Building related environmental diagnoses

Towards a broad and practical method for a comprehensive sustainability analysis of a building, including its sites' aspects on the basis of a limited set of objectively computable indicators.

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On a global level it is known that the environmental impact of the construction sector is huge. But how much of an environmental burden is a building? And what is the impact of an "environmentally friendly" measure on the environmental load? The lack of a tool that indicates how much of a burden a building induces is an important obstacle in making better designs and maintenance decisions from an environmental standpoint.

For products, the impact of all the material flows and other inputs and outputs on the environment could be determined in principle by means of an environmental life-cycle assessment methodology – LCA. With the LCAS' there are however still many problems regarding the assessment of the use and consumption of (nature) space and land, and the acquiring of objective input data. Furthermore the environmental impact induced by a building is far more than the sum of the materials. In view of the problems surrounding the definition of physical, quantifiable environmental measures for many relevant effects, a broad environmental assessment of a building is – for the time being – not possible with LCA.

For clients and designers in the building trade, it would be useful if the environmental impact induced by a building could be represented in a well-organized environment profile. Such a profile has to be composed of a limited set of objective, quantitative and verifiable indicators, each of which encompasses a certain part of the sustainability spectrum or environmental impact. We believe that such a profile could consist of a set of eight indicators: 3 site oriented, 3 building oriented, and 2 aimed at building parts.

A. Site oriented: use of space; oxygen balance; and accessibility.
B. Building oriented: water balance; energy balance; and Sick Building Syndrome.
C. Building part and material oriented: material-use balance; and reuse balance.

A comparison between the proposed set and LCA indicates that all relevant LCA aspects have been incorporated into the set. However, by contrast, the environmental aspects that are connected to four indicators, i.e. use of space, oxygen balance, accessibility, and water balance, cannot be worked out adequately in a LCA for buildings. Furthermore, the LCA pays no attention to the physical aspects that influence human well-being in a building. An environmental valuation with the proposed method therefore: has a larger assessment area than that which is covered by LCAS' nowadays; gives more insight in the environmental load aspects; and is more practical.

Key Words: **LCA, indicators, material flows, environmental impact, sustainable building.**

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1 A huge impact and a limited assessment

According to the State of the World, the direct environmental impact of the built surroundings is enormous. Each year about 3 billion tons of raw materials are transformed in bases, walls, floors, and roofs. The larger part of the other 6 billion tons entering the world economy is used for streets, bridges, and vehicles to connect buildings to each other. These giant material streams change landscapes drastically, use up nature and living space, and as a consequence bring about a high degradation and transection of ecosystems.

Comprehensive valuation of buildings concerning sustainability aspects
On a global level it is known that the environmental impact of the construction sector is huge. However, just how big a tiny part of the built surroundings is, i.e. a building with its site aspects, is unknown, we do not know how to calculate the environmental impact. Furthermore, it is not known how measures to reduce the environmental impact effect the total impact of a building: do certain measures make larger or smaller contributions? A comprehensive valuation across the entire life-cycle is not (yet) possible, which takes the environmental quality into account as well as other sustainability aspects of a building, including aspects connected with its location and the use of (nature and living) space.

2 Valuation of the environmental impact

Many institutes have recently published reports about methods for the valuation and classification of the environmental aspects of building materials (for an overview see [MBB 94, pp. 42–45, and pp. 38–39] and [MBB 95/1]). In the Netherlands there is a de facto standard method if the goal is to reach a quantitative, objective valuation of the environmental impact of products: the environmental life-cycle assessment of products – LCA methodology for short – of CML [Heij 92, Guin 95].

