E+ Project.

Another way to use Archimedes to obtain the LCA of the construction is to use the excel sheet developed in this project.

As a result of this project (BIM-LCA Construction), a web application has been developed that, based on quantities of material used in the construction of a building (single-storey housing, multi-storey building or industrial warehouse), makes an LCA to show a series of environmental impacts of construction in phases A1-A3 (extraction and manufacture of construction products). This app is available on the BIM-LCA Construction Project website (<https://bimlca.eu>)

An LCA Excel App has also been developed with the aim of performing building LCAs and showing the cost and environmental impacts of building construction (A1-A5). This Excel app is also available on the Project's website, and includes the options to choose among various materials for the structure (concrete, steel or wood), and to choose various types of foundations, doors, windows, insulation materials, floors, partitions, facades and roofs.

The LCA Excel project app, has a user guide, in tutorial format, that is part of the results of the BIM-LCA Construction project in the work package 3. This user guide is also available on the Project website.

## **6 – Development of the case study.**

### **6.1.- BIM models.**

The BIM model of the three alternatives studied begins with the modelling and design of the structure of the single-family house in CypeCAD. Figs. 10 and 11 show the model of the structure in reinforced concrete and structural steel in CypeCAD.

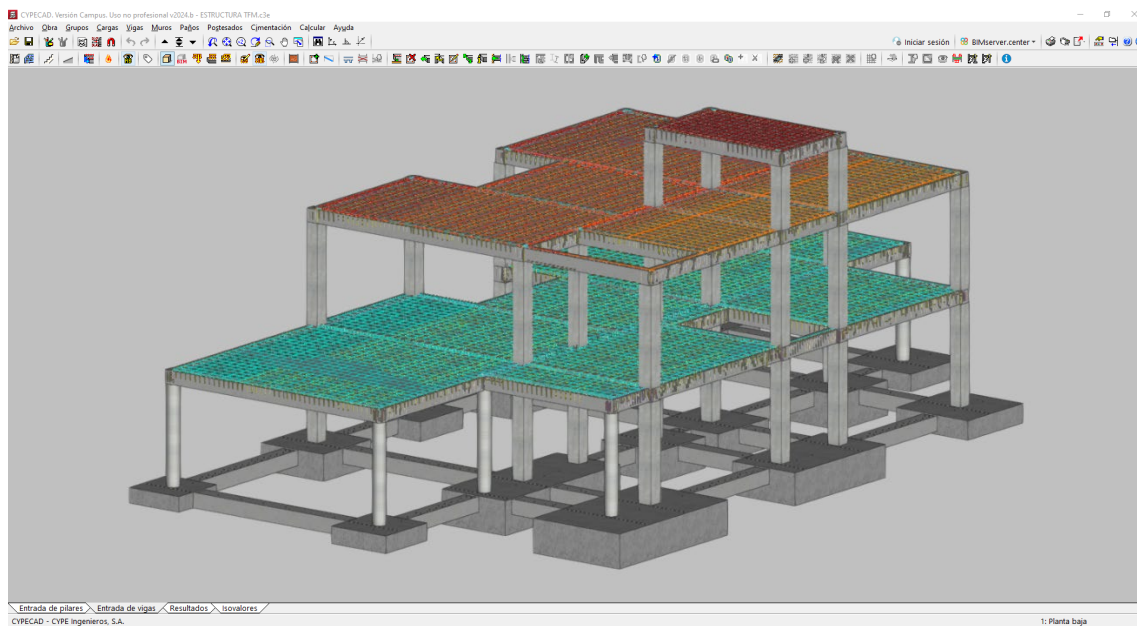


Figure 10. Reinforced concrete structure of the single-family house in CypeCAD

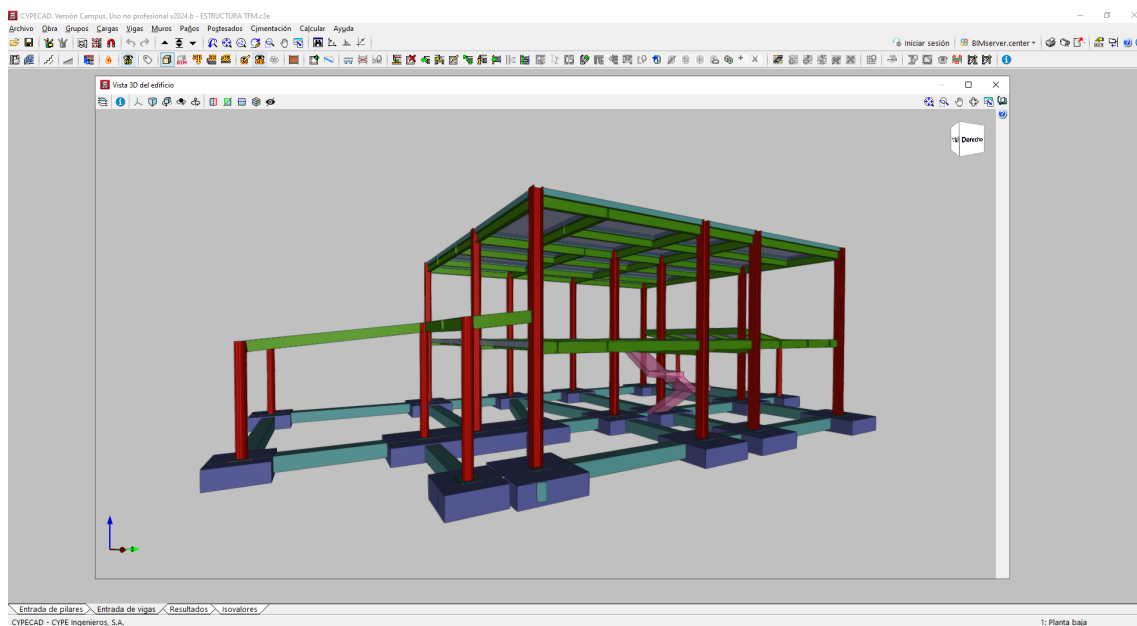


Figure 11. Steel structure in CypeCAD.

The next step in the construction of the BIM model has been to model the architectural elements of the house using Cype Architecture. Fig. 12 and 13 show this model in the aforementioned software.



