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Building Materials and Their Impact on the Environment

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Abstract

Traditionally, in the construction sector it has been common to use materials indigenous to the construction site, such as bricks, cork, wood, etc. and this has significantly reduced energy costs and environmental impact.
Similarly, there has been an adjustment of building design to local climatic conditions, resulting in improved building quality and thermal comfort for occupants. Currently, the massive use of global materials such as cement, aluminum, concrete, PVC, etc., has led to a significant increase in energy and environmental costs.

Keywords: materials, construction, LCA, environmental impact, energy costs

1. Introduction

According to various studies, the production of the materials needed to construct one square meter of a standard building can involve investing an amount of energy equivalent to that generated by the process of burning more than 150 liters of gasoline. Each square meter constructed will result in an average emission of 0.5 tons of carbon dioxide and an energy consumption of 1,600 kWh (which will vary depending on the design of the building) if only the material impacts are taken into account. Figure 1 shows the relative contribution of the main building materials to CO2 emissions in relation to one square meter of a standard building block, highlighting the high impact of materials commonly used in buildings such as steel, cement or ceramics.

We must learn to coexist with technological progress, without this having a pitiful impact on the most sensitive fiber of society and on the most economically disadvantaged sectors. A balance must be sought between technology and education so that they do not harm each other.

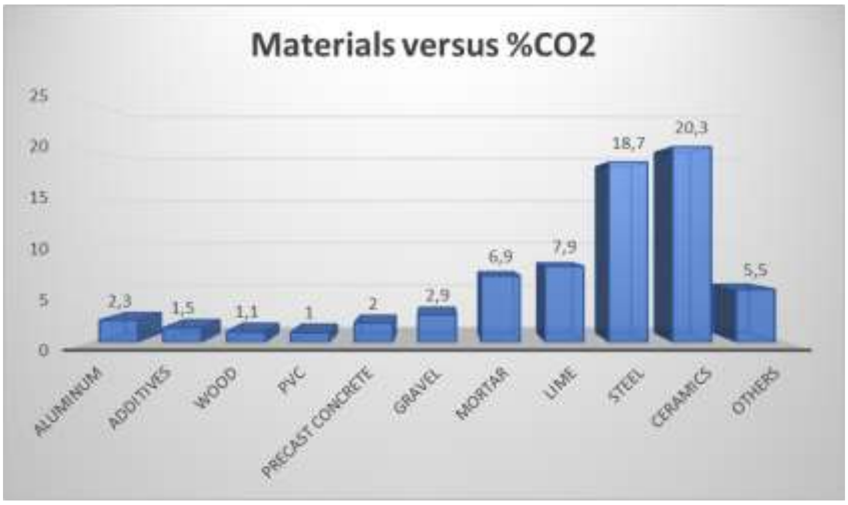

Figure 1. Contribution of the materials required for the construction of 1m on the CO_2 emissions associated with its manufacture.

Statistically, it can be said that the construction sector is responsible for 50% of the natural resources used, 40% of the energy consumed (including the energy used) and 50% of the total waste generated (28).

While it is true that the conversion of raw materials and the production of materials generates high environmental and energy costs, experience shows that it is not easy to change the existing construction systems and the irrational use of natural resources, where the priorities of recycling, reuse and recovery of materials are conspicuous by their absence compared to the traditional trend of extraction of natural materials. Therefore, there is a need to reconsider this worrying state of environmental crisis, finding ways to rationally use materials that fulfill their functions without harming the environment.

It is known that building materials affect the environment throughout their life cycle, from their first stage, i.e., from the extraction and transformation of raw materials to the end of their useful life, to their treatment as waste, through the production or manufacture of the materials and the proper use of these materials in the building.

2. Methodology and materials

Life Cycle Assessment (LCA) is one of the most appropriate methodologies for assessing the environmental impact of any type of product or service, and can therefore be applied to a material or construction solution, or to a building or group of buildings (14).

It is obvious that there is an interaction between all stages of a building's life: design, construction, use, maintenance and final disposal of the building. Therefore, a reduction of investment in the construction stage may lead to an increase of investment in the use and maintenance stages of the building.

