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Methodology to Evaluate the Embodied Primary Energy and CO_2 Production at Each Stage of the Life Cycle of Prefabricated Structural Systems: The Case of the Solar Decathlon Competition

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Abstract: The construction industry is responsible for a high percentage of the energy consumed on the planet and the emission of greenhouse gases, therefore it is considered necessary to rethink many of the processes that this industry carries out in order to reduce its environmental impact. For this, one of the paths could take into account the Life Cycle Assessment of the used materials, for which it is necessary to evaluate this aspect through indicators that allow the qualification and quantification of the weight of these environmental impacts. In this context, this article presents a methodological proposal for the quantitative evaluation of the embodied primary energy and CO_2 production at each stage of the life cycle of prefabricated structural systems, taking as case studies eight prototypes from the "Solar Decathlon" competition in its editions of Europe (2014), United States (2015) and Latin America (2015), through a Simplified Life Cycle Analysis, using the Eco Audit tool from CES Edupack. Through this analysis, conclusions are drawn about the optimization of a structural system with lower environmental demand and the possibilities of transferring knowledge from this competition to be applied in innovative systems of new housing models.

Keywords: solar decathlon; life cycle assessment; LCA; prefabricated structures; sustainability; CO_2; energy; prefabrication

1. Introduction

With reference to recent information from the International Energy Agency (IEA), the existing building stock is responsible for 50% of material depletion and 40% of energy consumption, and generates 36% of greenhouse gases (GHG) emissions and a third of the total waste [1]. Most developed countries are struggling to reduce carbon emissions into the atmosphere to meet the international agreements [2]. In the European Union, this sector consumes 40% of materials, 40% of primary energy and is responsible for generating 40% of waste [3].

According to the United Nations Environment Programme (UNEP) and the Organization for Economic Cooperation and Development (OECD) the built environment consumes 25–40% of global energy and represents a greenhouse gas emission load of 30–40% and generates 30–40% of waste [4].

These environmental impacts for which construction is responsible come from industrial processes such as the extraction and manufacture of materials, and transportation that involves the combustion of energy, mainly fossil fuels and energy generation processes, to inhabit and maintain buildings and buildings and waste generated at the end of the building's life [5–7].

The above describes a linear production model whose sequences extraction–manufacture–use and maintenance–waste are responsible for negatively impacting the environment [8]; a paradigm that should disappear by taking actions that close the cycles of materials used, as a condition of sustainability. In this sense, the management of raw materials in construction from its origin in the extractive industry to its final process in the dumping or recycling industry is essential, in order to develop a cyclical life cycle, the sequence of which is intended to be recycling–manufacturing–new-use–recycling [9].

Considering this situation, it is necessary to reduce the environmental impact for which this activity is responsible, putting special emphasis on the environmental impacts associated with the life cycle of construction materials and systems, energy and resource consumption, raw materials for operation, renovation and construction, as well as the generation of waste that the building demands [10]. To this end, it is necessary to evaluate this aspect through indicators that enable the qualification and quantification of the weight of environmental impacts [11], such as the embodied primary energy and its CO_2 production at each stage of the life cycle.

In recent decades, methodologies have been developed to assess environmental and impacts, such as Life-Cycle-Analysis (LCA), defined as "an evaluation of the inputs and outputs of a product system", a widely applied methodology whose framework is provided in standards ISO 14040 and ISO 14044 [12]. However, these standards address uncertainties analysis within the interpretation phase without systematic procedures and therefore many studies provide different approaches [13,14].

There are several uncertainties classifications which consider common sources (i.e., data comprehensiveness, subjective factors, temporal or local conditions) which may all affect the results of LCA studies [15–17]. One of the debated topics is the influence of uncertainties and the importance to include them in the analysis to improve the robustness of life-cycle assessment (LCA) and to allow a better interpretation and communication of the results [18].