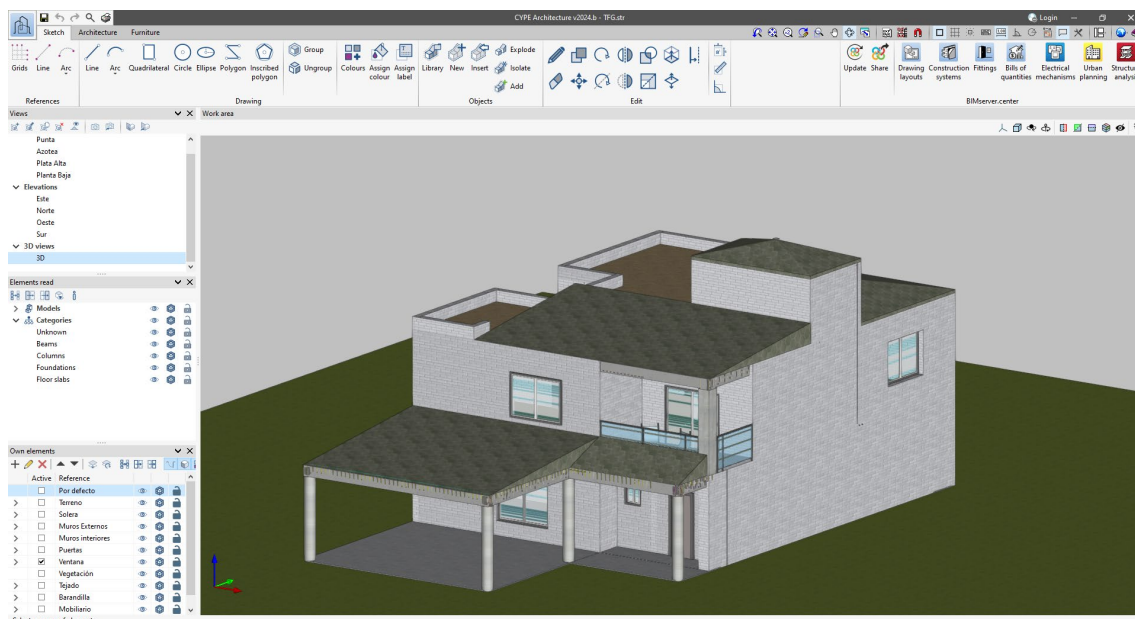


Figure 12. Architectural elements of the concrete structure house in Cype Architecture.

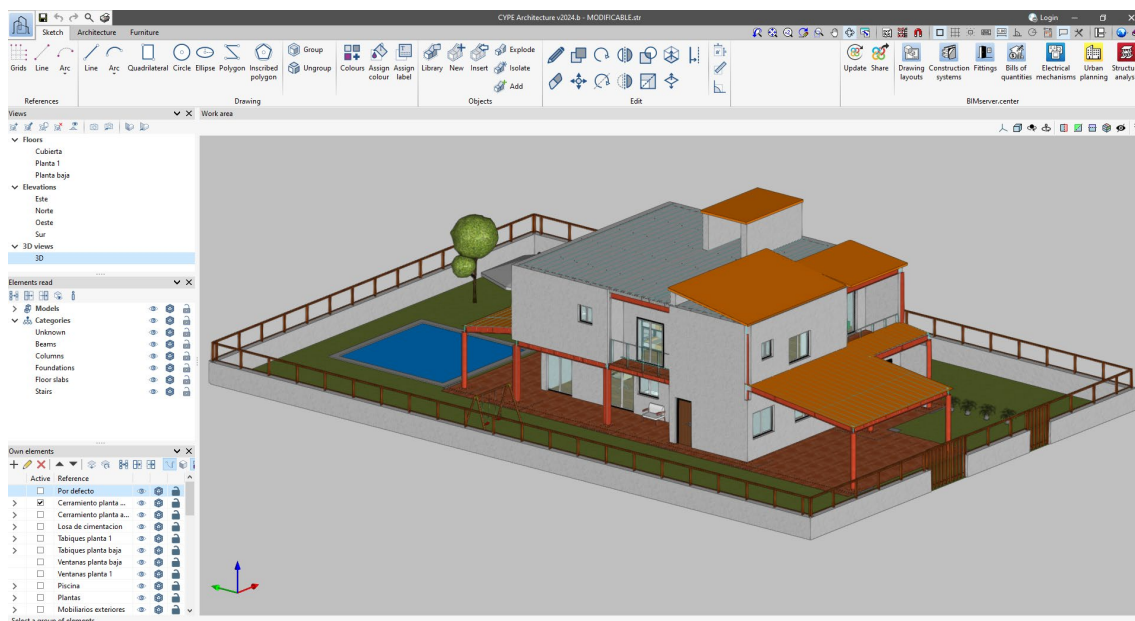


Figure 13. Architectural elements of the steel structure house in Cype Architecture

The amount of materials used in the design of the three alternatives studied has been calculated with OpenBIM Quantities, as well as their construction budget.

Figs. 14 and 15 show the models in OpenBIM Quantities.

A cost data base has been built for each model using Arquimedes. These databases with prices and description of the work units of the single-family house have been imported into OpenBIM Quantities for the calculation of the Bill of Quantities.

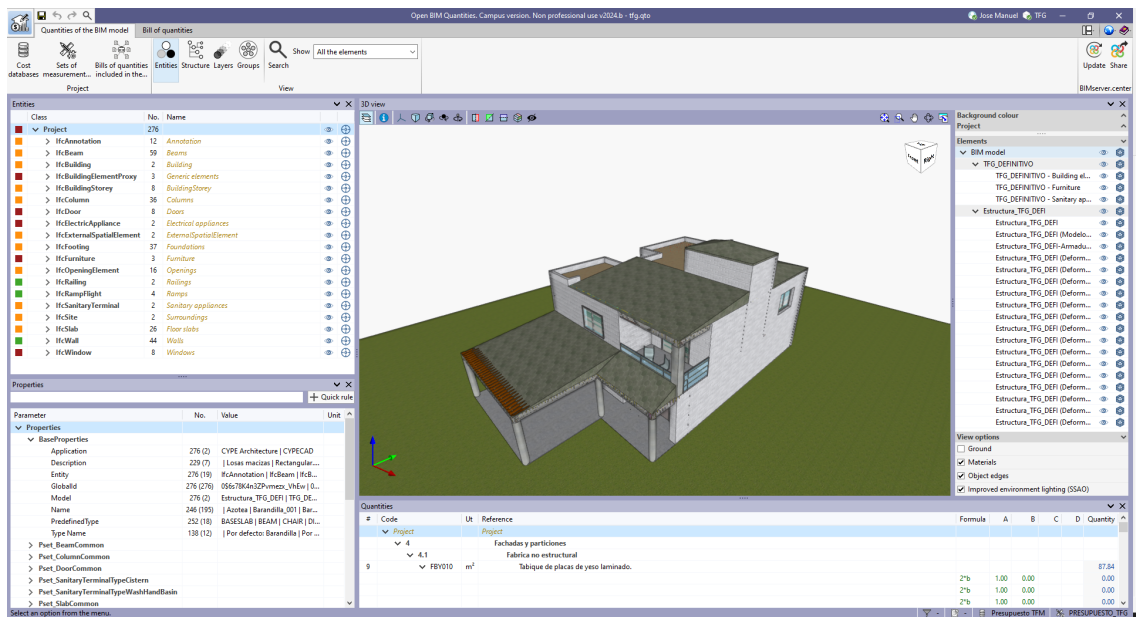


Figure 14. Architectural elements of the steel structure house in Cype Architecture

