LoRe-LCA

Low Resource consumption buildings and constructions by use of LCA in design and decision making

State of the art report -
Use of Life cycle assessment
Methods and tools

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Abbreviations

BMCC	Building materials and components
BREEAM	BRE (Building Research Establishment) Environmental Assessment Method
CEN	Comité Européen de Normalisation
CPD/CPR	Construction product directive / construction product regulation
DGNB	Deutsche Gesellschaft für nachhaltiges Bauen/Deutsches Gütesiegel für Nachhaltiges Bauen
EC	European Commission
EMS, EMAS	Environmental management system
ENSLIC	Energy Saving through Promotion of Life Cycle Assessment in Buildings
EPBD	Directive 2002/91/EC of the European Parliament and of the Council on the energy performance of buildings
EPD	Environmental product declaration
GWP	Global warming potential
HVAC	Heating, ventilating, and air conditioning
ICT	Information and Communication Technology
ISO	International Organization for Standardization
LCA	Life cycle analysis
LCC	life cycle costing
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LCM	Life cycle management
LCTh	Life cycle thinking
LEED	Leadership in Energy and Environmental Design
NGO	Non-governmental Organisation
PPP	Public Private Partnership
PFI	Public Finance Initiative
PVC	Polyvynylchloride (CAS 9002-86-2)
SETAC	Society for Environmental Toxicology and Chemistry
SME	Small and medium size enterprise
UNEP	United Nations Environment Programme
WP	Work package

1 Introduction

“Low Resource consumption buildings and construction by use of LCA in design and decision making (LoRe-LCA)” is a project within the EU-FP 7. The aim is to contribute to an increased use of Life cycle analysis (LCA) as a method to gather, analyse, valuate and document comprehensive information on buildings and constructions. The specific focus of LoRe-LCA is on building’s resource consumption (water, primary raw materials, energy, land) and waste generation. Work package 2 is dedicated to collect LCA projects and initiatives and to compare the use of LCA for assessing the environmental performance of buildings in (some) EU countries. From this evidence should derive what is meaningful and useful for practice of LCA in the construction sector as well as what are chances and barriers for a broader uptake.

Life cycle assessment is a tool to systematically evaluate the environmental impacts and aspects of a product, a service, a production system or a service system through all stages of its life cycle. Concerning buildings and construction work the whole life cycle of a building or a construction is considered and impacts of all life cycle stages are assessed. In construction practice energy certifications have gained a lot of attendance because energy certification is demanded by the Energy Performance of Buildings Directive (EPBD) in all member states of the EU. This means that the energy consumption of a building has to be calculated (heating, cooling and ventilation) and is passed on to the building or apartment owner. Thus much attention also of national and regional policies is focussed on the energy consumption of buildings, e.g. subsidies are granted on the energy consumption during the use phase of a building.

When energy consumption is reduced more and more the “grey energy” that is necessary for the production of building materials and products as well as the energy for transport of the latter is becoming more important.

LCA is an instrument to check all ways of resource consumption via products as well as during the construction, during use and after the use of the building. LCA is the next step to gain a comprehensive picture of the environmental impacts of construction works.

LCA is standardized within the ISO 14040 and ISO 14044 norms. According to the norm the four methodological phases of a LCA are:

- goal and scope definition,
- life cycle inventory analysis (LCI),
- life cycle impact assessment (LCIA) and
- interpretation

In contrast to the well defined LCA there exists a variety of concepts, techniques, instruments and tools that are also based on a life cycle approach but differ from LCA in one of the following ways[1]:

[1] The following list is inspired by the compilation of Udo de Haes/van Rooijen: Life cycle approaches. The road from analysis to practice. UNEP/SETAC life cycle initiative, 2005.

- they are analytic but focus on special issues like environmental risk analysis to identify the hazards of a substance or like recording the pathways of a material or a substance through the economy of a nation, or a region, or other, like material (or substance) flow analysis;
- they are using economic instruments and accounting like input/output analysis which links processes studied in LCA to monetary flows e.g. thus preventing to ignore small but expensive flows or services or LCC (life cycle costing) as an analysis of all costs of a product or a service throughout its life cycle;
- LCM (life cycle management) and some other programmes like green procurement or supply chain management which are implemented by policy programmes or voluntary by businesses to install a framework and guidelines to improve their environmental performance;
- they are procedural tools like Environmental management system (EMS or EMAS) or labelling and certification systems. These are practical tools to guide the process to reach and implement environmental favourable decisions.

The variety of instruments and tools is making it difficult for several actors in the practice to differentiate which methods are delivering which results best suited for their purposes. Another effect of this situation might be actors that stick to one tool they are acquainted with opposing all others.

This report is intending to investigate the current use of LCA, but also to ask on the “culture” of informations that are spread in practice and that might be generated by LCA and on prevailing attitudes towards LCA and other tools and legal requirements/demands concerning environmental issues.

2 Purpose and scope, method of the report

This report is centred on the use of LCA in construction practice. But as a matter of fact LCA is not very wide spread. Even life cycle thinking – as a more general way of being aware of impacts throughout the whole building life cycle but evaluating these only vaguely – is not a common practice with many actors in the construction sector. In several countries there are requirements to perform an environmental impact assessment as the first step to gain the permission for a construction that might affect the neighbourhood or the local environment. LCC is in specific attractive for construction practice and shall be covered by this report, too. Costs are a very prominent and often the most important component for the decisions that are taken throughout the design and tendering processes. Cost data have to be determined and are thus available in any case, comprising masses of building materials and building components, all kind of works, but also financing conditions, etc. More and more clients require calculations or at least estimations of operational costs like energy consumption or cleaning, too. There are expectations that LCC will promote sustainable buildings by revealing reduced resource consumption of innovative solutions for building systems or of optimised building structures.

The background of this report is to ask for possibilities and chances that could take us some steps further towards integrating LCA-calculations into decisions. We will describe the typical practice and its actors, focussing rather on buildings and only marginal on other construction works like roads, bridges, etc.

Research and use of LCA in the construction sector appears in two distinct contexts: on the one hand it deals with building products either materials or components like windows etc., on the other hand the whole building is examined. Whereas building products have always been a prominent subject of LCA and have been entered into the databases of most LCA tools, the latter is rather an object of research. There are several reasons why LCA on buildings has not been disseminated broadly in practice. First of all, buildings contain a huge number of different products. Some account for considerable proportions of the total masses or total volumes, others could be of special relevance to environmental or health impacts. Each product has its own life span and has to be replaced after reaching this moment during the building's life time. Secondly, the building itself might undergo major changes, like refurbishment, additional constructions/extensions, other occupants with different resource consumption patterns, etc. Finally, buildings usually have a unique design. Until now there have not been promising attempts to introduce a standardization of buildings with respect to impact categories of LCA.

