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Materials selection for green buildings: which tools for engineers and architects?

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Abstract

The selection of building materials plays a key role in the achievement of the ‘Green Buildings’ target and is performed both at an early stage of the design process (when general and strategic choices concerning the building are made) and at the working plan (when materials available on the market are selected). The latter aspect is important exactly as the first one for the actual fulfilment of ‘greenness’ requirements, but architects and engineers in charge of this choice often lack of evaluation tools supporting them in materials’ selection. In the present paper, after a brief discussion about the critical aspects of the definition of ‘green building materials’, the tools presently available for the selection of building materials are overviewed and discussed, with particular attention to the selection of materials at the working plan stage. The applicability of such tools is therefore discussed, with particular reference to the Italian market.

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1. Introduction

The building sector’s environmental impact is enormous, as it accounts for the use of 40% of the natural resources extracted in the industrialized countries, the consumption of 70% of the electricity and the 12% of potable water, and the production of 45-65% of the waste disposed to landfills [1]. Moreover, it is expected to increase, due to the growth in global population from 6.5 billion in 2005 to approximately 9.0 billion in 2035 [2]. In this scenario, the mitigation of the environmental impact of buildings is a primary issue.

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In the past decades, a great effort was addressed toward the reduction of the energy required in the operation phase of the building (energy required for heating, cooling, ventilation, lighting, hot water, operating appliances, etc.) and the adoption of more efficient technical solutions and materials [3] led to an improvement in the energetic performance of buildings during their service life. The contemporary impulse to the exploitation of renewable energy sources led to a rapid growth of the Zero Energy Building (ZEB) concept [4], implying a zero annual balance between the energy used for the building's operation and the energy gained from renewable sources, such as in 'solar houses' [5]. The Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings establishes the target of 'near zero energy buildings' for public buildings at 2018 and for all new buildings at 2020 [4].

Meanwhile, growing attention was addressed also to the pre-use phase of the building [6], i.e. to the environmental impact of building materials (raw materials extraction, manufacturing process and delivering to the construction site). Such impact can be quantified by means of the parameters identified in the Life-Cycle Assessment (LCA) procedure (ISO 14040), such as energy requirement, contribution to greenhouse gases production, water depletion, etc. Among these environmental parameters, which are fundamental for the mitigation of the buildings' impact but quite difficult to quantify and to transpose into public opinion, particular importance has gained the so-called 'embodied energy' (EE) of building materials [7]. Embodied energy usually represents the energy consumed in the materials' extraction, production and delivery to the construction-site, but according to several authors [2, 6, 8] it should include also the 'recurrent' embodied energy used in the maintenance and refurbishing processes of building materials and components, and the demolition energy, necessary for deconstruction of building and disposing of materials. Even neglecting the other forms of environmental impact caused by building materials, the only EE now accounts for 2-38% of the overall energy consumed over the 50-years building's lifetime in conventional buildings and for 9-46% in low energy consumption buildings [9], thus pointing out the great importance of the selection of sustainable building materials in the design process. Indeed, some authors state that low energy buildings perform better than zero energy buildings in a whole life cycle perspective [8], due to the use of high energy intensive materials (i.e. with high EE [2]) in the latter ones. For this reason, the need of 'life cycle zero energy buildings' or 'net-zero energy buildings' has been recently addressed, in order to take into account not only the operational energy, but the energy consumed in the whole life cycle, according to a real 'cradle to grave' philosophy [5].

The considerations reported above substantiate the key role that the materials' selection plays in the building design process for the achievement of the 'green building' goal. However, such selection give rise to two main questions:

- what are 'green building materials'?
- which tools are presently available for materials' environmental assessment and, hence, for their selection?

In the present paper, after a brief discussion of the critical aspects in the definition of 'green building materials', the tools presently available for the selection of building materials are overviewed and discussed. Particular emphasis is given to the selection of materials at the working plan stage, when architects and engineers must make a choice among the products available in the market and this give rise to several problems, which will be presented and discussed, with particular reference to the Italian situation.

2. 'Green building materials' definition

A univocal and universally accepted definition of 'green building materials' still doesn't exist and they are generally considered as environmentally friendly [10] or environmentally responsible [11] materials.

Due to this uncertainty, several materials have been launched in the market with a generic statement of ‘greenness’, but without any proof to substantiate it or even with misleading claims [10]. In several occasions, the green character of materials has been simply associated to their being ‘natural’, thus not considering, for example, that asbestos (added in the past to several building materials and now banned due to its carcinogen effect), radon (a radioactive gas possibly emitted by some stones in the building and harmful for lung cancer) or turpentine (solvent obtained by distillation of tree resins and harmful for human health) are natural [12].