The LCA methodology is now accepted as a basis on which to compare alternative materials, components and services. The generally applicable methodology is fully standardized through UNE EN ISO 14040:2006 and UNE EN ISO 14044:2006, and consists of 4 interrelated stages (15,16):

- Definition of objectives and scope.
- Inventory analysis, which quantifies all energy flows and materials entering and leaving the system throughout its useful life, which are extracted or emitted into the environment.
- Impact assessment, where a classification and evaluation of the inventory results is performed, relating the results to observable environmental effects through a set of impact categories (cumulative primary energy, global warming potential, water footprint, etc.).
- Interpretation, where the results of the preceding phases are evaluated together, along with the objectives defined in the study, in order to establish the final conclusions and recommendations. This includes various techniques such as sensitivity analysis on the data used, analysis of the relevance of the process steps, analysis of alternative scenarios, etc.

In the case of buildings, there is a methodological standard currently under development "Sustainability of construction works" of the Technical Committee 350 of the European Committee for Standardization (CEN/TC 350). This standard provides an LCA-based calculation method for assessing the environmental performance of a building and communicating the results of this assessment. According to this standard, the system to be analyzed must include the following 4 stages or subsystems of the building: production, construction, use and final disposal (7,8).

The application of the LCA methodology in buildings has innumerable advantages for the construction sector: it facilitates decision-making by construction companies and organizations with a view to planning eco-efficiency strategies in building, identifying opportunities to improve environmental impacts in the construction sector, considering the complete life cycle of buildings, setting priorities for green design or eco-rehabilitation of buildings, appropriate selection of suppliers of building materials and energy equipment, establishing strategies and fiscal policies to manage construction waste and transport of materials, defining new R&D&I programs, etc (2).

However, at present, there are several barriers and obstacles to overcome in order to achieve a wider application of LCA in buildings, among which are the existing prejudices about the complexity of LCA and the accuracy of its results depending on the databases or computer applications used, difficulties in the understanding and application of LCA results due to the lack of knowledge of LCA methodology among the sector's agents, as well as the lack of legislative requirements and the lack of incentives, which leads to a low demand for LCA studies in buildings (12,25,26).

Half of the materials used in the construction industry come from the earth's crust, producing 450 million tons of construction and demolition waste (CDW) annually in the European Union (EU), i.e. more than a quarter of all waste generated. This volume of CDW is constantly increasing, and its nature is becoming increasingly complex as the materials used diversify (5,6,10). This fact limits the possibilities for reuse and recycling of waste, which is currently only 28% (in the case of Spain, 5%), increasing the need to create landfills and intensify the extraction of raw materials (27).

The extraction and processing of raw materials is the most impactful stage, since the extraction of industrial rocks and minerals is carried out through open-pit mining, in its two forms: quarries and gravel pits.

The impact produced by quarries and gravel pits on the landscape, their topographic modification, loss of soil, as well as atmospheric and noise pollution, require a very detailed study of their effects in order to adopt corrective measures to eliminate or minimize the negative effects produced.

The production or manufacturing phase of building materials also represents another stage in their life cycle with many environmental repercussions. The truth is that in the production or manufacturing process of building materials, environmental problems derive from two factors: the large amount of powdery materials used and the large consumption of energy required to achieve the right product. The environmental effects of the materials manufacturing processes are therefore translated into CO2 emissions into the atmosphere, suspended dust, noise and vibrations, liquid discharges into water, waste and excess energy consumption.

The phase of use or rational use of materials, perhaps the most unknown but no less important, since it has an impact on the environment in general and on health in particular. The most common pollutants and toxins in indoor environments and their biological effects -inherent to construction materials in combustion processes and to certain products of use and consumption- range from gases such as ozone and radon, carbon monoxide, to volatile organic compounds such as organochlorine (PVC).