It is beyond the scope of this report to go into particular LCA studies and their conclusions. Only few and more general studies will be cited in the following chapter, that elaborate in some detail on demands of construction practice. Methodological issues and problems that are drawn up will not be covered in this report.

The report was prepared using the project teams' experiences and complementing it with literature and internet research. The first part (chapter 3 and chapter 4) contains all available research relevant to work package 2 of the LoRe-project which is dedicated to

LCA-use in construction practice. There are mainly two categories of research that were identified: First, there are those deliverables and reports of other projects that deal with the use of LCA in practice, e.g. with user needs, barriers to LCA and related methods, dissemination and target groups, etc. Second, there are some surveys performed with the intention to get information on LCA users and on LCA target groups. Whereas information regarding the first category was easily detected making use of the project teams' knowledge, surveys were determined by accessing a variety of information sources. Literature databases (e-Journals) like "Science direct", "SAGE", Electronic Journals Library, Directory of Open Access Journals, databases with tables of contents of even more journals (IngentaConnect, Informaworld), search with Google and Google scholar were exploited. We found that there were only very few surveys on LCA-use for the construction sector. Where possible the complete survey reports were consulted or else the information given in the journal paper(s). The results are compiled and the findings are extracted in chapter 4.

The second part of this report is a questionnaire survey to the project partners that should give a picture of LCA use in various European countries. This approach to collect information was chosen because it is especially important that there is a common understanding of the meaning and a common interpretation of the terms and concepts we are dealing with. Further on other projects yielded the experience that the return rate of a questionnaire to the huge number of possible addressees in the various areas and functions of the construction sector will be rather marginal. So we decided to access the expertise of the project partners and their colleagues in the first instance.

The questionnaire was proposed by the IFZ and agreed on by all partners. It was intended that also some additional views and perspectives from every participating country should be gathered from external persons, but this was not feasible with the given resources. So the evaluation in chapter 5 gives a general description of the state of the art in Europe (where a number of answers were indicating that there is a similar situation in several of the countries), supplemented by country specifics (where the answer of the partner was sufficiently detailed and precise). In chapter 6 some examples of making LCA attractive and useful for a wider audience in the construction sector are presented.

3 LCA use in construction practice

3.1 Definition of the building's life cycle and implications to LCA

Generally in LCA a products life stages are discriminated into before-use stages comprising the raw material acquisition, transports and manufacturing, the use stage and the end-of-life stage. The CEN TC 350 (Sustainability of construction works – Integrated Assessment of building performance) has distinguished 4 phases for buildings and construction works; adding a construction phase (including transport of products to the building site) to the stages mentioned above (fig. 3-1).

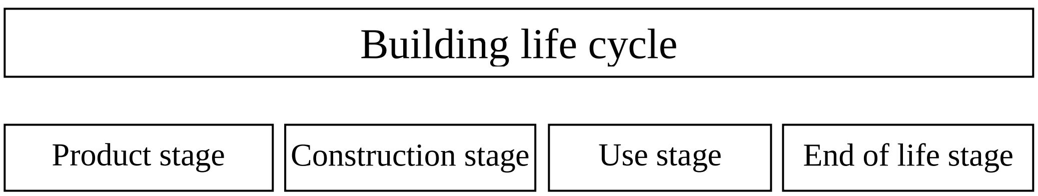

Figure 3-1 Building life cycle stages according to the pr-EN 15643 of CEN TC 350.

In construction practice the design and construction stages are often further divided following e.g. the national fee structure for architects and engineers. Another description going beyond the architects´ work to highlight in specific the clients ´decisions categorizes 6 phases: the (strategic) planning phase, the programming/briefing phase, the design phase, the construction and commissioning phase, the occupancy and the adaptive reuse/recycling phase [Preiser, 2005][2]. At the end of each phase is a review or evaluation step as a basis for the decision of the client.

Design phases and decisions do not cause environmental impacts and thus are not considered in LCA. But they are relevant to make a proposal which actor could possibly introduce LCA in a building project at which phase and in what level of detail depending on the data that are available in different phases (plan of building, bill of quantities, etc.).

The LCA of a building is not the sum of the impacts of all materials that were chosen in the design alone. It has to consider also the resources and impacts during the use phase.

The procedure of the calculation of a building-LCA starts with a compilation of the materials and the products that will be used in the building. Depending on the goal of the LCA study building life cycle stages or parts of the building may also be omitted. Each product that was found to be relevant for the LCA study has to be described by its LCA ("cradle-to-gate"). In addition the LCA of the building has to cover transport and construction processes, maintenance and end-of-life-treatment of these materials and products. It may be favourable not to aggregate the results of the latter processes as to allow other scenarios to be performed and to make a user-friendly interpretation feasible

[2] Preiser, W.F, Vischer, J.C.: Assessing Building performance, Elsevier, Oxford, 2005

with all assumptions kept distinct [Kotaji, 2003, p.7] [3]. Finally energy and resource consumption of the use stage of the building have to be calculated. The contributions to a building-LCA are shown in fig. 2. The same description is also valid for other construction works like roads, etc.

Most LCA-information of various building materials and components, nowadays also more and more on product level are gathered in the LCA databases (e.g. ecoinvent). But since every building is different all other contributions to the building-LCA are not standardized. Various calculations, software-tools and documents have to be used that go far beyond the databases: e.g. the design and the thermal properties of the building shell are important for the energy consumption during use, the location of the building is a factor for the transport distances, the inhabitants or users determine resource consumption during use and the maintenance and refurbishment activities.

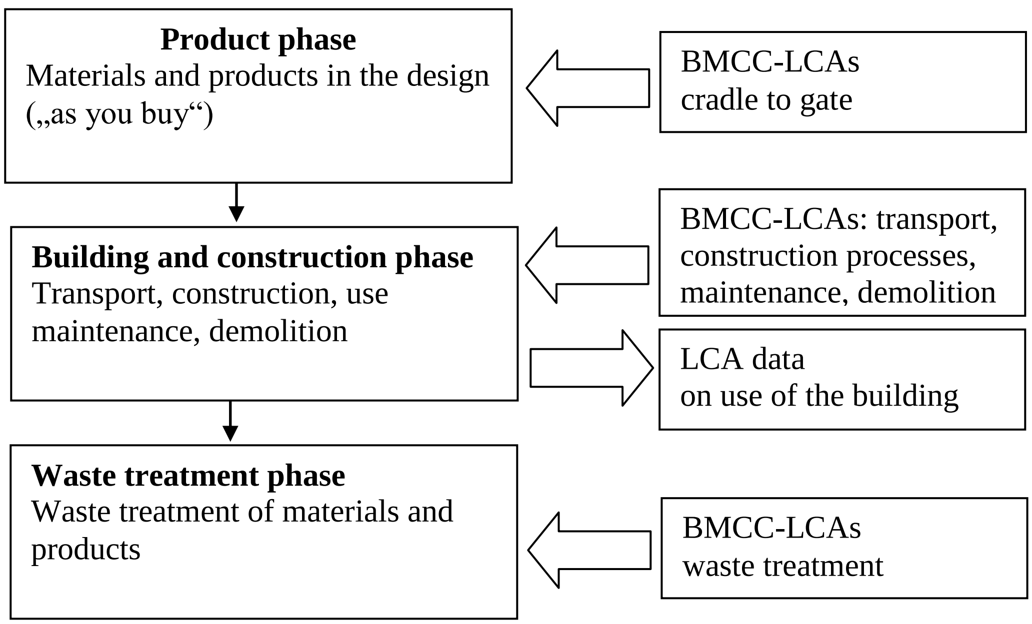

Figure 3-2 Relationship between LCA of the whole building and BMCC (=Building materials and components) [Kotaji, 2003]