According to a more sensible common perception, green building materials can be defined as:

- sustainable during their whole life-cycle, where their sustainability can be quantified by the LCA methodology, in a ‘cradle to grave’ perspective;
- not hazardous for human health, i.e. not leading to negative effects in terms of indoor air quality. In particular, they must not cause indoor pollution (volatile organic compounds, hazardous fibres dispersion, radon emission, biological pollutants proliferation [12]) and uncomfortable indoor climatic conditions (e.g. presence of damp in parts of the building or on surfaces [13]), both of the aspects to be jointly considered.

In dealing with such definition, a key issue immediately arises, that is the inexistence of a ‘perfect green building material’ in opposition to not-green materials, because the manufacturing, transportation, placing and disposing/recycle of materials always imply a not zero impact. For this reason, it’s impossible to note down an ultimate list of green materials: in every design process the *most* green materials should be chosen among the market available ones, on the basis of the best available technologies and the required materials performance. This puts a great responsibility on the decision-makers in building design and furthermore stresses the importance of materials selection.

3. Which tools for materials’ selection?

A preliminary consideration is due when coping with the issue of materials’ selection. Besides the ‘greenness’ requirement (as defined in § 2), materials must fulfil a wide range of requirements established by national laws, national/international standards, codes of practice and local building habits, at least in terms of:

- mechanical properties (for structural materials), such as strength, stiffness, behaviour in case of seismic actions, etc.
 - thermal performance, in order to achieve a satisfactory energetic behaviour during the operating phase
 - acoustic performance, in order to achieve a satisfactory indoor comfort
 - durability in the specific environmental context where the building will be located (the durability issue has strong implications in sustainability too, as it influences the materials’ life span)
 - weight and dimension limits, in compliance with the specific features of the building
 - safety during the materials handling and placing, as well as in case of fire
 - specific performances connected to the use of buildings (e.g hygiene requirements for hospitals, safety requirements for schools, colour and/or transparency requirements for libraries, etc.)
 - aesthetic outcome, also in connection with the local construction traditions
 - cost, according to the available budget,
- which makes the materials’ selection multi-criteria and quite challenging.

Provided that all the other requirements are fulfilled, the choice of materials on the basis of their impact on environment and human health takes place in two distinct stages of the design process. The first one is the very early stage (project appraisal stage), when the feasibility of different technological solutions is considered and the environmental matters can be incorporated in the decision-making process [14-15]. At this stage, for example, a choice among concrete, steel or hybrid structure can be done on the

basis of environmental criteria [15]. The second stage in which architects and engineers are called to choose the materials to be used in the building is the working plan, when a selection of market products must be made. Although this process might appear marginal for the achievement of the building's sustainability, this is not the case and the importance of a correct choice is primary, as discussed in the following paragraphs. Despite the significance of such phase, designers are often alone in the evaluation of commercial materials and in the assessment of their environmental 'quality'. Basically, the following evaluation tools can be envisaged: i) environmental assessment methods; ii) 'green' labels; iii) information provided in the technical datasheet by the manufacturer; iv) basic knowledge of materials' features and properties. The actual application and use of such tools is discussed in § 4, with particular reference to the Italian case.

4. Discussion

4.1. Environmental assessment methods

A large number of building environmental assessment tools, addressed to the different decision-makers involved in the design process, has been developed over last years and their use is expected to increase [16]. A useful classification can be made in 'qualitative tools', based on criteria system and scores, and 'quantitative tools', using quantitative input data and an LCA approach [16]: BREEAM, BEAT, BEE, EcoEffect, EcoProfile, Eco-Quantum, GBTool and LEED are some of the most known examples [14, 16-18]. These methods are often aimed to the certification of buildings, i.e. to provide an indication of their environmental performance, but they can be used also for evaluating the best options to be adopted during the design process.