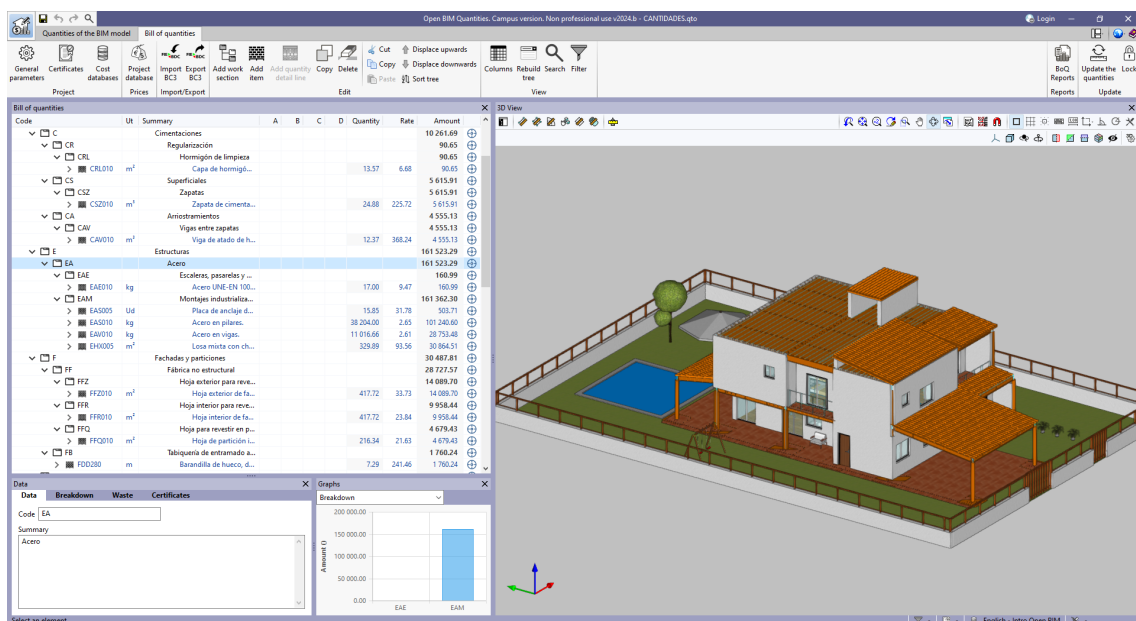


Figure 15. Architectural elements of the steel structure house in Cype Architecture

## 6.2.- LCA Analysis.

The SETAC (Society of Environmental Toxicology And Chemistry) defines Life Cycle Assessment as:

"An objective process for assessing the environmental burdens associated with a product, process or activity, identifying and quantifying the use of matter and energy, as well as emissions or discharges into the environment, to determine the impact of

that use of resources and those emissions or discharges, in order to evaluate and implement environmental improvement strategies. The study includes the complete cycle of the product, process or activity, taking into account the stages of: extraction and processing of raw materials, production, transport and distribution, use, reuse and maintenance, recycling and final disposal."

In accordance with the UNE-EN ISO 14040 standard, the development of a Life Cycle Assessment must include the following methodological stages:

- Stage 1: Definition of objectives and scope (Functional Unit)
- Stage 2: General Inventory Analysis
- Stage 3: Impact Assessment
- Stage 4: Interpretation of the results.

### **6.2.1. Objectives and scope of the LCA in the case study.**

The main objective of the Life Cycle Analysis of this case study is to evaluate the environmental impacts of the construction of a single-family house considering several alternatives in the use of construction materials (concrete, bricks, structural steel and timber) during the following phases of its life cycle:

- Product: A1 - A3
  - Extraction of raw materials (A1)
  - Transport to factory (A2)
  - Manufacturing (A3)
- Construction process: A4 - A5
  - Transport of the product (A4)
  - Product Installation and Construction Process (A5)

So the scope of this LCA includes the construction of the single-family home but not the use of it.

### **6.2.2. General inventory Analysis.**

The life cycle inventory analysis is the estimation of raw material and energy requirement, solid wastes, environmental emissions, water pollutants, and other emissions for the life of a process or product.

In the LCA of the single-family house developed in this project, this analysis can be consulted by unit of product, in the Environmental Product Declarations (EPD) of each material or product used in the construction of the house. Links to these

Environmental Product Declarations can be found in the "Materials" tab of the LCA Excel App developed in the project (<https://bimlca.eu>).

### 6.2.3. Impact Assessment.

The environmental impacts measured in this study are as follows:

**Table 2:** Environmental impacts considered

Environmental Impacts	Units
Abiotic depletion potential for fossil resources (ADPF)	MJ
Abiotic depletion potential for non fossil resources (ADPE)	kg Sb-eq.
Acidification potential (AP)	kg SO <sub>2</sub> -eq.
Global warming potential (GWP)	kg CO <sub>2</sub> -eq.
Eutrophication potential (EP)	kg Phosphat-eq.
Photochemical Ozone Creation Potential (POCP)	kg Ethen-eq
Ozone Depletion Potential (ODP)	kg CFC 11-eq

**Table 3:** Use of resources considered

Energy consumption	Units
Total use of renewable primary energy resources (PERT)	MJ
Total use of non renewable primary energy resource (PENRT)	MJ

The list of impacts of each single-family house alternative studied is included in annexes 1, 2 and 3 of this document.

Below are the PERT, PENRT and GWP impacts of the three alternatives studied

#### 6.2.3.1 Single-family house in concrete and bricks

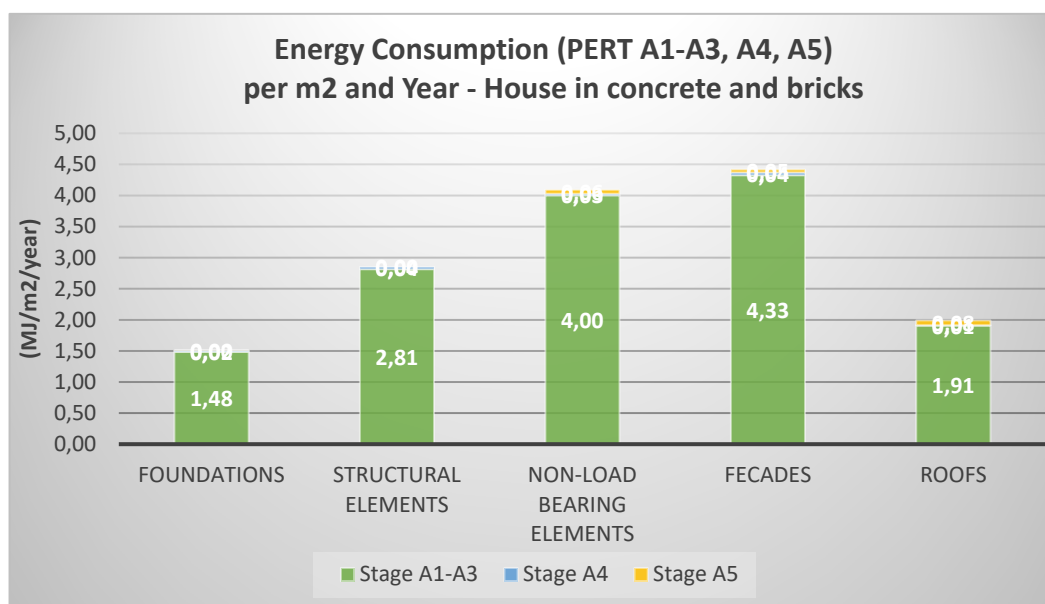


Figure 16. Total Renewable Primary Energy Consumption (PERT) per m<sup>2</sup> and year of the house in concrete and bricks