By conducting a life-cycle assessment across the entire life-span of a product, a large number of environmental aspects are taken into account. The first step in determining the aspects is the inventory of physical and measurable environmental inputs and outputs, such as the total mass of CO_2 (carbon dioxide) emission. Next comes the classification step into environmental effects. In the original LCA manual potentual damage to the environment is categorized in three domains:

- Pollution: emissions of hazardous substances into the air, water, and soil.
- Depletion: the use of biotic[1] and abiotic raw materials.
- Impairment: for our purposes all environmental effects that lead to a direct structural change in the environment. Impairment is related to the degree to which and way in which (living) space (of man, animal, and plant) is negatively influenced.

[1] Biotic: originating in living nature (e.g. wood). Abiotic: from non-living nature (e.g. petroleum, metal, stone).

A few LCAS' have been conducted for building materials (for an overview see [MBB 94, pp. 70–71]). At the moment research is being carried out on the assessment of the environmental impact of a building, using the valuation of the building materials as a basis [Mak 96].

Scheme 1: Environmental effects (based on LCA).

domain	environmental aspects [1]	environmental outputs and inputs [2]
pollution	greenhouse effect	CO_2, CH_4 emissions
	ozon layer depletion	CFK emissions
	fotochem oxydant	SO_2 emissions
	acidification	NH_3 emissions
	eutrophication	phosphates (caused by emissions to air)
	human toxicity	benzol emissions
	ecotoxicity	benzol emissions
	disturbance (noice, smell)	decibels caused by cars
depletion	abiotic	minerals (salts), metals, fosile fules
	biotic	wood (trees), plants, animal
impairment	impairment of ecosystems	no physical and measurable in- and outputs are definend
	impairment to landscape	

ad[1] environmental effects are changes in the environment caused by mankind
ad[2] env. inputs and outputs are quantitative measurable adds to or retrievals from the environment

Reduction to pollution valuation

The CML-LCA and instruments derived from that methodology helped in the development of cleaner products. The ECO indicator is one of the LCA-derived instruments for the design of more environmentally sounds products [Goed 95]. Used as a design aid in the development phase at Philips and Océ among others, this instrument has led to clear product improvements, both from an environmental perspective as well as from the perspectives of quality and economics. The valuation with the ECO indicator is essentially a valuation of air pollution emissions (including heavy metals in water and pesticides on land) [Goed 95, pp. 32, 38 and 39]. A considerable problem is that up to now a proper method for the quantification of quite a number of environmental aspects has been missing [Blom 95]. Another problem in conducting the environmental valuation of a product with the LCA method is how to obtain the right and objective data about the environmental inputs and outputs [MBB 94, p. 48, MBB 95/2, p. 17]. Because of these reasons, an environmental assessment in line with the LCA is mainly carried out by means of emissions into the air in practice.

3 The environmental impact induced by buildings

The environmental impact induced by building is much more than just the addition of the impact of the materials. Site effects, the use of space, play an important role. The environmental effects connected with the use of space are catogorized in the LCA under the domain "impairment".

Impairment; the degradation of (living) space

Direct damage to ecosystems and landscapes are often one of the most important threats to our environment [RIVM 92], because biodiveristy is lost. The present Dutch Minister of Housing, Regional Development and the Environment sees biodiversity and space as the core of the problems surrounding sustainability in the long run [Boer 95, p. 13]. One important space aspect is use of the soil. The top layer of the soil is the layer with a high degree of biological activity and a relatively large amount of biological material. Soil is an important substrate for the development of all life on land. If the soil is closed off because of built constructions then the life activities of the soil are lost. The possessed space throughout the Netherlands is approximately five times the total surface area of the Netherlands [Boer 95, p. 59]. "Besides the quantity or the surface, it is the quality of the supply of space" [Boer 95, p. 14]. The quality of a space is determined among other things by its multi-functionality in an ecological and anthroposophical view.

Impairment in building

Site aspects are of particular importance in building. Through building ground is irreversibly used; a return to a "natural"[1] state is practically impossible [Frisch 94, p.18][2]. Other aspects that play an important role with buildings are:

- Raising and readying of a site for building (building in fields).
- Accessibility. Nearly every building is used by people and therefore induces transport flows and thus additional environmental impact. An infrastructure is necessary for accessibility. The radiation of roads is far larger than the actual surface.[3]
- Groundwater depletion, draining of water, overflows to surface water.
- Human comfort in and around a building (Sick Building and micro-climate).

