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Requirements for an LCA-based Model for the Evaluation of the Environmental Quality of Building Products

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There is a growing concern about the concept of environmental quality (EQ) in the building product industry. A classification of existing EQ models is presented, as well as a discussion of the underlying assumptions of Life Cycle Analysis (LCA) and the significance of the results. It is proposed that some modifications to the classic LCA model are necessary to take into account the characteristics of building products and their associated actors. Some of these modifications can be achieved through simple extensions within the existing framework, others call for specific developments of the framework. A list of requirements is presented for building product specific EQ evaluation and improvement methodologies based on LCA. Copyright © 1996 Elsevier Science Ltd.

INTRODUCTION — BUILDING PRODUCT QUALITY

A BUILDING product, like any other product, can be viewed as a technical solution to multiple product-specific functional constraints (Fig. 1). A window, for instance, has to fulfill technical requirements for thermal, acoustic, mechanical, optical, safety and fire resistance. It also has to cost less than a certain price to have a chance in the marketplace. Each building product can be defined by a list of quantifiable technical requirements. Once every technical requirement has been listed and assessed, one can assess the overall quality of the product.

There is often no clear separation of function and performance between individual technical requirements of a building product: improved thermal insulation will most certainly cost more, but may also improve the acoustic performance at the same time. However, from the environmental point of view, as from any other, a variety of independent quantitative criteria can be defined. Lead water pipes, for instance, which have been used for a long time in buildings, perform very well as far as mechanical strength and resistance to corrosion are concerned but pose a threat to humans due to their toxicity. Thus, we can define the environmental quality (EQ) of a building product through the means of a list of quantifiable environmental criteria to be added to the current product-specific list of performance-based criteria. The problem then is to decide what the environmental criteria are to be, and how to assess them.

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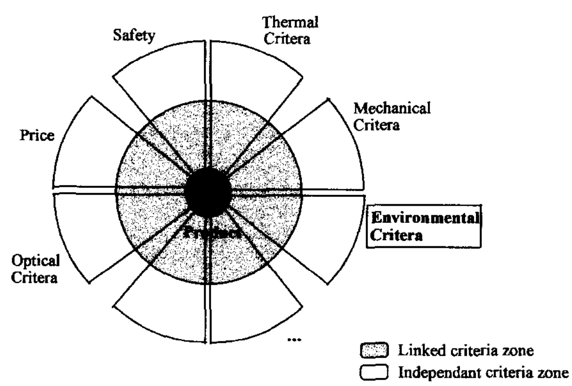

Fig. 1. Various views of product quality.

EQ EVALUATION MODELS

Rather than trying to design a new EQ evaluation model from scratch, we chose to analyze a wide range of existing models [12]. All are based on a system modeling of the product and deal with the input and output flows from/to the environment. We define two categories of models, depending on the approach used to link the product system to the environment.

Top-down models

This class of models starts from a list of environmental impacts, for which product-specific causal links are identified, resulting in a catalog of product technical requirements (« should contain x% of recycled materials », « should not use material y », etc.). Most environmental labels belong to this class, as well as building EQ models like BREEAM [12]. "Black listing" is the most extreme example of this approach.

Impact stressors	Unit
Biotic resources depletion	–
Abiotic resources depletion	an^{-1}
Global warming power	kg
Ozone depletion potential	kg
Human toxicity	kg
Ecotoxicity aquatic and terrestrial	m^3/kg
Photochemical oxid formation	kg
Acidification	kg
Nutrification	kg
Residual heat in water	MJ
Odor	m^3
Noise	Pa^2s
Damage to ecosystems and landscapes	m^2s
Victims	–

Fig. 2. Impact stressors [8].

Bottom-up models

Life Cycle Analysis (LCA) is the most prominent member of this class. In contrast to the previous class, bottom-up models are based on an assessment of material and energy flow balances for every step in the product's life, thus providing a way for a quantification of a pre-defined list of environmental impact indicators, also called stressors. A common list of such stressors is given in Fig. 2.