Finally, the final phase of the life cycle of building materials coincides with their treatment as waste. Most of this waste comes from the demolition of buildings or the rejection of building materials from new construction or renovation work. Usually referred to as rubble, the vast majority is non-polluting; however, some waste containing asbestos, mineral fibers or solvents and concrete admixtures can be harmful to health. Most of this waste is taken to landfills, which, although in principle do not pollute, do produce a great visual and landscape impact, in addition to the waste of raw materials that prevent their recycling.

3. Discussion

From a life cycle perspective, the reduction of the environmental impact of buildings involves the use of renewable or recycled materials from the biosphere, such as wood, animal or vegetable fibers, natural paints and varnishes, with a low level of industrial processing. In all these cases, most of the energy associated with their production comes from the sun, so that the consumption of non-renewable energies and associated emissions are considerably reduced.

An analysis of the different ceramic products (bricks, tiles and roof tiles) shows that ceramic tiles in particular have a high embodied energy content, mainly due to the high consumption of natural gas during firing. With respect to the different types of bricks, the use of lightened clay bricks, and especially silico-lime bricks, leads to a clear reduction in energy and environmental impacts.

It is worth highlighting the potential for reducing the existing impacts on ceramic products associated with a future technological replacement of the current gas kilns with modern biomass kilns, which would in fact represent a return to the origins of traditional ceramic production, characterized by its sustainability, both in the socio-economic and environmental spheres (9,11,28).

In terms of insulation, the impact of conventional insulation with a high level of industrial processing, such as polystyrene or polyurethane, is clearly superior to the impact of natural materials such as cork, wood fiber and sheep wool, or recycled materials such as cellulose fiber (24).

Due to the increasingly widespread use of synthetic fabrics, sheep's wool has become, for today's society, a product with an increasingly reduced market, being considered, in many cases, a 'waste' that is difficult to use (13). The creation of companies producing sheep wool as thermal insulation for buildings would make it possible to convert this "waste" of our time into a cheap and abundant raw material, which would also contribute to the sustainable and balanced development of rural areas (1,3,29).

On the other hand, cork production in the forests and pastures of southern Europe is one of the most ecological productions that exist, since it is extracted from the tree during the summer every 10 years, without causing damage to the tree and keeping alive an ecosystem of high ecological value, which would probably disappear due to land clearing, in the absence of economic exploitation (19).

However, there is currently a certain inertia in the use of conventional insulators, due to the existence of a more widespread commercial network and, therefore, a normally lower price, coupled with the lack of knowledge and, sometimes, skepticism among some designers for other solutions that are much more respectful of the environment. To change this situation, the use of natural and/or recycled insulating materials, which provide a similar or even higher level of insulation and

thermal comfort in buildings, should be encouraged by the various administrations, promoting the creation of a powerful commercial network of ecological insulators capable of competing, on equal terms, with traditional insulators (4).
With regard to cement-based materials, reducing their impact would require a clear commitment to replacing conventional materials and fossil fuels with alternative materials and fuels for the clinker manufacturing process. In most European countries, the percentage of alternative fuels used in the manufacture of clinker is above 35%, even reaching 80% in the case of the Netherlands, while in Spain this percentage is only 5%, with large differences between the different Autonomous Communities.

STAGES	**Incorporated elements**
Building production	Raw materials
Transportation	
Fabrication	
Building construction	Transportation
On-site construction processes	
Building use	Maintenance
Repair and replacement	
Rehabilitation	
Final energy consumption: heating, cooling, ventilation, domestic hot water, and lighting	
Water consumption	
Final building disposal	Deconstruction
Transportation	
Recycling / reuse	
Landfill/incinerator final disposal	
Building construction	

Table 1. Stages of an LCA applied to building construction

The use of alternative fuels in the cement industry would mean an energetic valorization of different types of waste, which would otherwise end up in a landfill or incinerator, causing much higher environmental impacts. This valorization would make it possible to convert waste into resources, helping to close the materials cycle, a key concept for achieving a true industrial ecology.
As for wood-based construction materials, they generally have a reduced impact, the less industrial processing required for each specific product, the greater the impact. The balance in carbon dioxide equivalent emissions is almost neutral, due to the low industrial processing, and would be negative (net absorption of emissions) if the end of life of the product were recycling or reuse instead of incineration (18).
In the current context where large amounts of money are being promoted and invested in CO2 capture and confinement in thermoelectric plants, it should be considered that the use of structural wood in buildings entails, provided that the felling processes are sustainable (which entails planting a new tree for each tree

felled), a previous capture of CO_2 in the forests and a storage of such CO_2 during the whole useful life of the building (50 years at least), which can also be extended in case of reuse of wood at the end of the useful life. This turns buildings with wooden structure into real "CO_2 storage", which should be promoted by the Administrations.