Rock et al. proposed connecting Life Cycle Assessment and Building Information Modeling for the early design stage, evaluating multiple construction options and the contribution of different building elements, identifying and visualizing design specific hotspots and improvement potential for reducing the building's embodied impact [19].

Probabilistic approaches for life-cycle analyses have been presented considering the possibility of structural enhancement over an extended building lifespan [12].

The traditional Life Cycle Analysis (LCA) cannot capture the effect of lowering emission factors for electricity generation since only static values are considered [2]. To overcome these limitations, a Dynamic Life Cycle Assessment was proposed in order to evaluate the consequences of electricity decarbonisation on the LCA, and provided a comparison with the literature results about similar constructions [2].

Zabalza et al. proposes a simplified LCA methodology and it allows global comparisons between the embodied energy and emissions of the building materials and the energy consumption and associated emissions at the use stage [20]. The results reveal that embodied energy is the second top cause of energy consumption in residential building, which can represent more than 60% of the heating consumption [20].

On the other hand, this linear model on which construction is currently based, starts from processes of little precision, no repeatability in operations and deficient quality control, and little rationalization of resources [21], which results in a great dispersion and waste of materials, and the adoption of imported systems or technologies, which causes high energy consumption and considers materials that are not compatible with the physical properties of local materials, which leads to dysfunctions in terms of durability and high maintenance costs [22].

Alternative and innovative construction systems, practices and processes should be proposed to those which are conventionally used, in order to contribute to the reduction in the environmental impacts of this activity [23].

Based on the above, prefabrication and industrialization as a construction process becomes a viable option to ensure savings and efficiency from the design and manufacture [24], with optimal use of raw materials, since greater quality and accuracy in the used parts and in the proposed facilities is achieved, along with efficiency and savings by optimizing the implementation, reducing execution times, including the independence of the weather, since a large part of the tasks is executable in a workshop, minimizing the environmental, acoustic and visual impact of the construction site itself, and even contributing to savings and efficiency at the end of the building's life by facilitating the dismantling and recycling process of the building itself [25]. These systems can also contribute to cost reduction, productivity by reducing absenteeism, labor supply, etc. [26,27].

In this way, and considering that, for the analysis of sustainable architectural paradigms that provide bases and innovative ideas focused on perfecting future habitable models, competitions are an ideal field of study; therefore, this document considers the Solar Decathlon competition as a case study.

The Solar Decathlon is the most transcendental and valuable competition in the field of sustainability, aimed at universities around the world in collaboration with public and private organizations, with the main objective of designing, building and testing a solar energy house connected to the electricity grid with the strategy of maximizing self-consumption, with the support of bioclimatic technologies and maintaining a low environmental footprint on a real scale, from an urban approach and in relation to a specific context, according to the edition of the competition [28,29]. The proposal is built, its consumption is subsequently measured and, finally, it is evaluated by a jury and compared to other proposed solutions.

This competition promotes interdisciplinary learning in engineering, design, communication and architecture [30]. Students from different disciplines participate in teams guided by several professors during a preparation period of 12 to 29 months, plus five weeks of on-site competition.

Beginning with the first event in Washington, DC in 2002, the Department of Energy's Solar Decathlon has brought attention to the promise of PV-powered and zero-energy homes through the format of a compelling collegiate competition. As an internationally recognized event, it demonstrates innovative solutions, using energy efficiently and generating the needs of modern home life with solar energy [31].

There are three basic principles that underpin the spirit of the competition:

- To supply the energy necessary to carry out daily tasks of feeding, cleaning, leisure, work, transport, etc., with an acceptable level of comfort and making exclusive use of the solar energy captured by the house during the days of the exhibition phase;
- To demonstrate to society, in a practical way, the existence of architectural design principles that make use of solar technologies and, through them, their aesthetic and energy benefits;
- To stimulate research and development related to renewable energies and energy efficiency, especially in the building sector.