Reviews and comparative studies about such tools have been carried out and some critical aspects have been highlighted. Concerning materials, several weak points can be envisaged:

- the methods for collecting data on materials' life cycle. The input data are usually collected from extensive database of building materials [17], which nevertheless obviously provide data referred to materials' categories rather than to single commercial materials. This leads to unavoidable errors in the evaluation, due to the different and quickly changing [17] manufacturing processes of materials, the difference in the formulation of materials, the difference (and often lack of knowledge) in the place where materials and their components are supplied, etc. As a matter of fact, the building materials' manufacturing processes are much less standardized respect to other goods, due to the unique character of each building [8] and to national/regional variations. An outstanding example of the uncertainty connected to dealing with simplified classes of materials is described elsewhere [6], where large difference in the embodied energy was found in literature and database data (e.g. from 0.84 to 312 MJ/kg for 'steel', from 17 to 239 MJ/kg for 'brass' and from 3 to 98 MJ/kg for 'paints').
- the functional unit adopted in the calculation. The choice of the functional unit [16] has a great influence on the results, as materials should be compared according to their main function in the building and an unsuitable unit may give misleading results. For example, the comparison between structural materials such as steel and aluminium should be made considering different cross sections able to give the same strength performance, notwithstanding their unit mass. Similarly, the comparison among flooring tiles should be made per unit area rather than per unit mass. Considering, e.g., the amount of waste from disposed concrete and wood leads to quite different outcome if weigh or volume are considered [17]. The environmental impact of the building per floor surface area is a significant unit for the building's certification, but not for the evaluation and selection of materials.

- the phases of life cycle. While there is a common agreement in considering the impact of materials in the excavation of raw materials, manufacturing process, delivery to construction site and operational phase of the building, some assessment tools do not cover maintenance, demolition and disposal.
- the length of the service life. Even if the materials of the building exhibit different service life according to their durability and accessibility [17], a conventional life of 50 years is usually considered.
- the ‘quality’ of the energy considered. The calculation of materials’ embodied energy can be carried out considering the end use energy (or delivered energy), which is the energy at the final use level, or the primary energy, which is the starting energy for the production of the end use energy (including the losses due to transformation and distribution). No clear agreement exists on the type of energy to be considered for EE determination [8].
- the differences in the weighing systems for the various parameters [14], which are of course the core of any environmental assessment.
- the lack of parameters taking into account the materials’ contribution to indoor air quality. This aspect is barely taken into account by the environmental assessment tools and suitable parameter are still to be developed [16], even if some efforts have been made to establish evaluation procedures for the assessment of the contribution of building materials to indoor pollution (such as the one proposed by the author in [19] and based on score lists).

The LEED-based rating system assigns a total of 4 points to ‘indoor environmental quality’, and precisely one point for each of the following: 1) adhesive and sealants with limited VOC emission, 2) paints and coatings with limited VOC emission, 3) low-emitting carpets, 4) absence of urea-formaldehyde resins in composite wood and agrifiber products [1]. The introduction of such parameters is surely worthy, but they give only a very partial account for all the potentially hazardous effects of materials in indoor environment, summarized in the terms Sick Building Syndrome (SBS) and Building Related Illness (BRI). The problems of radon emission, fibres dispersion and biological pollutants are not considered, as well as possible VOC emissions sourced by other building components (resilient flooring, thermal insulating materials, biocide treatments for organic materials, etc.). It’s evident that LEED credits cover only a minimum part of the requirements presently established by the European and international directives in the field of indoor air quality and pollution [12].

Due to these weak points, the comparison of materials by means of different assessment tools is difficult, if not impossible [17].

Moreover, the application of such tools requires a considerable effort in terms of time and cost and is usually carried out mainly for new buildings [14] (even if some tools, such as EcoEffect, were developed for existing buildings [16]) and for ‘high-quality’ buildings [17]. Nevertheless, the European building stock is characterised by old buildings, where renovation is the most frequent kind of intervention: for such cases the complexity of these tools prevents them from an actual application, also because a radical refurbishment of the building in accordance with severe sustainability requirements is usually not feasible for economical reasons.

All things considered, these assessment tools are mainly suitable for the early stage of building design, for a preliminary rough evaluation of the building materials’ environmental impact and, hence, for supporting the first ‘strategic’ choices. Their applicability to the selection of commercial materials is definitely scarce.

4.2. Green material labels

There is a considerable number of labelling systems for materials’ certification, promoted by different Institutions and Public Bodies involved in promoting the diffusion of the green building concept. Besides the national ones, which provide certifications whose accuracy and reliability must be evaluated case by

case (they are not discussed here as it would overcome the scopes of the present paper), Ecolabel can be considered a thorough and detailed certification system. The main merit of Ecolabel is the assessment of the environmental ‘friendliness’ of materials during their all life cycle, including also the contribution to indoor pollution and the presence of toxic/hazardous components, which might give rise to environmental concerns in the disposal phase at the service life end. Unfortunately Ecolabel is based on a prescriptive approach and the establishment of quantitative parameters and their thresholds is quite challenging, hence, so far, hard floor coverings (2002/272/CE) and indoor paints and varnishes (2002/739/CE) are the only building materials that were considered.