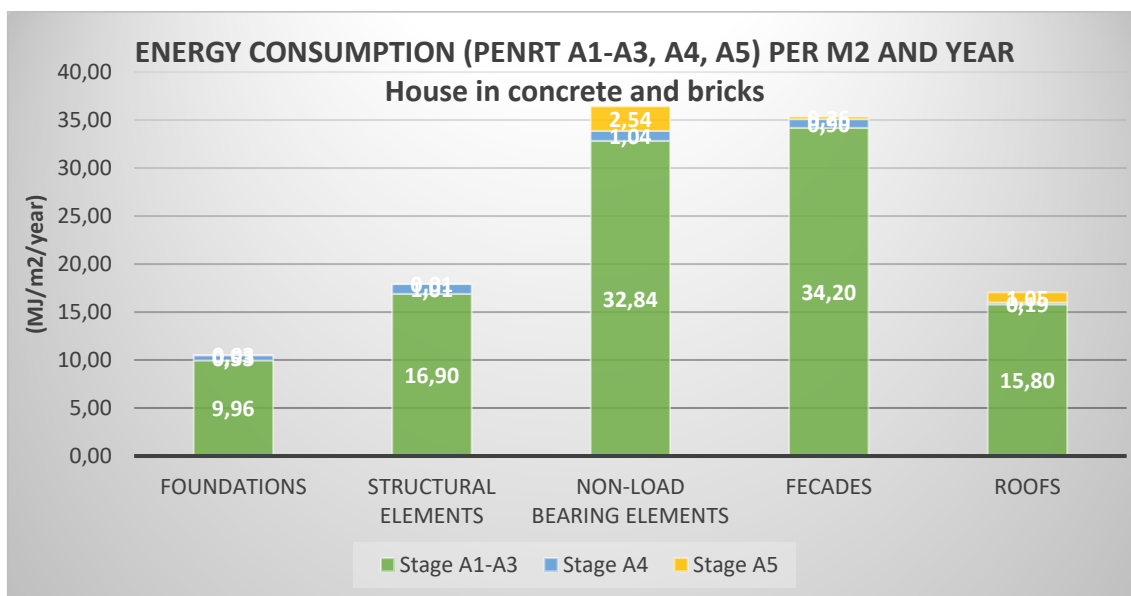


Figure 17. Total non-renewable Primary Energy Consumption (PENRT) per m2 and year of the house in concrete and bricks

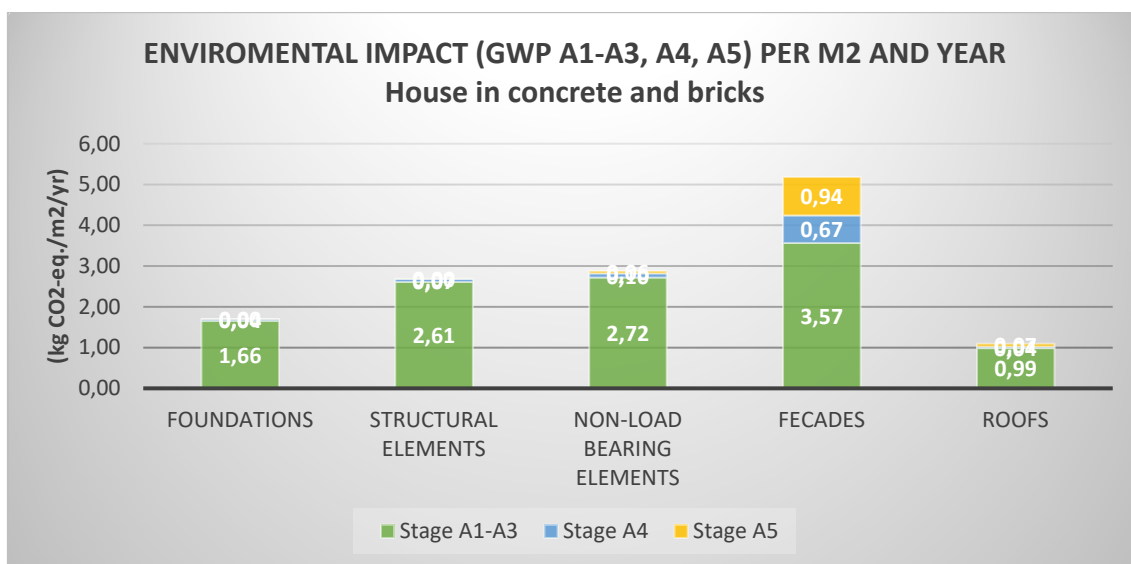


Figure 18. Global Warming Potential (GWP) per m2 and year of the house in concrete and bricks

6.2.3.2 Single-family house in steel and bricks

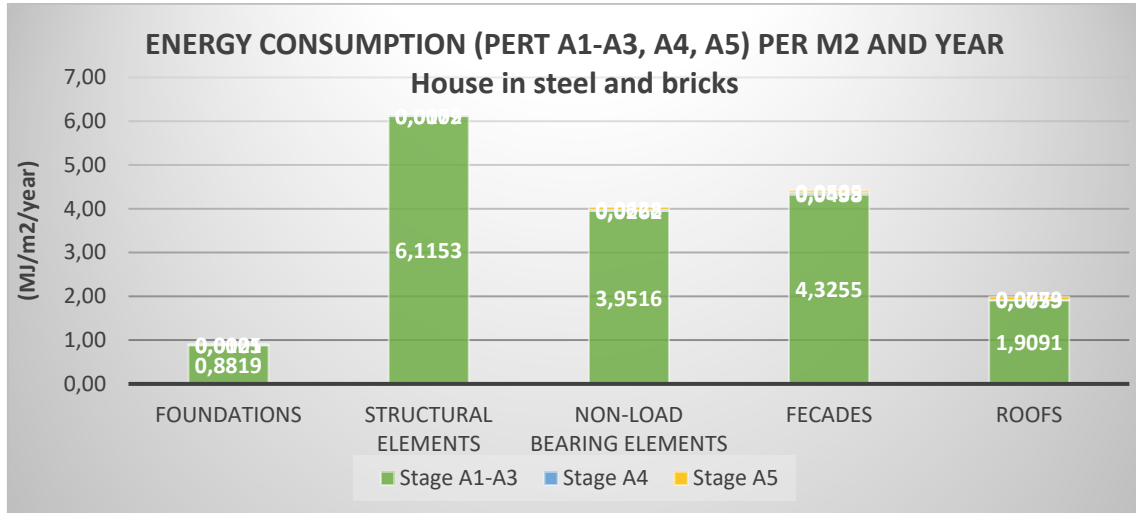


Figure 19. Total Renewable Primary Energy Consumption (PERT) per m2 and year of the house in steel and bricks