Impairment in the LCA method

In the LCA manual two categories of impairment are distinguished for listable environmental effects: physical damage to ecosystems and damage to the landscape.

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1 By "natural" state we mean that the influence of man is not larger than that of other species.

2 where it should be considered that "there no longer is any place on earth, where the influence of man is not greater than that of other species" [Frisch 94, p. 18].

3 Mit beziffert das Umweltbundesamt die Fläche dieses Umfeldes (einschließlich der Straßfläche) siebenmal so groß wie die eigentliche Straßfläche [Holz 88, p. 27].

An elaborate quantification of impairment has been lacking up to now [Blon 95, Harj 95]. From various perspectives, people are now looking into this problem [Vrom 95/4, pp.3,6, and 7]. The first steps have been taken to develop indicators for impairment or the use of (living) space [Frisch 94, Knoep 95]. Recently, a preliminary investigation was published on the methodology for the quantification of impairment [Blon 95]. The research leans towards indicators. For the time being it will not provide physical, measurable environmental effects, like air pollution (e.g. the total mass of SO_2 emissions).

Conclusions

To determine the environmental impact of a building, all these aspects have to be dealt with. Regarding the LCA method as a broadly applicable design tool that helps realise more environmentally friendly buildings, we can state that the method in its present shape is not capable of weighing the site aspects of a building: the location where the construction is to take place and the direct surroundings of the building[1]. It will be ten years in my view before we are able to assess a building and its accompanying site aspects integrally with the LCA methodology. Even if the methodology has been made suitable, the labour intensiveness [Berg 95] and the necessary amount of data make up a major problem in the drawing up of an assessment [MBB 94, p. 48, Schuur 94, p. 47, MBB 95/2, p. 17]. Clients and designers both have an interest in a practical and rapid valuation of alternatives for buildings and locations, a valuation that includes a large part of the assessment area. The present LCA seems to be less suitable for this.

4 Towards a method for integral assessment

For clients and designers in the building trade, it would be useful if the environmental impact of a building and its site an aspects could be represented in a well-organized environmental profile. The assessment by means of an environmental profile would have to be useable at all stages, that is to say the assessment methodology would have to work from plan development to renovation. This is the point of departure for the method proposed in this article. Such an environmental profile has to be composed of a limited set of objective, quantitative and verifiable indicators, in which each indicator encompasses a certain part of the sustainability spectrum or environmental impact.

Criteria

The requirements that have to be made of such a set of indicators are as follows: The indicators

- encompass the relevant environmental impact and other sustainability aspects as a set.
- are verifiable and measurable.
- are mutually independent of each other.
- are comparable to a reference level, so that the value of the indicator has meaning.

The set should contain the environmental impact aspects connected to the siteaspects to the building as a whole and to the construction.

[1] LCA cannot assess decisions related to the location of a building [Berg 95]. LCA is not the tool to evaluate the environmental aspects of a ... location [Berg 95].

Indicators for an environmental profile

We believe that an integral environmental profile could consist of a set of eight indicators: 3 site oriented, 3 building oriented, and 2 aimed at building parts. The following set of indicators is proposed:

A. Site oriented: *use of space, oxygen balance and accessibility.*

B. Building oriented: *water balance, energy balance and SBS*[1] *influences.*

C. Building part and material oriented: *material use and reuse.*

Reference levels

The indicators are expressed in a numerical value and then are standardised between 0% and 100%. The criteria for the 100% level are:

- The 100% level can be technically realised.
- The requirements for the realisation of the 100% level can be found in the Netherlands.
- At least one building, or part of a building, has been realised according to the 100% standard. The building should be found in the Netherlands or in one of the surrounding countries (B, G, GB, Scandinavian countries).
- The example building (or composed example from various buildings) should be documented to the extent that reference can be made to the documentation.