During the competition–evaluation period, prototypes are displayed while they are evaluated in ten different tests [32]: Architecture, Energy Efficiency, Engineering and Construction, Comfort, Marketing and Communication, Electrical Energy Balance, House Operation, Innovation, Urban Design and Accessibility and Sustainability.

From the tests mentioned above, it should be noted that the primary purpose of the "Engineering and Construction" test is to assess the design of the proposed construction system and the engineering solution at the competition site [33]. Based on this, each team must present the viability of its proposal, the correct integration and functionality of the structure, taking into account the electrical and solar energy production systems.

In this sense, it is worth emphasizing the large amount of detailed documentation that each of the teams presents about their prototype, which ranges from a detailed analysis of the context in which they place their proposal, studies of the problem they intend to solve, graphic information and processing of various data, architectural and construction plans, to research reports from different authors on which they base their proposal, concepts, theories and hypotheses. That is why the Solar Decathlon competition is considered a source of enormous value which has been the object of study of research articles, books and theses from undergraduate and postgraduate studies.

This article presents a methodological proposal for the quantitative evaluation of the embodied primary energy and CO_2 production at each stage of the life cycle of prefabricated structural systems, taking as case studies eight prototypes from the "Solar Decathlon" competition in its editions in Europe (2014), USA (2015) and Latin América (2015) through a Simplified Life Cycle Analysis, using the Eco Audit tool from CES Edupack. Through this analysis, conclusions are drawn about the optimization of a structural system with lower environmental demand and the possibilities of transferring knowledge from this competition to be applied in innovative systems of new housing models.

2. Methods

The case studies that have been selected to carry out this work come from the three editions of Solar Decathlon held between 2014 and 2015 (Table 1), which took place in France, the United States and Colombia, respectively.

Table 1. Competition editions up to 2020.

Year	USA	Africa	China	Europe	LATAM	Middle East
2002	Washington					
2003						
2004						
2005	Washington					
2006						
2007	Washington					
2008						
2009	Washington					
2010				Madrid		
2011	Washington					
2012				Madrid		
2013			Datong			
2014				Paris •		
2015	Irvine •				Cali •	
2016						
2017	Denver					
2018			Dezhou			Dubai
2019		Ben Guerir		Budapest	Cali	
2020	Washington					Dubai
2021				Wuppertal		

The • is used to indicate that the edition has been chosen as a case study.

Among the participants in the Paris and United States editions, the three prototypes that obtained the best score in the "Engineering and Construction" test in each of these two editions, under the evaluation criteria determined by the competition, were taken. To these six prototypes, we will add those presented by the team made up of the University of Seville and the University of Santiago de Cali [24], and the team from the Instituto Tecnológico y de Estudios Superiores de Monterrey, both of which participated in the first Latin American edition of the competition (Colombia, 2015).

These eight prototypes (Table 2) will, therefore, be compared to determine which structural system is optimal from the point of view of the embodied primary energy and its CO_2 production, throughout its life cycle.

Table 2. Case studies.

Solar Decathlon Europe 2014 (SDE14):	CASA (CA) Universidad Nacional Autónoma de México and Industrial Design Research Center and the School of Engineering and the School of Arts (Mexico).
	Renaihouse (RE) Chiba University (Japan).
	Casa Fénix (FE) Universidad Técnica Federico Santa María-Valparaíso (Chile) and Universidad de la Rochelle-Espace Bois de l'IUT (France).
Solar Decathlon USA 2015 (SD USA15):	SU + RE House (SU) Stevens Institute of Technology.
	Casa del Sol (CS) University of California, Irvine, Chapman University and Irvine Valley College.
	Nexushaus (NH) University of Texas at Austin and Technische Universitaet Muenchen.
Solar Decathlon Latin America and the Caribbean 2015 (SDLAC15):	Kuxtal (KX) Instituto Tecnológico y de Estudios Superiores de Monterrey, Campus Querétero (Mexico).
	Aura Project (AU) University of Seville and University Santiago de Cali (Spain-Colombia).