LCA is a conceptual model which is still evolving. However, its main features are well established [6, 8] and involve two phases as follows:

- the data production phase, comprising Goal Definition, Inventory and Classification stages;
- the data utilization phase, which includes a Valuation step, the goal of which is to assess a product overall EQ, and a Results Reliability and Product Improvement analysis.

There are now standardized methodologies for performing LCAs in France [1] which are becoming familiar to a growing community. However, reviews of currently published methods [4, 12] have shown that there are fundamental differences in the details between methodologies and that there are, as yet, no widely agreed upon data or EQ model for individual building products.

Choice of an EQ model

In contrast to the bottom-up approach, the top-down EQ model class relies more on an expert analysis of EQ, the underlying assumption being that experts are able *today* to answer the question "How good or bad is this product for the environment?". This simple question has no answer so far, yet some EQ assessments are performed using top-down models. Additionally, they are rather mono-criterion oriented, and thus prone to « pollution shifts »: the benefits of one criterion will most certainly have unexpected bad consequences on another criterion. Mandatory technical solutions like recycling, for instance, can help reduce resource consumption but may require more energy to achieve than simple dumping.

On the contrary, LCAs take into account the problems of quantifying multi-faceted variables at the cost of a more thorough, and also, more complicated model. Bottom-up models do not rely on a fixed definition of what an environmentally friendly product should be like. Consequently, they are also less suitable for use as a basis for environmental labeling, but more useful as tools for designing products with higher EQ. This is why we finally chose to develop an LCA-based EQ evaluation tool [4].

However, in the long run, LCA results could provide top-down models with a sound basis for criteria definition and quantification, thus opening a door for less costly and time consuming methodologies.

LCA FOUNDATIONS

In LCA, the product is modeled as a system (product tree) in order to assess its material/energy balance. The environment is described by a different type of model. We list below some of the basic and often implicit hypotheses that are intrinsic to both models, and analyze their consequences on the meaning of the results they produce. Concept definitions can be found in [15].

Basic assumptions

Time stability. The first assumption made in an LCA is to consider the product system as a time stable system, in contrast to the models of the technical processes and environmental phenomena which include a time scale. This implies, for example, that when a product reaches the end of its service life, i.e. 10+ years after its manufacture, the resulting waste will still be dumped as it used to be 10 years ago. Making this assumption enables one to simply obtain an instant picture of a product's life cycle, but it does not take into account the fact that an instant picture is not realistic, since technical processes and environmental phenomena have both evolved in the meantime.

Separability. The LCA model also assumes that the system drawn around a product is completely independent of other products outside the system. It has been known for a long time now that this assumption, while necessary to avoid an unmanageable expansion of the product system description, does not necessarily accord with reality [11]. While making such assumptions is necessary for the modeling of the system, various devices are used to better reflect its reality, such as allocation procedures [5], external cost LCAs [9] or the inclusion of additional modeling using input/output matrices [2, 10].

Precision. Thirdly, it is assumed that no flow can have more than one accurate value. If LCA is used for a whole industrial branch, the various processes and flows within the product system are averaged to establish accurate flows [7, 3].

Steady state. Most of the time, risk is not assessed in LCA, the assumption here being that the product system is in steady state. This assumption is not compulsory, but must be kept in mind when performing an LCA or using LCA-generated data.

Punctual and continuous world model. All environmental flows are supposed to come from, and go back to, the same source. This is a consequence of LCA not taking into account any spatial information on environmental flows. The world model is also assumed to react continuously to continuous solicitations. This is clearly discordant with the real world, where small changes can cause earthquakes!

The meaning of LCA data

As a consequence of the assumptions, LCA data can have very different meanings, when compared with other typical physical measures. Since they are not absolute values whose precision denotes realism, LCA data are often misused. This point is discussed below.