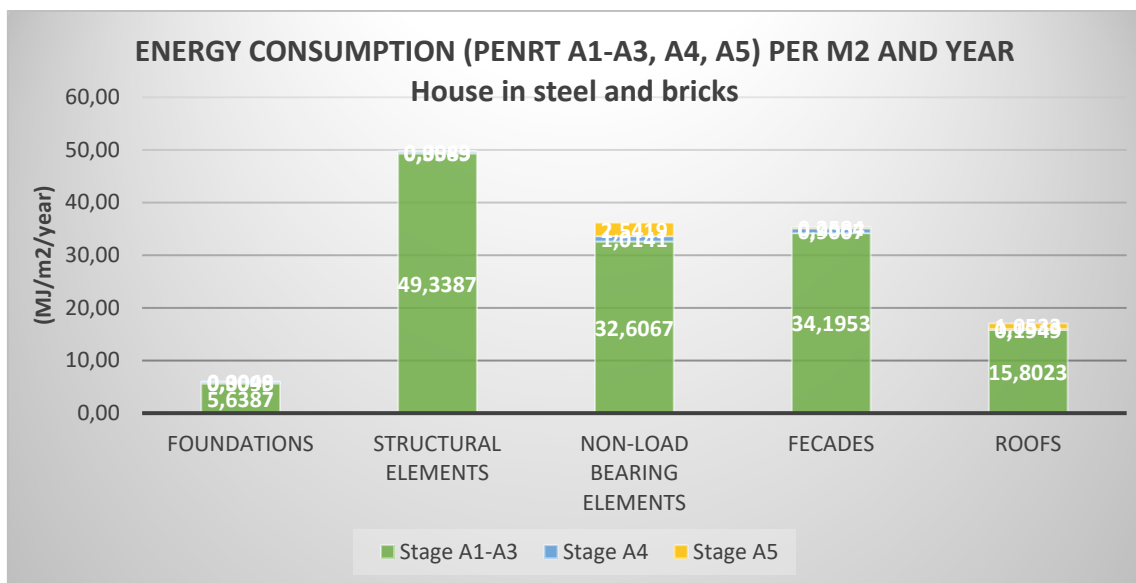


Figure 20. Total non-renewable Primary Energy Consumption (PENRT) per m2 and year of the house in steel and bricks



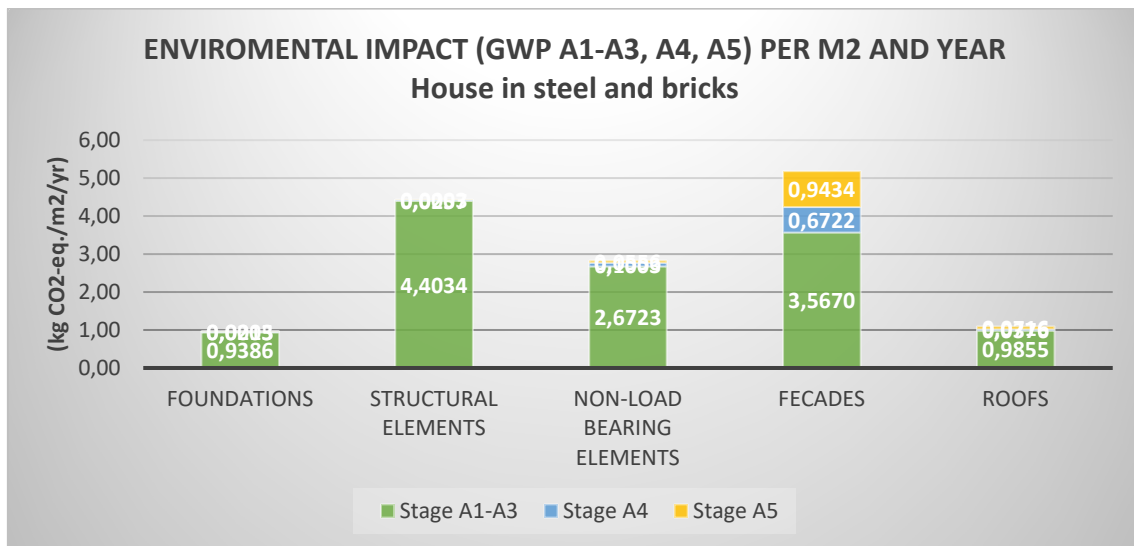


Figure 21. Global Warming Potential (GWP) per m<sup>2</sup> and year of the house in steel and bricks

### 6.2.3.2 Single-family house in timber

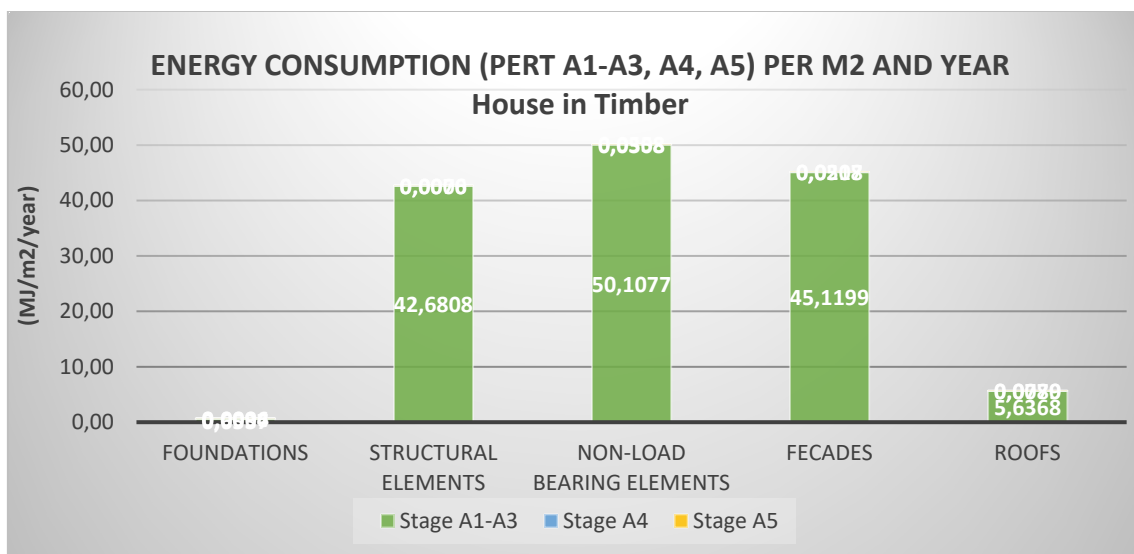


Figure 22. Total Renewable Primary Energy Consumption (PERT) per m<sup>2</sup> and year of the house in timber.