The reason for selecting these editions of the competition as an object of study is the possibility of being able to contrast structural solutions developed in the same temporal context, carried out in the western world, where the historical–cultural links are considered to be very evident, and where the perception of industrialized construction in society has a similar impact, especially between Europe and Latin America.

2.1. Case Studies

CASA (CA) (Figure 1): the structure of this prototype is developed from the "Space frame" system, made up of a set of steel profiles. It also has a wooden framework for the interior partitions.

Weight: 15,845.32 kg

Area: 120.75 m^2

Figure 1. CASA. SD Europe 2014.

Renaihouse (RE) (Figure 2): Constructively, this prototype is divided into three cores. Its main material is wood, which is used both for the supporting structure and for the interior partitions of the house.

Weight: 12,258.18 kg
Area: 83.40 m^2

Figure 2. Renaihouse. SD Europe 2014.

Casa Fénix (FE) (Figure 3): This prototype uses only wood as a construction material. It is based on load-bearing panels that will have two functions: exterior enclosure and load-bearing wall.

Weight: 5457.74 kg
Area: 58.88 m^2

Figure 3. Casa Fénix. SD Europe 2014.

SU + RE House (SU) (Figure 4): This is a prototype that uses both wood and steel. It uses the Ballon Frame as a construction system to form the enclosure of the private area of the house, the supporting structure is also made of wood. However, it uses steel elements for the porch of the house, both pillars and beams.

Weight: 10,978.79 kg
Area: 114.98 m^2

Figure 4. SU + RE House. SD USA 2015.

Casa del Sol (CS) (Figure 5): Here again, both wood and steel are used. However, this team uses metal profiles for the main structure of the prototype, reserving wood for secondary elements.

Weight: 17,101.87 kg
Area: 91.48 m^2

Figure 5. Casa del Sol. SD USA 2015.

Nexushaus (NH) (Figure 6): In this prototype, steel was used as the material of the supporting structure, both exterior and interior, and wood was used to form the enclosure of the house through the Ballon Frame System.

Weight: 3967.70 kg
Area: 61.20 m^2

Figure 6. Nexushaus. SD USA 2015.

Kuxtal (KX) (Figure 7): This prototype used "Steel Framing" as a structural solution, based, therefore, on steel elements. A secondary structure based on C'formed-purlin profiles was attached to it. Parapet.

Weight: 4759.76 kg
Area: 68.24 m^2

Figure 7. Kuxtal. SD LAC 2015.

Aura Project (AU) (Figure 8): This solution was based on three structural prisms made of metal profiles, which were subsequently assembled with dry joints. Wood (OSB boards) was used as part of the enclosure of the house and bamboo as an element for the ventilated façade.

Weight: 10,269.74 kg

Area: 81.20 m^2

Figure 8. Aura Project. SD LAC 2015.

Next, Table 3 analyzes the different structural systems, according to the selected parameters, which were used in each of the prototype case studies. These must be based on prefabricated and industrialized systems, as this is one of the premises of this competition, as the first test will be to build/assemble the prototype within a maximum period of 10 days.

Table 3. Comparative analysis of the parameters under study.

	[CA]	[RE]	[FE]	[SU]	[CS]	[NH]	[KX]	[AU]
Prefabrication	•	•	•	•	•	•	•	•
Industrialization	•			•	•	•	•	•
Commissioning efficiency	•	•	•	•	•	•		•
Material availability	•	•	•	•	•	•	•	•
Use of local materials		•	•					•
Possibility of recycling elements	•	•	•	•	•	•	•	•
Possibility of reusing elements	•			•	•	•	•	•

The • is used to affirm.

2.2. Analysis Levels

Following the process of the intended analysis, the methodology distinguishes three levels of study.