Flows and stressors. Most public databases give very accurate flow values but omit to mention the extent to which the precision hypothesis has been forced and may not even provide the user with an error factor for the data. Thus, often precision hides imprecision. Since there is no "natural" frontier to the product system (hence the separability assumption), stressor values depend greatly on the limits chosen [6, 11]. This is particularly tricky because the stressor units are well known physical units (kg, MJ, ...) and thus are very often considered as measures in the physical sense. There is also a great deal of controversy about the actual correlation between the stressors and the real state of the environment. Consequently, it is important to remind the user that a stressor is only an indication of a potential impact on the environment [14]. Lastly, since stressors are calculated from flows, the precision of the latter is linked to the precision of the former. Again, no indication is generally given to the user concerning the relevance of variation in a given stressor between two alternative systems.

Data manipulations. Since it is far easier to compare single values than multicriteria sets, stressors are often left out, to concentrate only on a selected value. Comparisons can also be carried out without taking into consideration the separability hypothesis, i.e. without checking whether one is comparing identically separated (i.e. comparable) systems. Since LCA data are still scarce, every published value tends rapidly to become an official value. Additionally, LCA data are inevitably the result of a great deal of data manipulation which may be prone to mistakes. Unfortunately, if such an error occurs, it is very unlikely that it can be detected at a glance.

LCA AS AN EQ EVALUATION TOOL FOR BUILDING PRODUCTS

Despite the necessity for including basic assumptions on the LCA model and the pitfalls in the process for the unaware user, we consider that LCAs are an excellent basis for the evaluation of a product EQ since they provide a usable tool for a quantification of the environmental impacts of a product through its life cycle. However, when considering using an LCA to assess the EQ of building products, one has to bear in mind that the actual model is not fully compatible with both the products' and the actors' characteristics. We call *actor* someone who is responsible for the EQ of a product and is using LCA to evaluate and improve it. He is not necessarily performing the LCA himself.

As a guideline for a detailed analysis of these incompatibilities, in addition to the previous analysis of the LCA basic hypothesis, we suggest the use of the conceptual framework outlined in Fig. 3.

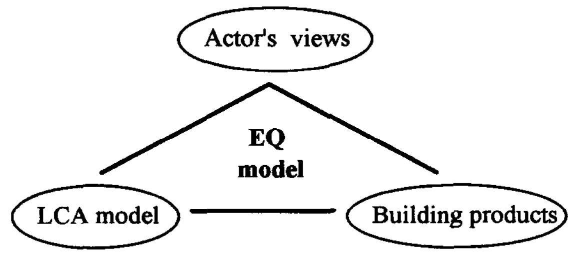

Fig. 3. Three-sided context of a building product's EQ evaluation model.

That the expected EQ model should be a combination of building products' real characteristics with the actual LCA model is rather obvious. At least, every time an LCA is undertaken for a new product, the product tree has to be drawn according to the product's characteristics.

We consider it necessary to emphasize the importance of the actors' views as a possibly strong modifier to the actual model. Current LCA models can be of limited use to an actor because they impose an answer on him without really giving him the possibility to detail his expectations of the results, and thus deprive him of the possibility of taking real decisions in the process. LCA should be viewed only as the calculation part of a more global procedure for EQ management and design that has to be clearly defined. LCA as a design tool should not be viewed as an implicit norm on EQ.

HOW TO SUIT THE LCA MODEL TO THE ACTOR'S VIEWS?

EQ is a new concept for many actors. Some tend to be "over-technical", i.e. they view every environmental aspect through the lens of more familiar technical characteristics of the product. Others are "over-environmental", i.e. they consider that EQ is the prevailing quality criterion in a product.

From our growing experience with building product EQ evaluation, it appears that such a list cannot be really accepted by a typical actor. There are two main reasons for this situation.

1. Every building product manufacturer, for instance, is improving his products according to a specific corporate policy that stresses some aspects of the EQ list, but leaves others out.
2. Using a design tool implies that decisions must be made (choice between alternative technical solutions, for instance). While there is no normalized definition of EQ, it is very unlikely that an actor would make a choice according to criteria that are not relevant to him.