The criterion for the 0% standard is the present minimum legal requirement. For example, energy use could be expressed in kJ/year use of primary energy (from fuels). The 0% level is indicated by the EP standard (Energy Performance standard). The 100% level for energy use is set at 0 kJ/year primary energy. The 0 and 100% standards meet the criteria.

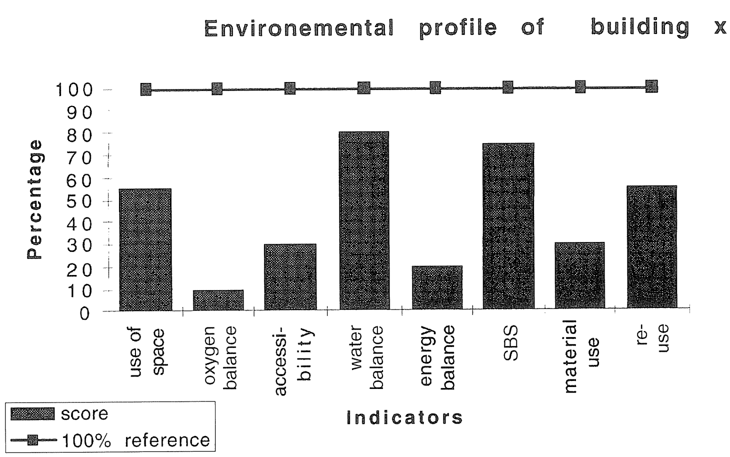

Fig. 1. Overview of the environmental profile of a hypothetical building.

[1] Physical aspects that determine human well-being in a building: Sick Building Syndrome.

Description of the indicators

In this section the indicators will be explained. We shall indicate what kind of a measure they are and what their significance is. The standardisation that allows for calculations will be indicated for the reference levels.

A. Site oriented indicators

	Measure	Meaning	Express. in	Reference 100%	Level 0%	Range / limits	Remarks
Use of space	for the amount of (living space) that is taken up by a building and that is not available for other functions	the preservation of (living) space is the most important item for the achievement of a sustainable development, next to the use of fossil fuels and bio-diversity	amount of space that is taken away * "natural" quality * time	is zero: no (new) use of space with respect to the situation before a building was completed	the VINEX standard	the use of space by a building and its direct environment. The use of space that arises as a result of the extraction and manufacture of building materials is not assessed here	The use of space induced by transport to and from the building is indirectly assessed in accessibility
Oxygen balance	for vegetation in and around a building, counter measure for acid rain and green-house effect	trees, shrubs, and flower beds make valid contributions to remedying air pollution (filter function) and to a balanced micro-climate	litres of oxygen used / produced per annum	use of oxygen through use of energy, people and machines compensated by production from vegetation	no compensatory vegetation measures	note that oxygen use through transport from and to the building is not included in the oxygen balance	indicates (partly) possibilities for ecosystem development
Accessebility	for the accessibility by public transport, by bicycle, or on foot	the traffic to and from a building takes up half of the environmental impact of a building and its environment	relativer distance to public transport stops	a location in which the distance to express trains <500 m and the frequency of express trains >10 per hour	Next bus stop >1000 m, frequency <1 per hour	only possibilities to reach the building in question are considered. Outside the calculation is how commuters really travel and come from	the least burdening way to travel is on foot or by bicycle. The worst way is all traffic by car

The water and oxygen balance together form a good measure for the degree to which the damage to the environment is compensated, and with this to what extent new eco-systems can develop.