For the first level, a Simplified Life Cycle Analysis of the projects is carried out, using the ecological audit tool "Eco Audit" of CES EDUPACK, which is based on Granta's environmental data to quantify the environmental impact of the key life phases of a material, product or building, having more than 3000 materials and more than 200 different processes within its database, thus allowing the environmental impacts of each of the parts of the life cycle of the studied structural system to be identified [2,12]. In the Eco Audit, the user enters information on each of the components of the system, selecting the material, the recycled content (if any) of each material, the weight it represents in the system, the primary processes for the manufacture of that material, and the end of life that it is supposed to have. For the transport, the user chooses one or several types of transport by which the material is transported throughout the life cycle of the product, and enters a numerical value of the distance that each component/material will travel. Finally, information is entered for the use, if there is energy involved in the use of the structural system, which is not being considered in this simplified analysis. This is combined with the ecological property data of the materials and processes used to make the structural system, resulting in a calculation of energy use and CO_2 production at each stage of the system's life cycle.

It should be mentioned that the following criteria were taken into account for the calculation of the Simplified LCA of each prototype by means of this tool, and to encourage its comparison with the others:

- For wooden elements, "landfill" was considered to be the end of life of the material en donde se considera el carbono biogénico en el cálculo de la huella de carbono;
- Two analyses were carried out for the steel elements, one with "landfill" as the end of life of the material and the other with "recycling" as the end of life;
- For mixed systems that include wood and steel, two analyses were performed, since the life span of these materials is different; for both materials, "landfill" was considered as their final disposal. Subsequently, the data obtained on embodied energy and CO_2 footprint of wood and steel were added up (this result was taken into account for the qualification of the Simplified LCA parameter);
- For the analysis of the transport of materials, a radius of 200 km was estimated from the place where the material was obtained to the location of the prototype (this was decided to make the comparison viable, and because this information was not specified in all the SD project deliverables). Likewise, 200 km was entered into the Eco Audit tool, as this is what the GREEN certification system considers to be the maximum proximity to consider a material to be "regional";
- The life span for structural systems and/or wood-based elements was 50 years;
- The life span for structural systems and/or elements using steel as a raw material was 75 years;
- The life span of the building when it comes to mixed systems (which consider steel and wood elements), two runs were carried out in the program, one of all the wooden elements whose considered life span is 50 years, which yielded certain results of incorporated primary energy and CO_2 production, and later another run of all elements in steel whose considered life period is 75 years, with which other results of incorporated primary energy and CO_2 production were obtained and in the end these both results were added to obtain a final quantification of both variables.

At the second level, with the value of the built area of each project, the CO_2 footprint of building 1 m^2 of the structural system of living/useful area of each prototype is calculated and a new comparison between the prototypes is made.

At the third level, a quantitative-comparative evaluation is made based on the results obtained from the Simplified Life Cycle Analysis described above and the weight obtained for each structural system of each prototype from a heading that considers a range of energy use and carbon production that takes into account the highest value and the lowest value of the analyzed prototypes (Table 4); starting from this range, "quarters of ranges of embodied energy and CO_2 production" are assigned for the weightings of each prototype. As it is about making a contribution to the way of evaluation that the SD competition follows, this simplification becomes a suggestion proposed by the authors, which should be reviewed in each case of each edition of the competition.

Table 4. Simplified life cycle assessment (LCA) assessment heading.

1	2	3	4
From 54.44 to 72.58 MJ/year per M2.	From 36.29 to 54.44 MJ/year per M2.	From 18.15 to 36.29 MJ/year per M2.	From 0.0 to 18.15 MJ/year per M2.

Figure 9 shows a flow chart illustrating the three different levels that were followed for this study.