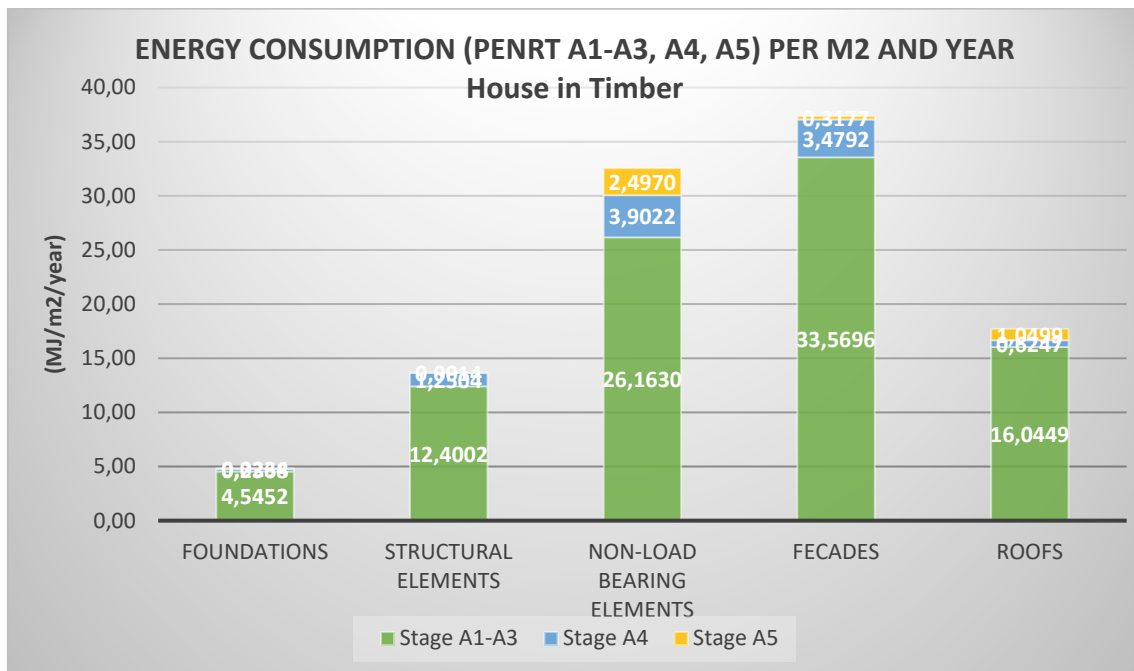


Figure 23. Total non-renewable Primary Primary Energy Consumption (PENRT) per m2 and year of the house in timber

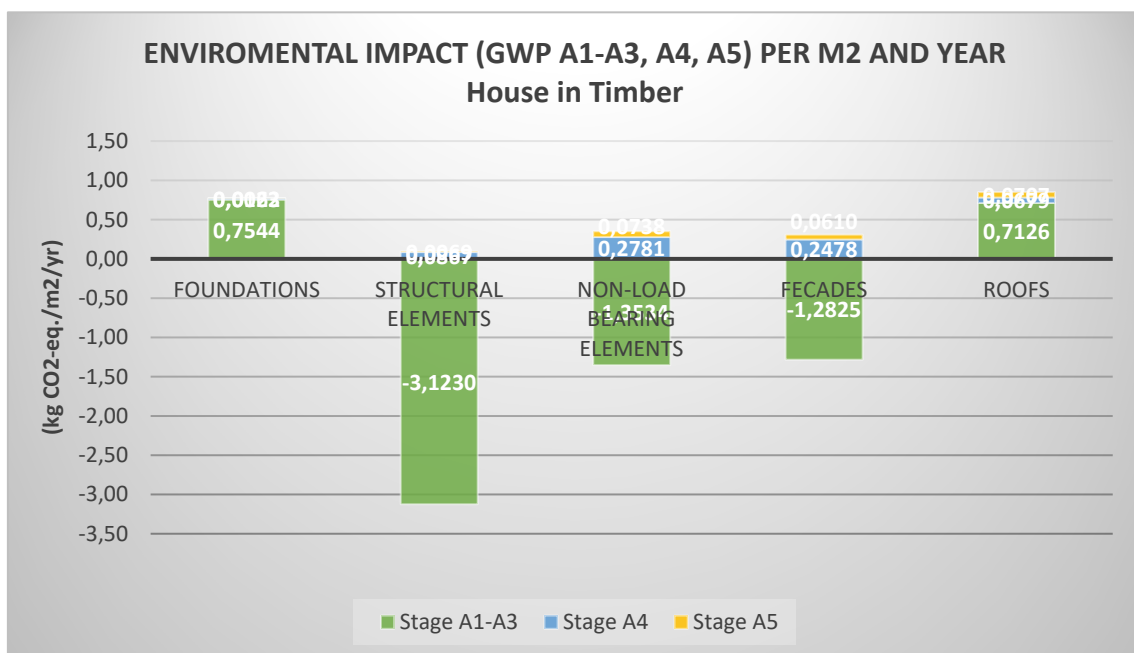


Figure 24. Global Warming Potential (GWP) per m2 and year of the house in timber

#### 6.2.4. Interpretation of the results.

The interpretation of the results of the LCAs carried out is included in the next section of this document (Section 7), where a comparison is made among the results obtained in each alternative studied.



## 7 – Analysis of the different alternatives studied.

This section compares the results, in terms of costs, primary energies consumed and CO2 emissions or equivalent, of the three solutions studied for single-family housing (concrete and bricks; structural steel and bricks; and wood).