It is not predefined how detailed the LCA of a building has to be. A rough structuring could be referring to cost categories or to technical specifications like: structural works/shell/core, HVAC, finishing, outside facilities. Often only the first category is focussed on because the main differences in resource consumption result from here. From the perspective of a “whole building design” this certainly should be complemented by issues like toxicity of substances, replacement cycles, etc.

Scenarios for future developments regarding the use, maintenance and refurbishment of a (new) building for the next 50 years or even longer can only be based on assumptions and are thus estimations that are less precise the more remote they are in future. In specific

[3] Kotaji, S., Edwards, S., Schuurmans, A.: Life cycle assessment in building and construction. A state-of-the-Art report, SETAC press, 2003

this is an important issue for the modelling of the end-of-life stage of the building concerning waste treatment.

LCA studies in the construction sector are laborious deriving from the complexity of a whole building, the relatively long lifetime, probably occurring changes in use and in size (affecting the functional unit of the LCA study) and little possibilities to standardize (buildings are unique and design matters: different buildings with the same materials will usually have different impacts).

For constructions, such as dikes, etc., the environmental performance of the constituent material as well as the construction impact on landscape and biodiversity will often dominate the LCA impacts. For buildings, the Life cycle environmental impacts are often dominated by energy consumption during use phase. It has been estimated that the use phase in conventional buildings represents approximately 8% to 90% of the life-cycle energy use, while 10% to 20% is consumed by the material extraction and production and less than 1% through end-of-life treatments [Kotaji, 2003, p.5]. In energy efficient buildings the material contribution (production, waste treatment) gains in importance.

3.2 General remarks on LCA use in construction practice

It has been stated [Kotaji, 2003, p.2] that there is a distinction between the LCA practitioners and other actors who often know little about LCA. In many cases the LCA practitioners tend to work at the level of individual materials and products, while the user of the LCA data (i.e. designers, etc.) are concerned with the whole building performance.

For most building projects architects and/or project managers are the central persons that manage the requirements on the building during the planning process and construction: the legal requirements and reduction of environmental (and other) risks, the client's wishes and expectations, the needs of builders and construction companies, the information interface to engineers, etc. LCAs of buildings would rely heavily on the input of these persons. It would facilitate the LCA greatly if they experienced LCA as a valuable decision support tool towards a building with minimal impacts on the environment. Several aspects must contribute to this perception, among those e.g. the following:

Additional efforts have to be balanced with benefits, synergies have to be recognized: calculations that are necessary for subsidies (e.g. energy calculations) or for certificates (e.g. BREEAM), compilations for tender documents and evaluation of offers (e.g. bill of quantities). From this perspective LCC seems to be an appropriate approach for integrating resource related impacts of the use stage and end-of-life-stage.

The interpretation of the LCA results has to be easier and less ambiguous. It has been proposed [Peuportier (ENSLIC), 2008] to take account of the proper normalisation (e.g. relating CO_2 emissions of a building to an average emission per inhabitant and year, at a national or European level), the comparison of the performance of a project with references (standard construction, best practice, etc.) and the comparison of different design alternatives for the same project. LCA should give reliable environmental information the architect can take into account in his design and integrate like other determinants (cost, functional requirements, aesthetics, etc.).

3.3 Life cycle costing for buildings and constructions

The life cycle costing (LCC) concept emerged in US to aid procurement decisions of the public sector. Nowadays it is applied to many other different areas, like the health system, manufacturing; and in specific buildings and constructions. The running costs of many assets in the construction sector are adding significantly to the budget. Building owners realized that lowest-initial-costs-solutions could end up quite expensive if the expenditures over a longer time period are taken into account. The task of LCC is to estimate the overall costs that will arise during the building's life stages (see fig. 3-1). It is appropriate to do this economic assessment in the design phase of a building for various competing project alternatives over the economic life of each alternative and to select the design that ensures the facility will provide the lowest overall costs. To determine the effects of alternative designs and to express them in economic terms is the aim of LCC.

Building-related costs usually fall into the following categories[4]:

- Initial Costs—Purchase, Acquisition, Construction Costs
- Fuel Costs
- Operation, Maintenance, and Repair Costs
- Replacement Costs
- Residual Values—Resale or Salvage Values or Disposal Costs
- Finance Charges—Loan Interest Payments
- Non-Monetary Benefits or Costs

Operational expenses for energy, water, and other utilities are based on consumption, current rates, and price projections. Energy consumption depends on the building envelope and the building use profile and is calculated e.g. by means of a simulation software. Non-fuel operating costs, and maintenance and repair costs are often more difficult to estimate than other building expenditures. Operating schedules and standards of maintenance vary from building to building; even for buildings of the same type and age.

The number and timing of capital replacements of building systems depend on the estimated life of the system and the length of the LCC study period. The residual value of a system (or component) is its remaining value at the end of the study period, or at the time it is replaced during the study period.

Non-monetary benefits or costs are project-related effects for which there is no objective way of assigning an economic value. Examples of non-monetary effects may be the benefit derived from a particularly quiet HVAC system or from an expected, but hard-to-quantify productivity gain due to improved lighting. By their nature, these effects are

[4] Sieglinde Fuller: Life-Cycle Cost Analysis (LCCA), on www.wbdg.org,last updated 12-03-2008, accessed in Oct. 2009

external to the client organisation who ordered the LCC, but if they are significant they should be included in the project.

Only those costs within each category that are relevant to the decision and significant in amount are needed to make a valid investment decision. Costs are relevant when they are different for one alternative compared with another; costs are significant when they are large enough to make a credible difference in the LCC of a project alternative.

Clear definitions and terminology, an explanation which cost components should be included, data requirements and a common methodology were given by the international standard ISO/FDIS 15686-5 (Buildings and constructed assets – service life planning, part 5: Life-cycle costing.