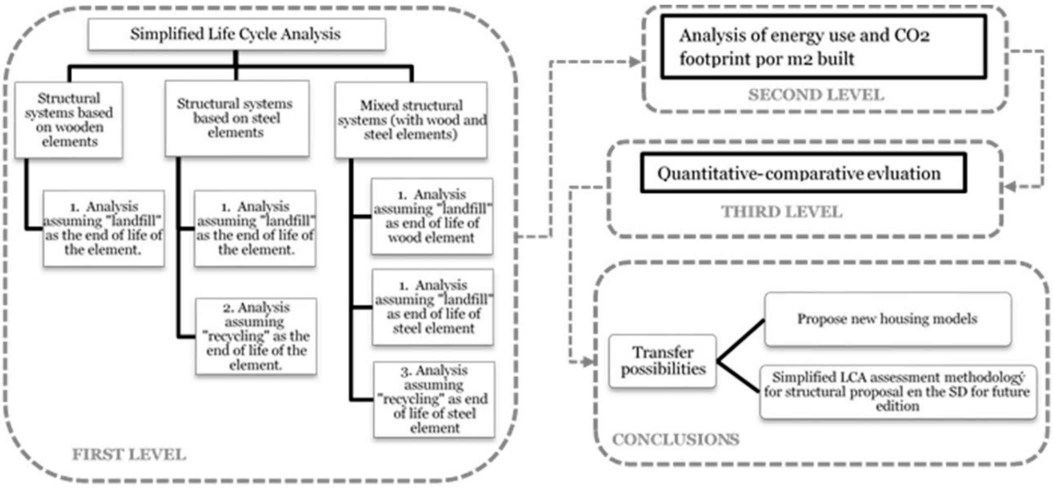

Figure 9. Diagram of the used methodology.

3. Results

The results at each of the proposed analysis levels are here described and discussed.

First level: simplified life cycle analysis

The results of the Simplified Life Cycle Analysis Eco Audit tool for SD projects are shown below in terms of the energy use and CO_2 production for which each building is responsible, taking into account the materiality, use and transport of the elements that make up the structural system.

Table 5 shows the first results of the analysis of the structures assuming "landfill" as the end of life of wood and steel elements.

Table 5. Energy use and CO_2 production of SD prototypes per year.

	ENERGY USE	CO_2 PRODUCTION
SU+RE HOUSE	3200 MJ/year	218.1 CO_2/year
CASA DEL SOL	6640 MJ/year	431.40 CO_2/year
NEXUSHAUS	1485 MJ/year	80.80 CO_2/year
KUXTAL	2590 MJ/year	182.00 CO_2/year
AURA PROJECT	4006 MJ/year	260.50 CO_2/year
CASA	8001 MJ/year	548.30 CO_2/year
RENAIHOUSE	2730 MJ/year	173.00 CO_2/year
CASA FÉNIX	1060 MJ/year	46.50 CO_2/year

From this first Simplified LCA, it can be seen that the structural system of the CASA prototype is that it uses more energy and produces more carbon, highlighting that it is the project that proposes more steel elements in its main structural system, while CASA FÉNIX is the smallest, where it is worth noting that it is the lightest structural proposal, based on wooden elements.

Based on the above, and as previously stated, it is necessary to carry out another Simplified LCA, since at the end of the life of the steel elements, these can be recycled, thus obtaining negative values for embodied energy and the production of CO_2, that is, when these steel elements are recycled, there is less impact on the environment (Table 6).

Table 6. Energy use and CO_2 production of SD prototypes per year.

	ENERGY USE	CO_2 PRODUCTION
SU + RE HOUSE	2600.0 MJ/year	183.06 CO_2/year
CASA DEL SOL	3999.6 MJ/year	278.07 CO_2/year
NEXUSHAUS	1061.0 MJ/year	56.00 CO_2/year
KUXTAL	1552.7 MJ/year	103.60 CO_2/year
AURA PROJECT	2906.0 MJ/year	194.50 CO_2/year
CASA	5147.7 MJ/year	361.64 CO_2/year
RENAIHOUSE	2730.0 MJ/year	173.00 CO_2/year
CASA FÉNIX	1060.0 MJ/year	46.50 CO_2/year

Similarly, in the table above, it can be seen that the CASA prototype is still the one that has the greatest environmental impact and, on the other hand, the Casa Fenix project is the one that has the least impact; despite the fact that in this second analysis the end of life of the steel elements was recycled. However, it should be stressed that these are the prototypes with the largest and smallest built surface area.