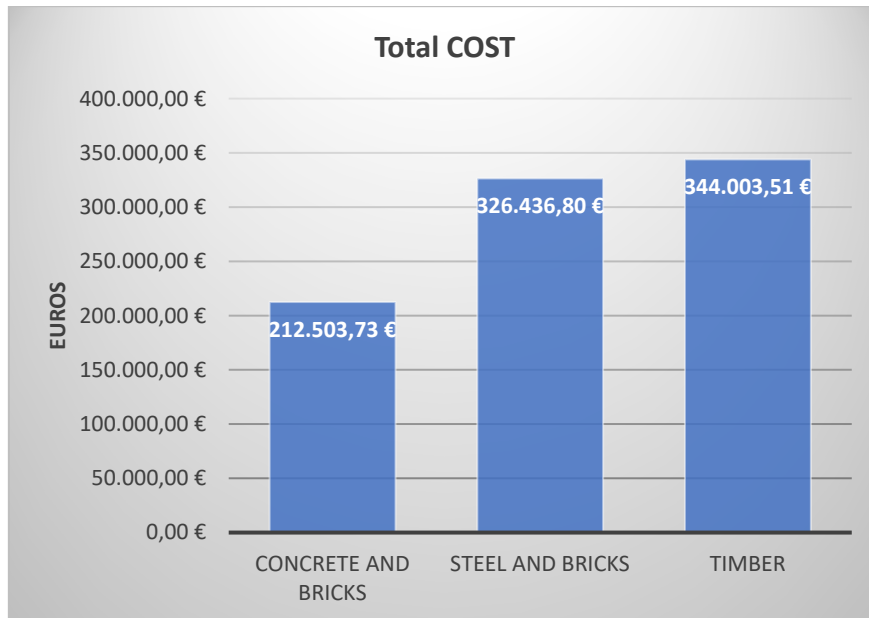


Figure 25. Total cost of the three studied alternatives

Fig. 25 shows the total construction cost of the three solutions. We can see that the most expensive solution is the house in timber. The second most expensive is the single-family house with a steel structure and brick walls. And the cheapest is the house with a reinforced concrete structure and brick walls.

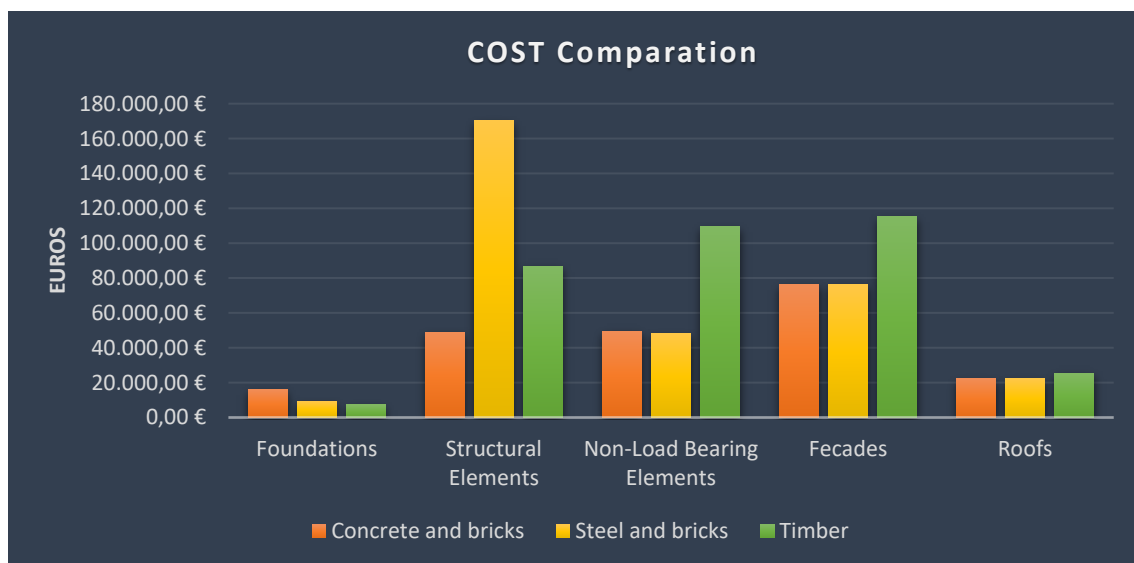


Figure 26. Cost comparison of parts of the building in the three studied alternatives

Fig. 26 shows the cost of each chapter of the construction budget of the house: foundations, structural elements, non-load bearing elements, facades and roofs, for the three different solutions. In this figure 26 we can see that:

- The most expensive foundation is for the house with a reinforced concrete structure, as it weighs more and needs a larger foundation.
- The most expensive structure (beams, columns and slabs) corresponds to the steel structure, followed by the wooden structure. And finally, the cheapest structure for the house studied is the one with reinforced concrete.
- The most expensive interior walls and facades correspond to those built in wood.
- The cost of roofing is similar in all three solutions.

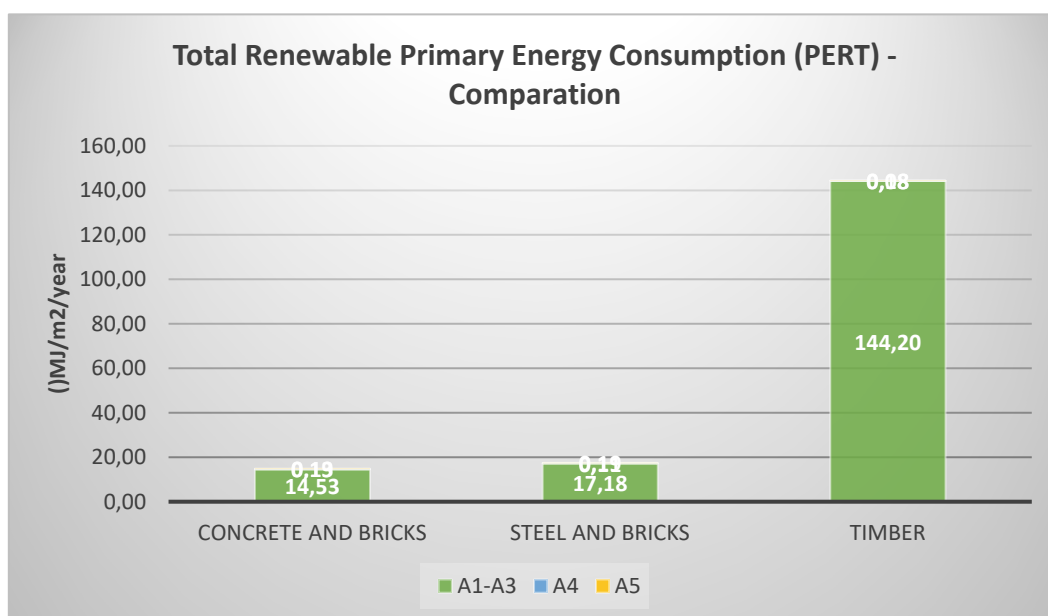


Figure 27. Total Renewable Primary Energy Consumption (PERT) - Comparison

Fig 27 and 28 shows the renewable and non-renewable primary energy consumed in the construction of the house for each solution studied (concrete, steel and wood) in MJ per square metre and year. The graph of Fig. 27 shows that the highest consumption of renewable energy occurs in the construction of the wooden house. The wooden house consumes a greater amount of energy because the process of manufacturing technical wood, such as cross-laminated timber (CLT) panels and glued laminated timber (Glulam) beams and pillars, consumes a large amount of energy per volume of material. The aim is to ensure that this energy comes from renewable sources to minimise the impact on the environment.