4 Projects und activities review

Life cycle thinking is and has been an important idea for European policies and programmes. Examples include the Integrated Product Policy Communication [COM(2003)302] , as well as the two Thematic Strategies on the Sustainable Use of Natural Resources [COM(2005)670], and on the Prevention and Recycling of Waste [COM(2005)666]. The Sustainable Consumption and Production Action Plan (SCP) integrates these and other related policies, aiming to reduce the overall environmental impact and consumption of resources associated with the complete life cycles of goods and services (products).

To further promote LCA as a method and its practice the “European Platform on Life Cycle Assessment” has been setup as a project of the European Commission, carried out by the Commission’s Joint Research Centre, Institute for Environment and Sustainability (JRC-IES) in collaboration with DG Environment, Directorate for Sustainable Development and Integration. The project started in 2005 (the end was scheduled in 2009) and its aim was to support the availability and exchange of consistent and quality-assured life cycle data and the use of Life Cycle Assessment (LCA) in business and in public authorities. To ensure greater coherence across instruments and robust decision support, hence increased acceptance, the Platform supported the development of the International Reference Life Cycle Data System (ILCD), the European Life Cycle Database (ELCD), the international LCA Resources Directory, as well as an email discussion forum.

4.1 Studies and projects on LCA in buildings and construction sector

There have already been several projects dedicated to LCA in buildings often delivering a description of available tools for LCA in buildings for various stakeholder groups and in different countries. Only the most important ones in terms of practical use of LCA in Europe and internationally are presented in this chapter focussing on the outcomes and conclusions. The order of presentation is roughly chronological.

4.1.1 IEA-ECBCS Annex 31

The aim of Annex 31 "Energy related environmental impact of buildings" was to describe the energy based impact of buildings and building stock on public health and the environment. The actors participating in the building process should be made aware of the consequences of their actions on the environment during the entire life-cycle of the building, and to assess and minimise these. To support this, Annex 31 collected and presented tools and instruments to aid decision-making in building related decision processes. Calculation and evaluation methods were also collected on suitable product and environmental models. In specific methods, tools and information sources for calculating energy and mass flow over the life-time a building were presented.

Within the project one task was to provide LCA-practitioners with a survey of internationally available databases. All possible and especially all building specific information about available databases in every participating country was collected.

The following list was compiled containing examples of issues relevant to energy consumption that should be taken into consideration in the planning and decision making process. All relevant topics of construction practice were identified that could be tackled with LCA:

- Basic decision (Rehabilitation/New Construction/Demolition)
- Formulation of User Requirements/Degree of satisfaction (Air quality, comfort,…)
- Size/Geometry/Room Layout/Room Use (geometric solution)
- Analysis of the site and remarks concerning the site
- Selection of the type of energy supply
- Selection of heating and other servicing systems
- Selection of the level of insulation
- Selection of the main building materials (Transportation, embodied energy)
- Selection of construction principle (composite materials)
- Selection of transportation and manufacturing techniques in the construction process
- Guidelines for care, maintenance and monitoring
- Creation of structural, measuring engineering and organisational prerequisites for monitoring
- Quality control/quality assurance of construction (durability)
- Monitoring of use according to original purpose
- Management of maintenance and refurbishment
- Behaviour of users
- Management of operation and operational control
- Demolition and disposal planning
- Demolition and disposal management
- Disposal and recycling possibilities

The IEA Annex 31 was conducted from 1996 to 1999, results can be found e.g. at http://www.uni-weimar.de/scc/PRO/; the technical synthesis report [Richard Hobday (ed.), 2005] is available at http://www.ecbcs.org/docs/index.htm. Annex 31 served as one of the first international structuring efforts referring to LCA in the building sector.

4.1.2 REGENER

The European project REGENER within the APAS programme dealt with an "European methodology for the evaluation of Environmental impact of buildings - Life cycle assessment". The 4th report[5] was on applications by target groups. The conclusions drawn in this report concerning LCA of buildings were:

1. LCA based tools were already operational in experimental projects at that time. They allowed precise comparisons of alternatives on the basis of a multicriteria environmental profile. First sensitivity studies showed the environmental benefit of renewable energy applications in the building sector.
2. The precision of the evaluations performed was often questioned by decision makers; so an error analysis could be very useful. Some data differed between the different data bases, and some processes were very uncertain, especially those occurring at the end of the life cycle.
3. Concerning the use of LCA based tools by professionals, target groups had been identified and deriving dedicated tools from the general LCA basis seemed promising. Identification of input-output appropriate to the various building actors according to the phase of the project was stated to be the next necessary step.
4. The first demonstration projects for which LCA methods were used showed the ability of this approach to integrate environmental concern in decision processes. In general, these applications supported energy efficient or renewable energy technologies in the building sector by showing their environmental benefit. The corresponding supplementary investment (increased glazing area, masonry for thermal inertia, ...) was shown to be soon compensated by energy gains during the utilisation phase, leading to a beneficial balance over the whole life cycle. Life cycle optimization of energy, environmental impact and manpower was said to be the new challenge for building professionals.

4.1.3 NAHB Workshop on applicability of LCA tools to the home building industry

The report presents the discussions of a meeting of experts hosted by the National Association of Home Builders (NAHB) in 2001[6]. It examined the applicability and utility of LCA tools for the residential building industry in USA. The report contains a critique of LCA and offers suggestions on how it could be made more useful. The results

[5] European methodology for the evaluation of Environmental impact of buildings, Part 4 Application by target groups, final report of the REGENER project, January 1997
[6] NAHB (Nat. Assoc. of Home Builders): LCA Tools to measure env. Impacts: Assessing their applicability to the Home Building Industry, final report, 2001

suggested that LCA tools were not ready for homebuilders to use as a practical resource at that time:

- The information produced by the LCA tools is not valuable as stand-alone data. The data would need to be coupled with other information since the LCA data is not an absolute measure of product value;
- The data output is too complex for home builders to use in a timely manner;
- Input data is sparse and includes many assumptions that are hidden from the LCA tool user;
- Uncertainty in the results is not addressed.

Some recommendations of the authors were given to remedy information deficits and enhance the attractiveness for builders as a target group:

- A clear explanation that the tool does not include cost in its analysis (or an explanation of how cost is included), but is designed to capture only the environmental impacts of the building product;
- An explanation of the scale used in the output stage. For example, if a tool's output gives vinyl siding a number of 24 and for cementious siding, a number of 30 – on what scale is this analysis based? What are the units? Builders can understand the units used in costing a product (e.g., dollars) or in sizing a product (e.g., inches). However, how do they gauge how much better or worse a product is based on the numbers in the tools' output? and
- Instructions, recommendations, or suggestions on how to factor the LCA results from the tool into an overall product selection decision.