B. Indicators related to the building as a whole

	Measure	Meaning	Express.in	Reference 100%	Level 0%	Range / limits	Remarks
Water balance	for the use of drinking water and counter measures for the draining of water as well as a measure for dehydration	hardening and the related loss of a buffer capacity of the ground is the most important cause of floods / high water levels and overflows of contaminated water to surface water	m^3 drinking water use and m^3 waste water per person per annum	drinking water: 4 l. per person per working day Waste: no drainage, nor dumping in sewers	drinking water: no saving measures Waste: all water dumped into sewers	building and the accompanying infrastructure (opening, parking, vegetation). Includes rain water	
Energy balance	for the use of fossil fuels	the greater part of air pollution of a building in use is (indirectly) caused by external energy use	kJ (kilo-Joule) of primary energy used per annum	0 kJ / year use of external energy	use according to EPN	(here, external means that energy does not originate from generation from sustainable sources)	the balance is composed of : electricity use and energy for heating
Sick Building	for the extent to which users can influence interior climate	sick-building syndrome	a relative measurement of influencing factors	all 20 factors can be influenced by the user	0 factors can be influenced by the user	interior climate of a building. The outside climate is excluded	

C. Indicators related to building parts and materials

	Measure	Meaning	Express. in	Reference 100%	Level 0%	Range / limits	Remarks
Material use balance	for the harmfulness of materials for man and the environment	the material use for the construction of a building has a large influence on aspects like pollution, damage to ecosystems and human health	relative harmfulness scale	the same building executed with the best possible choice of material	the same building executed with the worst possible choice of materials	the relative level with respect to other materials in their application in the building in question	the harmfulness scale is a composite of six (main) criteria, which are all expressed in performance scales
Reuse balance	for the use of raw materials and waste. To what degree the building parts and materials can be reused after demolition	in the built environment, approximately 40% of all raw materials is used up. Through reuse, the use of primary raw materials drops as well as the amount of waste	two factors: the high quality of the reuse and the number of times that reuse is possible	for now 100% primary reuse	complete disposal	building sec (infrastructure is not assessed). The use of secondary raw materials is assessed under the factor material use	note: burning is in a very restricted sense a kind of reuse

Further elaboration

The possibility to operationalise the proposed set-up first of all depends on the extent to which a verifiable formula can be found for each indicator. This has to happen in such a way that the quantitive scaling between 0% and 100% is made possible, without the necessity of an expert judgement. A second point in operationalisation is the unambiguous definition of the reference value.

The practical detailing will take place under the name BEDS, Building related Environmental Synthesis, in a cooperation under the same heading between MICHIEL HAAS, director of NIBE[1], and Ph.D. student at BPU[2], Eindhoven University of Technology, PAUL KOSTER (initiator), Bouwinfo Koster, the UCB[3], and the author of this article. The research is accompanied by professor Peter Schmid (BPU). In phase 1, which will last until September, four of the eight indicators will be operationalised in such a way that calculations will be made possible. In addition, the practical applicability will be demonstrated by means of a prototype of a software assessment system.

[1] NIBE, Nederlands Instituut voor Bouwbiologie en Ecologie (= Netherlands Institute for Building biology and Ecology).

[2] BPU, Bouwkunde, Produktie en Uitvoering (= Building, Production and Construction).

[3] UCB, Universitaire Centrum voor Bouwproduktie (= University Centre for Building Production).

5 Comparison with LCA

An integral building assessment by means of indicators should encompass all relevant environmental aspects from the LCA. Scheme 2 shows to what degree and how the various LCA aspects are operationalised in the set of indicators. In scheme 3 an indication is given of which part of the LCA belongs to each indicator.