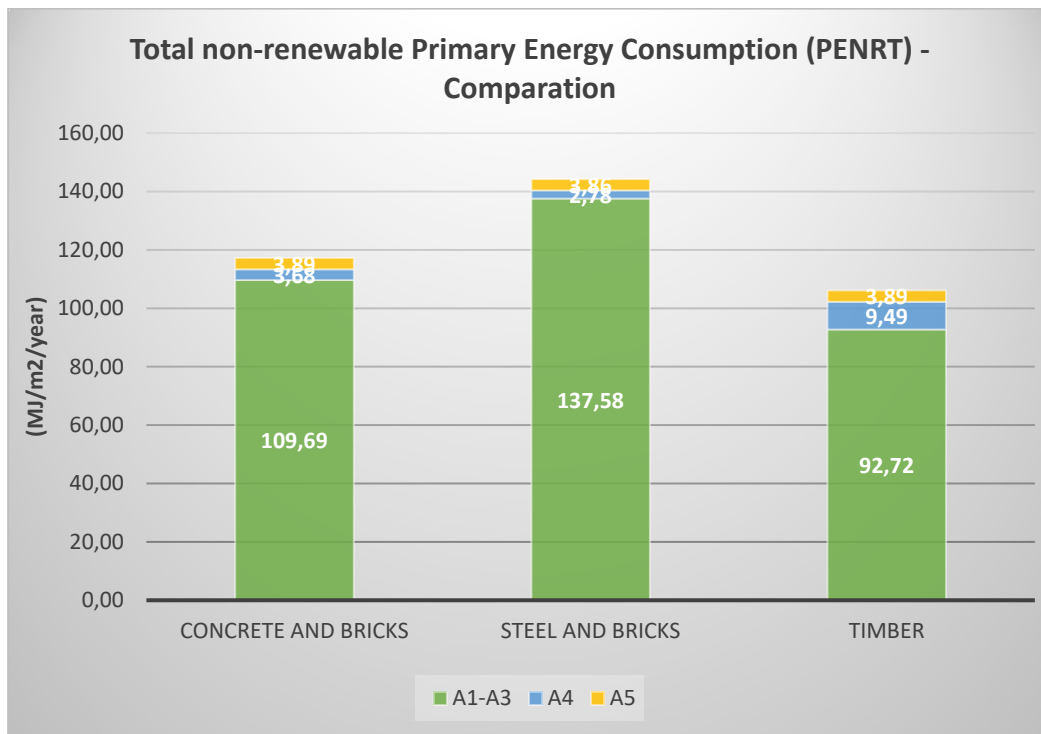


Figure 28. Total non-renewable Primary Energy Consumption (PERT) – Comparison.

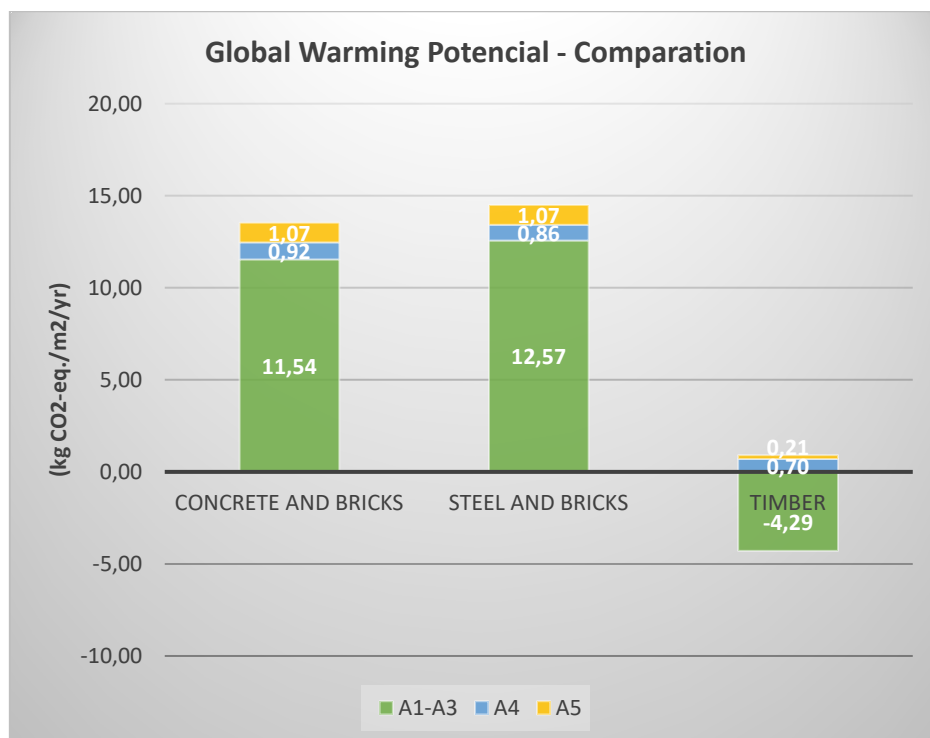


Figure 29. Global Warming Potencial Comparison

Fig. 29 shows the greenhouse gas emissions in Kg of CO<sub>2</sub> eq. per square meter of construction and per year for the three alternatives studied. We can observe that the emissions produced in stages A1 to A5 of the house life cycle in the wood solution are negative. This means that the wood, while in the tree, absorbs more CO<sub>2</sub> than it is

emitted by the extraction of raw materials, transport, manufacture and installation of the construction products in this wooden house solution. The CO<sub>2</sub> emissions due to the steel-framed house are slightly higher than those produced in the construction of the reinforced concrete framed house.

## 8 – Conclusions and recommendations.

### Conclusions:

The life cycle assessment is a useful tool for making decisions in design stages about the choice of more sustainable materials and solutions in building construction.

The BIM methodology allows you to build 3D models and obtain the quantities of materials to be used in the construction of buildings to subsequently perform an LCA, saving time in the analysis.

Of the three solutions studied for the construction of a single-family home, the one that uses timber in the structure and in the interior walls and façade is the slightly more expensive but environmentally more sustainable solution.

It has been proven that the single-family house solution in wood is the one that consumes the most primary energy. If the energy consumed during the manufacture of the technical wood elements is renewable energy, the environmental impact of this solution is considerably reduced.

### Recommendations:

Optimisation in the design of buildings, either through parametric studies or through numerical optimisation, would make it possible to save material and therefore obtain more sustainable solutions, which produce lower environmental impacts.

The use of timber framing for the interior walls in the wooden house instead of CLT panels would save material and make the wood solution cheaper.



## 9 –References

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## **Annex 1. LCA with Excel app of a single-family house concrete and bricks**



## **Annex 2. LCA with Excel app of a single-family house in steel and bricks**



### **Annex 3. LCA with Excel app of a single-family house in timber**