The SU + RE HOUSE prototype has more built area but fewer elements than the component in its structural system. This then has a large "portico" area (which is in fact the main conceptual space for the prototype's coastal-style social life) and this portio has no walls or deck/ceiling).

RENAIHOUSE is a similar case, as it has a central patio with practically an open plan without vertical support elements other than the bedroom and service modules. Therefore, it has a large built/habitable area and few structural elements that impact LCA.

Second level: Analysis of energy use and CO_2 footprint per m^2 of construction

Once the previous results were obtained, it is worth mentioning that the values of energy use and CO_2 production are linked to the built area of each prototype, which vary depending on the architectural proposal they present to seek a solution to a specific problem of the place of their location, which also has to do with the edition of the SD in which they competed. For this reason, the results of the calculation of these variables per square meter of construction, considering landfill as the end of life of the wooden elements and recycling as the end of life of the steel elements, are shown below in Table 7.

Table 7. Energy use and CO_2 production of SD prototypes per m^2 built per year.

	m^2 BUILT	ENERGY USE	CO_2 FOOTPRINT
SU+RE HOUSE	114.98 m^2	27.83 MJ/year	1.89 CO_2/year
CASA DEL SOL	91.48 m^2	72.58 MJ/year	4.71 CO_2/year
NEXUSHAUS	61.20 m^2	24.26 MJ/year	1.32 CO_2/year
KUXTAL	68.24 m^2	37.95 MJ/year	2.66 CO_2/year
AURA PROJECT	81.00 m^2	49.45 MJ/year	3.21 CO_2/year
CASA	120.75 m^2	66.26 MJ/year	4.54 CO_2/year
RENAIHOUSE	83.40 m^2	32.73 MJ/year	2.07 CO_2/year
CASA FÉNIX	58.88 m^2	18.00 MJ/year	0.79 CO_2/year

From the table above, these values are compared in Figure 10, which shows the importance of this analysis, since by separating the total area of the prototypes from the impacts they cause, the project with the greatest environmental impact changed and is now Casa del Sol; however, Casa Fénix continued to be the project with the least impact, like the other environmental impact positions of the other prototypes.

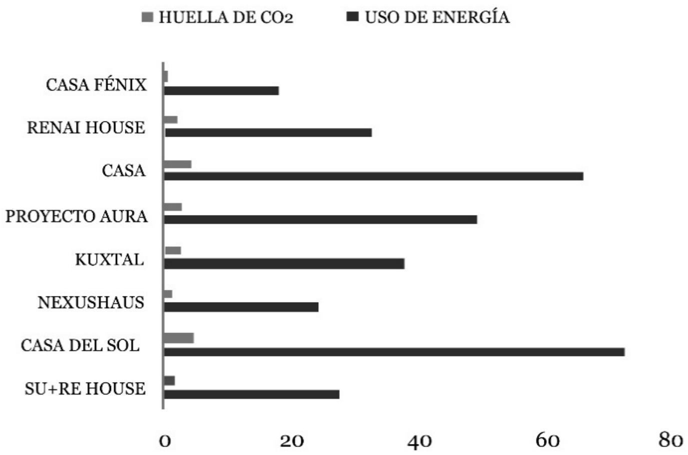

Figure 10. Comparison of energy use and CO_2 production of SD prototypes per square meter per year. Source: Own elaboration from ACVS.

Third level: Quantitative benchmarking

After carrying out the analyses described above, the structural systems of the SD case studies are subsequently evaluated in a quantitative and comparative manner, as part of the methodological proposal for the evaluation of environmental impacts in this document, based on the heading set out in the methodology, of the structural solutions projected by the teams in the competition focused on Simplified Life Cycle Analysis (Figure 11).