4.1.4 PWC-Study on LCA Tools and EPDs

In June 2002 this study[7] was prepared for the European Commission (DG Enterprise, Construction Unit) by Price Waterhouse Coopers (PWC). Existing LCA-based tools for environmental performance information on both product level and building level in the construction sector in Member States and Norway were analysed focusing on the environmental product declaration (EPD) schemes. An important objective of the project was the involvement of various stakeholders such as construction materials industry, architects, construction companies, standardisation bodies, building institutes, building regulators, environmental regulators and environmental pressure groups by the organisation of two expert workshops in Brussels and by expert interviews. However the authors stated in the Management summary that they still felt that the final users (architects, civil engineers) had not been involved in this study as much as they wished

[7] Cees van Halen, Peter Vissers, Eric Copius Peereboom, Philippe Osset, Stéphanie Gaymard, Agnes Schuurmans: Comparative study of national schemes aiming to analyse the problems of LCA tools (connected with e.g. hazardous substances) and the environmental aspects in the harmonised standards, 2002; see: http://ec.europa.eu/enterprise/construction/internal/essreq/environ/lcarep/preface.htm

them to be which also reflected the relative absence of user groups in CEN and the national EPD-scheme development. As the main conclusion an urgent need for standardisation was stated.

The reasons for the poor standardisation and co-ordination in the field of LCA and EPD were attributed to the following issues:

- complexity of models, methodological difficulties and scientific disagreement;
- historical bottom-up development: clear top-down guidance is required to enable harmonisation;
- sectors sensitivities: certain industrial sectors are not enthusiastic for reasons of competitiveness, costs and confidentiality;
- low end-user and industry involvement, high technician involvement leading to a large variety of (local) commercial solutions;
- few drivers for harmonisation until now as result of low end-user and industry involvement.

4.1.5 LC Initiative - WG on LCA in building and construction

The United Nations Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC) launched an International Life Cycle Partnership, known as the Life Cycle Initiative in 2002. The background was to enable users around the world to put life cycle thinking into effective practice. The initiative was meant to contribute to the 10-Year Framework of Programmes to promote sustainable consumption and production patterns, as requested at the World Summit on Sustainable Development in Johannesburg, 2002. A working group on LCA in building and construction was founded and as an output a State of the Art report was published[8].

This report described the key requirements for LCA studies in building and construction, like the setup of a proper functional unit, that has to reflect the performance requirements of the building or construction. Guidelines for scenarios for prospective life cycle stages (service life scenarios, end-of-life scenarios) were given. The difficulties that arise for allocation and system boundaries because of the complexity and the longevity of buildings and constructions were outlined and methods to deal with these were proposed. Special topics like indoor air quality and land use were discussed.

Another activity was the LCA Case Study Symposium held 7-8 December 2006 in Stuttgart, which focussed on building and construction and attracted 200 participants from within this field.

Also the Life cycle Initiatives Task force on Communication of Life cycle information dealt with the buildings and energy sector in two workshops 8 September 2005,

[8] S. Kotaji, A. Schuurmans, S. Edwards: Life cycle assessment in construction practice, SETAC Europe, 2003

Barcelona, and 6 December 2006, Stuttgart. The contributions were gathered and summarized.[9] The focus was on environmental product information schemes like eco-labels (ISO-type I) and environmental product declaration (ISO-type III). Questions that were raised comprised: Who are the users of LC Information and their needs, which tools are used to communicate, are they successful/appropriate, is information credible, how to guarantee, How to involve stakeholders, recommendations for future best practice.

Points of discussion were (among others):

- Credibility: eco-labels often lack source credibility, whereas process credibility hampers EPDs. Role and limits of EPDs (for B2B) is in practice determined by understanding the information; an average EPDs could help and serve as a benchmark for a specific product group. Interesting is also which indicators, costs and barriers to SMEs exist. Concerning the barriers difficulties in comparing results was mentioned (different background databases give different results), verification vs. certification and harmonization were also mentioned.
- Too less attention on the demand side: Further work on user needs is necessary, adapting the format and contents of LC information in order to induce a real change in behaviour of consumers.

Conclusions drawn were:

- Necessity of a parallel strategy focus is as well on methodological issues and on involving market actors, improve EPDs (consistent background database, standardized reporting format, benchmarks with average sector values,…), include user relevant information (health, safety, costs),
- Limits of LCA were seen among other because there is still no commonly agreed methodology concerning assessment of toxicological impacts, biodiversity losses and abiotic resources depletion.
- Recommendations for different stakeholders (business and industry, policy-makers, research/academia, LCA and EPIS community) hence were compiled.

4.1.6 PRESCO

PRESCO, the "European thematic network on practical recommendations for sustainable construction" (http://www.etn-presco.net) assumed that in future environmental design tools based upon the life cycle assessment methodology will be used in the design process of buildings and constructions in order to get more sustainable buildings. Therefore the network aimed to assist LCA-based environmental assessment tools in their development.

[9] Paolo Frankl, Pere Fullana, Johannes Kreissig: Communication of life cycle information in buildings and energy sectors, reviewed final draft, july 2007.

A report[10] was launched with a description of various national tools and a comparison was presented of 5 different case study buildings calculated using the tools. The exercise was undertaken in three levels: simple geometry - complete building - improved building design according to the PRESCO-recommendations.

For the interpretation of the results it was stated that the practitioners (architects, civil engineers, etc.) must be trained. Building designers are no environmental experts and to interpret the results of an LCA some minimal knowledge is needed. Impact reduction targets e.g. greenhouse gas emission reduction should be integrated in the design briefs for low impact buildings.

4.1.7 ENSLIC

Some gaps are addressed in the ongoing ENSLIC-Project (Energy Saving through Promotion of Life Cycle Assessment in Buildings) regarding environmental indicators, easily understandable presentation of LCA results to users, simplification and adaptation of LCA to various purposes (e.g. early design phases)[11].

Potential users of LCA have been listed according to the life cycle phases of a project. The main barriers against the use of LCA in the building sector have been addressed (uncertainties, low link with labelling/certification, difficulty to formulate and follow up measurable goals, cost and complexity) and some solutions have been proposed: inter-comparison of tools, raising awareness of public authorities, integration of environmental targets in development programmes and simplification of input-output.

4.1.8 COST-Action 25

This COST Action operates under the designation “Sustainability of Constructions: Integrated Approach to Life-time Structural Engineering” (web site: http://www.cmm.pt/costc25; end date is December 2010).

The main objective of the Action is to promote science-based developments in sustainable constructions in Europe through the collection and collaborative analysis of scientific results concerning life-time structural engineering and especially the integration of environmental assessment methods and tools for structural engineering.

A series of country reports was published that provided a survey of sustainable approaches in the participating countries Greece, Netherlands, Poland, Romania, Portugal, Sweden and Turkey.