Scheme 2: Incorporation of environmental effects in set of indicators.

environmental causes by buildings effect		covered by the accompanying indicators	covering
Pollution			
– greenhouse	traffic from and to a building and energy use during building in use are the main cause of greenhouse gases	energy en accessibility	full
– ozon	CFK's, now forbidden, are in the building construction the cause of ozon layer depletion	material use	to a large extent
– fotochem. oxydant.	transportation from and to and the use of energy of a building are the main factors causing smog	energy, accessibility, oxygen balance	to a large extent
– acidification	traffic from and to a building and energy use during the use of a building are the main cause of acidification emissions; the oxygen balance as a neutralisation indicator	energy, accessibility and oxygen balance	full
– human toxicity	human toxicity is mainly caused by the production of building materials and by the traffic from and to. Human toxic aspect is one factor in the indicator material use	material use, oxygen balance	to a large extent
– eco toxicity	eco toxiciy is mainly caused by the production of building materials and by the traffic from and to a building	material use, and reuse	partly
– water pollution	0 drainage, 0 overflow to surface water	water balance	full
– soil contamination	dumping is responsible for the bigger part of direct contamination of soil	reuse and material use	to a large extent

Scheme 2: Incorporation of environmental effects in set of indicators.

environmental causes by buildings effect		covered by the accompanying indicators	covering
Depletion			
– metals	by full primair reuse as 100% norm	reuse	full
– fossile fuels	the depletion of fossile fules is 0 Joule extern use of energy, max. reach by foot and bike, oxygen in balance	energy en accessibility	full
– minerals	by full primair reuse as 100% norm	reuse	full
– wood	by full primair reuse as 100% norm	reuse	to a large extent
Impairment			
– ecosystems		use of space, (oxygen balance, material use)	full
– landscape		use of space, accessi-bility (oxygen balance)	to a large extent

Scheme 3: Relation between the set of indicators and LCA.

indicator	connected LCA-part	connected environmental effcts
Site oriented		
– use of space	impairment; use of living space (partly for biodiversity)	impairment to ecosystems and landscape greenhouse, acidification human and eco toxicity
– oxygen balance	impairment	oxygen and water balance are a good indication how far the direct impairment is compensated
– accessibility	pollution impairment; use of space	accessibility by foot, bike or public transport as an indicator for by traffic induced env. impact
Building related		
– water balance	pollution to soil, water pollution impairment	through overflow and sewage pollution of surface and ground water and soil
– energy balance	pollution to air (greenhouse, acidification)	greenhouse, acidification (and in a minor way smog)
– SBS-influences	not in LCA	could be restrictively classified in forms of impairment
Building parts and materials		
– material use	the whole LCA area except reuse and plus impairment of biotopes	N.B. in sofar the building is seen as the sum of the materials
– reuse	depletion (and waste)	

From the perspective of LCA, scheme 2 demonstrates that all relevant LCA aspects have been incorporated in the proposed set. Only human and eco-toxicity may be too indirectly expressed in material use. However, by contrast the environmental aspects that are connected to four indicators, i.e. use of space, oxygen balance, accessibility, and water balance, cannot be worked out adequately in a LCA for buildings. Furthermore, the LCA pays no attention to the physical aspects that influence the human well-being in a building. For an integral assessment this is an aspect that should not be neglected.

6 Conclusions

Considering the problems surrounding the definition of physical, measurable environmental measures for many relevant environmental effects, a broad assessment of a building is only possible for the time being on the basis of indicators, expressed in verifiable index figures.
For the development of as assessment method on the basis of indicators, we have three central concepts:

a. An integral assessment (of the environmental impact connected to a building).
b. An objective verifiable assessment.
c.. A practical and recognisable assessment.

Integral: Each relevant aspect of the environmental impact during the assessment of a building is reflected by at least one of the eight indicators. The proposed method therefore has a relatively larger assessment area than that which can be covered with the LCA method. In the environmental profile the site aspects are clearly expressed.
Calculable: Every indicator will be expressed in a verifyable calculable formula.
Practical: For het same assessment range the amount of data neeeded to calculate the indicators is much less than those needed for the LCA-valuation. The environmental profile has been presented to various maintenance managers. Execpt from 'oxygen balance' and to a lesser acount 'use of space' the indicators were recognized and accepted as usefull.

We think this set can help to get a step closer to a comparable valuation of the environmental impact of buildings.

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