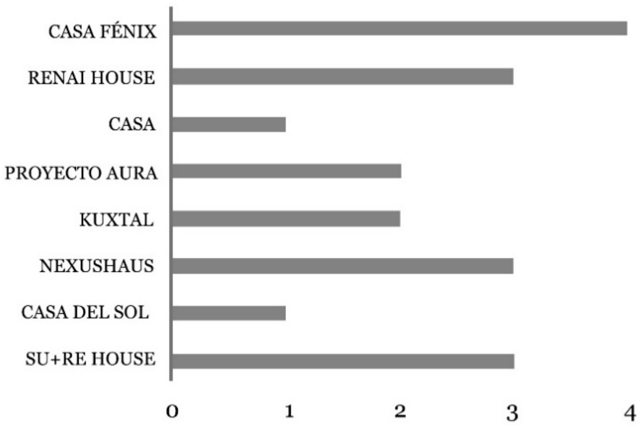

Figure 11. Score obtained by each of the SD prototypes according to the heading. Source: Own elaboration.

Figure 11 shows the two structural systems of the two lowest rated prototypes, CASA and Casa del Sol, agreeing that these are the proposals that use the most energy and produce the most CO_2, the heaviest ones. Neither of them consider the use of indigenous materials, both base their main structural system on steel and metal elements and are the ones with the largest built area (the first and third prototype with the largest area, respectively). On the other hand, the best weighted system is Casa Fénix, which, despite the fact that its structural system does not achieve the industrialization of its elements, and they cannot they be reused, but only recycled at the end of their useful life, turned out to be the one that uses the least energy and produces the least CO_2 when considering the use of autochthonous materials, the prefabrication of their pieces, the use of lightweight wooden elements and the optimization of the living spaces, as it is the prototype with the least built surface.

4. Conclusions

Finally, the potential of this study and analysis of SD prototypes for their implementation in the search for technological and constructive innovations applicable to new housing models is here presented, as well as the potential of this methodology for evaluating the simplified LCA of SD structural proposals, as a reference to be put into practice in the ponderable aspects of the competition in future editions.

From the study and analysis of the weighted tests in the different editions of the Solar Decathlon treated in this document, it can be deduced that it is necessary to have some test or set of criteria that quantitatively evaluate (score) the Life Cycle Analysis of the prototypes, since it is an international competition which universities from all over the world participate in, with different social, climatic, geographic, natural and economic resources problems and contexts, among other factors that intervene depending on the site and/or the proposed location of the project. It is of fundamental importance that the solutions proposed by each team are taken into account and regulated in a concrete way, from the design, composition, transport, use and end of life of each of the elements that materialize the prototype; since, currently, no aspects related to the LCA of buildings are being considered. The aim would be to develop construction models that cause less impact on the environment.

By deepening and carrying out a Simplified LCA of the above-mentioned SD prototypes, it can be inferred that by designing regional materials with greater supply than demand on site (wood preferably over steel) to prefabricate and industrialize structural elements with qualities such as lightness and that can be reused and subsequently recycled at the end of their useful life, these also make it possible to easily assemble and disassemble the structure to optimize its transportability, and that such transport is by land (preferably over air or sea transport), over the shortest possible distances, resulting in structural solutions with lower energy consumption and CO2 production. Likewise, by ensuring that a set of elements form flexible, adaptable and perfectible modules, they produce more sustainable systems.

Likewise, in the search for knowledge transfer that can be extrapolated to the development of new construction solutions for residential buildings, it is concluded that the above-mentioned characteristics of the structural system are fundamental for achieving models with a lower environmental impact and are more sustainable than those used conventionally.

Thus, it is considered that the methodology used to evaluate the "Engineering and Construction" test in this competition is excessively subjective, leaving its evaluation in the hands of the judges who are responsible for analyzing the construction systems of each prototype. For this reason, it is considered that this type of competition should include a more objective evaluation, based, in part, on an analysis of the primary energy and CO_2 emitted by each of the proposed construction solutions.

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