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[10] Peuportier, B., Putzeys, K.: PRESCO Workpackage 2: Inter-Comparison and Benchmarking of LCA-based environmental assessment and design tools. Final report, 2005
[11] Peuportier, B, et al.: ENSLIC_Building. State of the art report, 2008

4.1.9 CRiP (Construction Information Platform)

A somewhat different background has the “Construction Information Platform”. The European Commission has contracted this initiative in 2009 to analyse and assess the information needs of the construction sector operators in relation to EC activities. This action is developing a web platform to allow construction operators to access information with relevance for the sector, covering the regulatory and normative framework as well as policy initiatives and relevant research programmes and projects. It is intended that this platform would become a “one-stop shop” able to provide profiled links to relevant web pages from portals of the European Institutions (including Agencies) with possible links to national governmental or public organisations.

A web-survey on information needs in the construction sector was recently online undertaking an assessment of the need for EU related sector information among various actors (http://www.constructioninformationplatform.eu.). Although this project is not dealing with LCA it seems interesting because it addresses information needs and deficits in the construction related legislation and standardisation.

4.2 Studies and projects on LCC in buildings and construction sector

There are numerous studies, projects and literature which deal with LCC in the construction sector. In fact the construction sector was one of the first sectors where LCC was developed and applied. In specific non-building construction projects like roads have been a field of application for long. But to use LCC as a tool for sustainable building design, installations and management is a rather new topic. It was already stated that taking account for life cycle costs favours sustainable solutions. But the link between LCA and LCC is quite weak.

Costs that are related to environmental issues are difficult to account for. An LCA can help in identifying several of these costs, because to some degree the processes in the value chain are the same in LCA and LCC. General information gathered in LCA may therefore be helpful in LCC and vice versa[12]. E.g. LCA can identify whether a design alternative requires special permits. Furthermore LCA may be used to estimate risks, especially together with those LCA impact assessment methods that model damage. Such an item in the LCC can be dealt with as an insurance fee or in case the risk is too high, as a way to include necessary preventive actions.

In the EU project DANTES, (Eco-Efficiency evaluation of new and existing products, www.dantes.info), an attempt is made to use LCA information to identify and estimate environmentally related costs and benefits in an LCC.

[12] Steen, B.: LCA as input to LCC. Presentation at the 3rd International conference on Life cycle management, Zurich, 2007
Norris, G. A.: Integrating Life Cycle Cost Analysis and LCA, International Journal of Life Cycle Assessment, 2 (6) 2001

This chapter does not attempt to be comprehensive but cites only a few well known examples for LCC in sustainable construction practice.

4.2.1 LCC refurb 3

The outcome of this project is a guidebook aiming at energy managers and the property industry and addressing the use of integrated planning techniques and life-cycle-cost-analysis (LCCA) to assess and compare potential investments when refurbishing existing buildings. Best practice examples should transfer knowledge of optimum refurbishment to the public sector. The guidebook is split into three sections: - Integrated planning: integration of technical, financial, environmental and social criteria with a high degree of communication amongst team members and a long term approach; - Applying LCCA and integrated planning: performance requirements and boundary conditions; - A list of best practice examples from Germany, France, Slovenia, Austria, Finland, Greece, Norway, the Czech Republic.

Project within EU Altener / Save, project finished in 2005.

4.2.2 Davis Langdon “Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology”

In 2006 the European Commission appointed Davis Langdon Consulting, UK, to undertake a project to develop a common European methodology for Life Cycle Costing (LCC) in construction. The origins of the project lay in the Commission’s Communication “The Competitiveness of the Construction Industry” [COM (97) 539] and the recommendations of the Sustainable Construction Working Group established to help take forward key elements of the Competitiveness study. The Task Group recommended the development and adoption of a common European methodology for LCC in construction taking into account the work done under international standard ISO 15686. This methodology should allow for the definition of a harmonised framework to facilitate the development of software tools to estimate Life Cycle Costs on a European basis.

Davis Langdon carried out an analysis and evaluation of the different national approaches to LCC and developed an EU-wide methodological framework for the estimation of life cycle costs for buildings and constructed assets. As part of their work, they elaborated guidance on how to make cost estimates at each stage of a construction project, from the initial appraisal to the completion and post-occupation phases, including the disposal of the asset. A number of concrete case studies were undertaken to illustrate the practical implementation of this EU-wide approach.

The results of this work are intended to support contracting authorities, private investors and practitioners in the procurement of large-scale sustainable construction projects. It should be considered as complementary guidance to ISO 15686.

As a follow up, Davis Langdon defined a concept for a promotional campaign including a training framework (January 2010). All reports are available on http://ec.europa.eu/enterprise/sectors/construction/competitiveness/life-cycle-costing/index_en.htm.

4.2.3 LCC-Data

The main goal of LCC-Data is simplifying the data access as well as to define storage possibilities to ease and extend the use of LCC in construction, and hence improve the decision process towards more sustainable buildings. This means defining cost categories, developing indicators (like € per m2, € per employed persons, etc.), to create a database for storing and benchmarking of costs, and ensure simplified data exchange between different ICT-tools used in planning and decision. Easy access to comparable data gives the building owners possibilities to benchmark their building, with emphasis on energy use and operation cost.

Project within Intelligent Energy- Europe, http://www.sintef.no/Byggforsk/Forskning-og-utvikling/LCC-DATA-Life-Cycle-Costs, project duration 01/12/2006 to 31/05/2009

4.2.4 InPro

InPro - Open Information Environment for Knowledge-based Collaborative Processes throughout the Lifecycle of a Building - is an industry-led collaborative research project aiming at the early design phase of a building. It is part-funded by the European Commission under framework program 6, started in 2006 until 2010; project web-site: http://www.inpro-project.eu

The background of the project is the perceived major technology shift the construction industry is standing before: from the traditional 2-dimensional drawings to 3-dimensional Building Information Models. Advanced design, communication and simulation tools give an opportunity to change the way how work is done in the industry, including open collaboration between stakeholders, design for increased energy efficiency, flexibility, constructability, comfort, etc.

InPro aims to provide knowledge on good IT Tools and Methods to use them, know-how of processes that these tools and methods can support and models of organizational structures that create incentives for new ways of working in different contractual models.

4.2.5 Immovalue

The IMMOVALUE project aims at integrating energy efficiency and life-cycle cost aspects into property valuation standards. As one of the largest single operating expenses, energy costs deserve great attention from banks, valuers, owners and property managers. Looking at income-producing properties, such costs often represent up to 30% of the net operating income. By securing and intensifying the market impact of energy performance certificates and life-cycle cost (LCC) approaches the link between energy performance of buildings and property valuation can be strengthened.

Project website: www.immovalue.org; project duration: September 2008 – April 2010

4.3 Studies and projects on surveys of LCA in practice (not construction related)

Only recent work that is publicly available in a sufficiently detailed report and that was claiming a comprehensive analysis is included in this chapter. The surveys thus should be valuable also for construction practice and give insight into more general requirements.