We suggest then that the EQ criteria list should be opened to negotiated user-defined criteria. While departing fundamentally from the classical LCA standpoint, we think that this approach is an important step towards the development of a management procedure for product EQ. These new top-down criteria can be introduced providing that they are clearly expressed and justified by the actor.

As previously explained, numerical results do not convey the full meaning of an LCA because they hide most of the methodological bases for the assessment. Thus the user is left with numerical data that mean less than they appear to. Hence it is very useful to develop a computer data model to keep track of a wide range of variables and assumptions for each individual value, as well as for every link between initial and aggregated data, thus allowing the user to know the background to the results he is using. Finally, it seems important to help the user handle multicriteria data (sorting, selection, ...). Again user-friendliness should be looked for, and over-aggregation should be avoided to preserve understandability.

HOW TO SUIT LCA TO BUILDING PRODUCTS?

Compared with "classical" products for LCA (beverage containers, material manufacturing processes, etc.), the obvious difference of building products lies in their three specific phases: installation, service life, and end of life.

Installation phase

Installation begins when the product is brought to the building site and ends when the installation is complete. It clearly appears that some processes required to install the product, like stocking and lifting, are much more dependent on site conditions and building type than on the product itself. Lastly, depending on the type of building and the site's planning, waste quantities and energy consumption, for instance, will vary. They will also be influenced by the skill of the worker, up to a point where a single value cannot be representative any more. Thus the flow precision hypothesis is strongly violated.

Service life

For a given building product, this phase commonly ranges from five to 100 years and more, depending on mostly unpredictable external conditions (climate, type of user, change of use, etc.). This causes in most cases a violation of the time stability hypothesis and calls for some sort of flow value actualization. Again, depending on the same external conditions, maintenance and replacement processes will occur at varying frequencies, thus again violating the flow accuracy hypothesis. Lastly, since the product participates in the building's life as a component, one has to decide for some flows whether they should be allocated to the product's or to the building's system. *Traversing flows* are a recurring type of such flows. A window, for instance, is the "hole" through which an important quantity of the building's heat will be lost. One then must decide whether this flow is accounted for in the product's inventory, as is often the case, or left to the building's responsibility.

End of life

The end of life phase begins when the product is taken off the building. Most of the time in the building industry, this phase is a demolition during which it is very difficult to identify the product's role and consequently to quantify the input and output flows. Separability here is again the issue. In some other cases, however, the product is individually removed when the building is de-constructed or refurbished, for instance. Also, open loops are common for building products at this stage, and require specific allocation rules.

REQUIREMENTS FOR A BUILDING PRODUCT LAC-BASED EQ MODEL

This analysis demonstrates that changes to the classic LCA model are required to prepare it for the evaluation of building products' EQ through an evaluation of their environmental impacts. Some of these changes are simple adaptations of the classic LCA model while others seem to depart from the classic framework but could prove to be interesting additions to the actual model. As a possible result, the following requirements of a developed model are listed.

1. Special frontier rules should be defined to force separability, relying mainly on the product/building duality and the function of the model as a design tool [16].
2. Building product specific processes should be modeled.
3. The time stability hypothesis must be either forced or canceled, whatever is possible and suitable.
4. The precision hypothesis has to be canceled [13].
5. Data quality and relationships between data must be documented and preserved as much as possible through the whole process, using for instance a computer data model.
6. The impact stressors list must be opened to user-defined criteria, according to a well documented negotiation procedure.
7. Assistance should be given to the users in managing multicriteria results as such [17].
8. A computer program should be developed to assist the whole process.

General advice underlying these proposals includes keeping the three-sided context in Fig. 3 in mind and that openness should be sought at every step of the process.

This project is now well advanced. The resulting model, nicknamed « EQuity », should be operational by the end of the year and will be presented in another paper [18]. We are currently dealing with points 5–8 in collaboration with building product manufacturers.

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