4.3. Technical datasheets

The selection of the materials to be used in the building is usually made on the basis of their ‘technical datasheets’, provided by the manufacturers and reporting the main features and properties of materials and components. This document should provide accurate and reliable information about materials: in Italy general guidelines for technical datasheets preparation are reported in the Italian standard UNI 9038 [20]. Despite such effort, the datasheets are often regarded as an advertising tool and hence they report vague, inaccurate or even misleading information. A wide survey on several building materials (both structural and finishing) available on the Italian market showed that an exhaustive description of the material’s formulation in terms of components is often lacking, or it’s inconsistent with the data reported in the datasheet itself. Concerning the environmental ‘quality’ of materials:

- the possible contribution to indoor pollution is seldom considered. The main exceptions are paints, whose datasheets usually report the VOC amount in the material. The datasheets of composite wood in some limited cases report the formaldehyde content according to EN 120:1992 (Wood based panels - Determination of formaldehyde content - Extraction method called the perforator method), while in sporadic cases datasheets of ceramic tiles and bricks report data on radon emission. However, when not directly reported in the technical datasheet, indirect information on the formulation of the investigated materials and on the presence of hazardous components can be found in the ‘safety datasheet’, separately reporting the safety and health information and usually provided by the manufacturer on request rather than directly downloadable in the relevant website. Safety datasheets are mandatory whenever hazardous substances are present and thus they must fulfil a well defined format, where information are ordered and exhaustive, and represent a valuable tool for building designers;
- at present, the data concerning the environmental impact of materials are almost totally lacking. Only few manufacturers in the cement and concrete field are beginning to provide the Environmental Product Declaration (EPD) according to ISO 14025:2010 (“Environmental labels and declarations - Type III environmental declarations - Principles and procedures”). In most of the cases, no data are provide on the manufacturing process, the energy used and the supply place of raw materials, thus making any evaluation (even qualitative) quite impossible.

Despite the often incomplete information reported in technical datasheets (which however can be partially integrated by the data in the safety datasheets), such datasheet represent the base on which evaluation should be founded. As a matter of fact, a strong differentiation among commercial products was registered during the on-the field investigation, even within the same category of materials, which highlights the key role that specific technical information should play in the materials’ selection phase and the inapplicability of general environmental assessment tools. E. g., cork panels for thermal insulation of walls and floors can be obtained by: (i) high-temperature aggregation of ground cork in a water vapour atmosphere, without the addition of synthetic resin, (ii) microwave aggregation of ground cork, without the addition of synthetic resin, (iii) room-temperature process employing synthetic resin as binder [6].

Thus, a more widespread use of EPD must be regarded as the most practicable way toward a sensitive choice of materials at the working plan and construction stages, otherwise designers have no access to the necessary information for whatever environmental evaluation. However, a ‘sustainability’ perspective on materials’ selection (according to the LCA principles recalled in ISO 14025), although fundamental, is only partial for the achievement of the ‘Green Buildings’ target, as the aspects of environmental impact and contribution to indoor air quality should be always jointly considered.

4.4. General knowledge of materials’ technologies and properties

In § 3 the multi-criteria nature of materials’ selection in compliance with the specific requirements of each building and the great commitment of architects and buildings were discussed. Hence, a deep knowledge of materials’ features, technologies and properties must be considered as a final integrative tool for a sensible evaluation and selection of materials and the ‘culture’ of materials should be promoted at any education level.

5. Conclusion

The selection of commercially available building materials during the working plan phase of the design process plays a basic role in the application of the green building concept, especially in Europe, where intervention works are often at a micro-scale level due to the conspicuous stock of existing buildings. Despite the wide range of building environmental assessment tools recently developed (which give a valuable aid in the early design stage), architects and engineers are presently left nearly alone in this selection, with particular reference to the Italian case. As a matter of fact, they presently have no access to any information concerning the manufacturing process in the technical datasheets of materials and this prevents them from having the chance for a sensible choice. A valuable contribution toward the delivery of environmental information by the manufacturers is represented by the recently introduced Environmental Product Declaration (EPD), but this declaration is not mandatory and hence it is still barely used in the Italian construction product market. However, the aspects of environmental impact and contribution to indoor air quality should be always jointly considered and suitable evaluation tools (tailored on the information provided by the manufacturers in the materials’ datasheets and easy enough to be extensively applied to new and existing buildings) are still to be developed.

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