4.3.1 LCInitiative[13]: Life Cycle Approaches. User Needs Survey 2003

A User Needs Survey was conducted to assess the main needs and opinions concerning the three topic areas LCM, LCI and LCIA and to develop subsequently an action plan in these areas to improve the use of life cycle approaches in practice.. A questionnaire was mailed to the interest group (some thousands of contacts) and later placed on the web site of the Initiative. Only the results of the mailed group were used in the report.

In total, 317 usable responses on the User Needs Survey were counted. The majority of responses came from Europe (186 out of 317 responses). North America and the Asian/ Pacific regions were second (46) and third (36) respectively. More diversity could be found when the responses were categorised according to their work sectors. Most respondents had an academic background (100 respondents), followed by industry (81) and consulting (40). These results showed a strong bias towards a European and academic background. This bias might have influenced the results that were derived for the three topic-areas.

For LCIA, users gave the highest priority to the development of a global, science based and transparent set of recommended methodologies and factors, both at midpoint level (the level of environmental processes and conditions) and at damage level (the level of human health and biodiversity). Furthermore, a high need was identified to include also environmental issues that are relevant for developing countries, and to broaden LCIA to the social and economic dimensions of sustainability.

Special attention in this report was given to the state of life cycle approaches in SMEs and developing countries. Special needs of SMEs and developing countries were identified through interaction with the user community in forums and workshops (consultative process).

Based on the outcome of this consultation four issues were discussed further: the need for simple tools and better data availability; the need for broadening the scope of life cycle

[13] Udo de Haes, H., van Rooijen, M.: Life cycle approaches. The road from analysis to practice. UNEP/SETAC life cycle initiative, 2005.

tools; the need for the removal of trade and cost barriers; and the need for capacity building. The discussion on simple tools and capacity building is also relevant for SMEs, both in industrialised and developing countries. More fundamentally, life cycle approaches are often seen as being not in line with the interest of developing countries. Life cycle approaches often are costly, and may well discriminate against developing countries, because of the higher environmental burdens due to less advanced technology.

4.3.2 Life cycle Practitioner survey, US, 2005[14]

Although not intended to be statistically valid, the survey conducted at the University of Washington wanted to investigate how LCA was being conducted, how results were being used, what benefits had been realized from the use of LCA, and what barriers existed for increased application of LCA.

Sixty-five LCA practitioners participated in the survey, with 66% from North America, 23% from Europe. The largest group of respondents categorized their organizations as materials production and manufacturing/ construction (47%), followed by academia (20%), consulting and government (both at 11%), and nongovernmental organizations (6%). Within these organizations, respondents function as researchers (20%), are involved in college or university education and research (15%), are business managers or product and process designers/ product stewards (both at 14%), are involved in environmental health and safety (12%), and are at between 3 and 5% in marketing and sales, professional education, primary and secondary (K-12) education, and public policy.

These practitioners used LCA results in business strategy (by 63% of respondents), in research and development (62%), as input into product or process design (52%), in education (46%), in policy development (43%), in labelling/product declarations (37%), in sales (26%), in procurement (20%), and for other uses (8%). The latter includes invitation to tender.

Survey questions concerning how LCA is being conducted focused on the type of LCA used (streamlined, based on national input-output matrices, or based on process chains), data sources for inventory analysis and impact assessment, LCA tools, and peer review practices. Within the context of the type of LCA used, 77% of respondents have developed LCAs following ISO 14040 standards (ISO 1997) and 69% using streamlined LCA[15] or economic input-output methods[16]. Fully 54% of respondents note the use of both, leaving 15% of respondents never using ISO LCA and 23% of respondents never using streamlined LCA or economic input-output methods.

Inventory data were collected from industry by 75% of respondents, from databases developed for LCA costing more than U.S. $10,000 by 23% of respondents, from inventory databases developed for LCA costing less than U.S. $10,000 by 52% of

[14] Cooper, J.S., Fava, J.: Life Cycle Assessment Practitioner Survey. Summary of Results, Journal of Industrial Ecology (2006)
[15] Definition ref. to Todd and Curran, 1999
[16] Definition ref. to Hendrickson et al., 1998

respondents, from literature or databases not developed for LCA by 58% of respondents, and using models based on science and engineering principles by 43% of respondents.

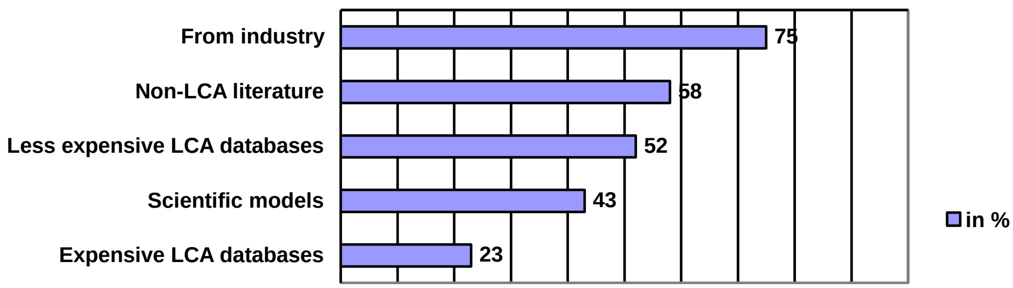


Figure 4-1 Origin of data used in LCA studies [Cooper, Fava, 2006]

Inventory data collection was cited as the most time-consuming and costly part of LCA by 68% and 63% of respondents, respectively. Interestingly, of those citing inventory data collection as the most time-consuming or costly part of LCA, 86% use data sources other than those developed for LCA for the majority of their data. Analysis and interpretation of inventory data and impacts were only cited as the most time consuming part of LCA by 15% of respondents and the most costly by 20% of respondents. This response was underscored by the widespread use of off-the-shelf LCA software, used by 69% of the LCA practitioners responding to the survey.

The primary sources used by the respondents, industry and non-LCA literature, tend to involve a significant amount of work to extract useful results. Given the prominence of these two sources, it’s no surprise that 68% of respondents ranked data collection as the most time-consuming part of LCA and 63% said it was the most costly. While extensive industry and process-specific data collection results in the most accurate footprint reasonably possible, we believe that the costs of this precision can exceed the real business benefits in many cases.

Practitioners saw the benefits of LCA because it is a good tool to examine the environmental impacts of products, a quantitative way to estimate the life cycle resources and burdens, and a way to quantify alternatives in product systems. They also believed that LCA imparted value by providing additional information to internal product design and development teams, as well as providing environmental information to customers; apparently this customer interaction appeared to be more related to business-to-business than consumer interest.

When asked why LCA is not applied to more products and processes, several reasons were repeatedly stated:

1. Time and resources requirements for the collection of data
2. Complexity of the LCA method
3. Lack of clarity as to the relative benefits compared to the costs of conducting the LCA studies, including lack of apparent downstream interest or demand.