For all these reasons, it would be advisable to modify the current building regulatory framework in order to promote the design of buildings with wooden structures to the detriment of conventional structures based on reinforced concrete, since, in addition to the clear environmental advantages, wooden structures offer better resistance in case of fire.

Despite their low impact, wood products have a certain potential for improvement, mainly related to the replacement of conventional urea-formaldehyde and melamine-formaldehyde resins with natural resins that offer the same technical specifications in the final product. The production of natural resins is one of the traditional trades that is becoming extinct in many areas. The use of new resin exploitation techniques for use in different wood products would result in the creation of employment and wealth in rural areas.

Finally, it should be noted that the reduction of impacts on metals such as aluminum, steel and copper requires, in addition to a rationalization of their use, an increase in the production of the secondary steel, aluminum and copper industry to the detriment of the primary industry. This industry contributes to the depletion of iron, bauxite and copper reserves, and includes high impact processes such as electrolysis and pyro/hydro-metallurgy. Administrations should establish incentives for the development of the secondary industry of these products, which would contribute to increase their recycling, favoring the transformation of waste into resources that contribute to preserving the planet's mineral reserves (20,23).

4. Conclusions

A sustainable building should be characterized by a maintained balance between the production of materials, their consumption for the construction and/or rehabilitation of buildings and the use of the necessary natural resources. To prevent the production of materials from affecting natural resources, it is necessary to promote the use of available technical improvements and innovation in production plants, and to replace, as far as possible, the use of finite natural resources with waste generated in different production processes, closing product cycles, which implies a clear commitment to reuse and recycling, and minimizing in any case the transport of raw materials and products, promoting the use of locally available resources.

Materials with lower environmental impact, for use in construction, should incorporate environmental sustainability criteria, such as high energy efficiency, durability, recoverability, renewable resources, use of clean technology and waste recovery (17). Although there is no universally accepted methodology to quantify the multiple and varied existing criteria, it is possible to use another methodology such as Life Cycle Analysis. It is true that this methodology is costly, but it is the most reliable tool for assessing the environmental burdens associated with a product or activity. Therefore, it is necessary the collaboration between the Administrations and the construction industry sector in order to elaborate a Life Cycle Inventory.

Likewise, there is a lack of a National Sustainable Building Plan that includes not only the criteria relating to the use of materials with low environmental impact, but also other thematic blocks referring, among others, to energy efficiency and the management of construction and demolition waste (22).

In the management of these wastes, it is necessary to develop standards that require the incorporation of recyclable materials from treatment plants installed for this purpose in all construction projects. For this reason, it is essential to simultaneously promote an adequate materials market that overcomes the disadvantages of the low acceptance of recycled products, on the one hand, and the final price of the recycled product or material, which is higher than that of materials made from raw materials, on the other.

With regard to public projects, the regulations governing Public Administration Contracts should take into consideration the environmental variable, rewarding those projects that use construction materials that generate the least amount of construction waste (21).

At present, the demolition of buildings at the end of their useful life makes it very difficult to separate the different materials, most of which end up in landfills and/or incinerators. Therefore, in order to make the recycling of building materials possible, it is necessary to promote a radical change in the design of buildings, so as to favor the disassembly of building materials at the end of their useful life. This important conceptual change is already a reality in sectors such as the automobile industry, where current regulations encourage automobile manufacturers to design vehicles to facilitate the recycling of their various components through an appropriate selection of materials, increasingly of recycled origin, and assembly techniques.

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