The survey appears to indicate that today's LCA practitioners rely heavily on the growing LCA computing infrastructure. We draw this conclusion based on three things: (1) the dominant use of off-the-shelf software, (2) the identification of inventory data collection as the most time-consuming and costly part of LCA when dedicated LCA data sources do not dominate, and (3) method complexity as a barrier to further application of LCA. All three points emphasize the need for methodological transparency related to inventory and impact data sources as well as in LCA and sector-specific analysis tools if LCA is to move further into public and private decision making.

4.3.3 CALCAS

Although not specific for the construction sector CALCAS ("Coordination Action for innovation in Life Cycle Analysis for Sustainability") was a relevant European project addressing within some deliverables also practical issues.

CALCAS was financed by the Sixth Framework Programme of the European Commission. The main goal was the review of the basic current paradigms of LCA in order to overcome its present limits. The general objective of CALCAS was to advance and further develop ISO-LCA to deepen the present models and tools to improve their applicability in difficult contexts (issues of time and space, multicriteria analysis, etc.) and to broaden the LCA scope e.g. incorporating social sustainability aspects and linking to neighbouring models to improve their significance. The project was started in 2006 and will last until 2009, information is available on the CALCAS homepage http://www.calcasproject.net/.

Within CALCAS a survey on the influence of internal and external drivers on the application of life-cycle tools in companies was carried out by means of a standardized questionnaire[17]. The questionnaire contained 8 questions on general information (e.g. Is a EMS implemented in the company?, What is the kind and frequency of life-cycle approaches used and what are future expectations concerning the frequency of applications, etc.), on drivers and objectives which they are pursuing and how they assess the future importance of the respective driving factors and whether specific environmental policy actions affects the application of product assessment tools within companies. It was sent to 55 companies in Germany, Sweden, Italy and the Netherlands. A total of 25 companies from Germany, Italy, Sweden and the Netherlands answered the questionnaire, rendering a response rate of 46%. The recipients were large international businesses from chemical industry, the automotive industry, packaging producers, producers of healthcare technologies, producers of home appliances and other consumer goods.

The survey among European companies delivered various explicit results. The most important ones can be summarized as follows:

- 92% of the surveyed companies have implemented an EMS.

[17] Kristina Neumann: Life cycle approaches in European companies: The influence of internal and external drivers on the application of life cycle tools, IÖW Berlin, Master Thesis, 2007

- While simple LCA is used most frequently, environmental indicators, Risk Assessment and checklists are used regularly.
- The future application frequency is projected to increase considerably for reasons of rising market and customer demands for environmental product assessments.
- The main external drivers for the application of life-cycle approaches are future environmental legislation and market/customer demands. Internal drivers are product-related environmental challenges and anticipated environmental advantages. Companies are thus influenced by regulatory, market and ecological pressure.
- The surveyed companies use the tools in order to improve products' environmental compatibility, to improve their competitiveness and image and to compare own products. Further, the goal is frequently to use assessment result for marketing purposes and to improve supply chain management.
- With a few exceptions, the future importance of the internal and external drivers is expected to increase. Particularly market/customer demands, environmental legislation and products' environmental performance are believed to play a considerably greater role in the future.
- Policy actions that affect the application of life-cycle approaches presently are based on product declaration schemes and producer responsibility. The majority of companies believed that these policy measures would have influence in the future as well and would further be complemented by product standards, green design guidelines, take-back obligations and consumer campaigns.

The frequent usage of environmental indicators, simple LCA or checklists indicated a preference for systematic, though simplified form of assessment. The survey showed that companies use life-cycle approaches for problem specific applications of existing products. Improving environmental performance of products implies that certain products, that are to be optimized, are chosen in order to decrease environmental impacts. This was primarily due to reasons of expected future environmental legislation and to improve corporate image. Life-cycle approaches were thus applied in order to realize external as well as internal goals. Improving competitiveness and environmental image as well as checking challenges of future environmental legislation indicate anticipative application patterns. Anticipation aimed at ensuring that corporate practices are in line with legal and public framework conditions and at estimating potential risks. On the other hand, improving product performance and supply chain management as well as comparing products served primarily to control corporate activities. Further, 32% of the applications of life-cycle approaches were triggered by emerging green markets and 28% were used in order to identify future markets. This behaviour indicated that businesses act proactively and realize chances of product-related environmental improvements. The fact that internal and external drivers were evaluated with almost equal importance showed that generally a combination of external and internal factors triggered the application of life-cycle approaches. The companies of this survey therefore showed offensive as well as defensive behaviour.

Another survey within CALCAS was relating to decision making and decision support[18]. The overall objective was to identify decision-making situations where life cycle approaches were considered to play an important role as sustainability decision support. The survey targeted the following four main stakeholder groups: Public authorities, Business (industry, retailers), NGOs (incl. consumer associations), and - R&D programmers (national funding organizations and research institutes).

Questions were on the stakeholders' current use of life cycle approaches and its challenges; and how stakeholders want life cycle approaches to develop in the future to become more useful in sustainability decision making.

In total, 25 interviews were conducted and a questionnaire was sent out to 220 stakeholder representatives; the response rate was only 6 percent of which 70 percent represented businesses.

The priority messages regarding life cycle approaches and its challenges were:

- ISO-LCA is considered to be an "expert model" which takes too long time and the results are often complicated,
- too few are interested in the results of a full LCA, and
- difficulties to find methods that meet actors' needs.
- The priority messages regarding future needs and evolution of life cycle approaches are:
- simpler interfaces (adapted to the required application or sector),
- clear standards for data gathering,
- less time consuming models,
- greater transparency,
- integration of economic elements in LCA models, and
- data representative to different levels of resolution (geographical coverage),

The issues specified above comprised a complex mix of requests such as increased flexibility, accuracy and user-friendliness, which perhaps might be too much of a challenge to incorporate in one system model. The results are input to a final report on the user needs perspective (to be delivered).

[18] Thomas Rydberg, et al.: Results from survey of demand for life cycle approaches in sustainability decision support: User needs. Deliverable D9, July 2008.

4.4 Studies on practical use of LCA in construction and on user needs in the construction sector

4.4.1 Survey of BEES Users[19], 2001

BEES (Building for Environmental and Economic Sustainability) is a tool that evaluates the life-cycle environmental and economic performance of different building products (2001: 65 products, 2009: 230 products) by using the life-cycle assessment approach specified in ISO 14040 standards. All stages in the life of a product are analyzed: raw material acquisition, manufacture, transportation, installation, use, and recycling and waste management. Economic performance is measured using the ASTM standard life-cycle cost method, which covers the costs of initial investment, replacement, operation, maintenance and repair, and disposal.

The BEES software is fairly straightforward. To conduct a BEES analysis, the user selects the building products to be compared, the transportation distances for each, the importance weights of environmental impacts included in the environmental performance score, and the relative importance of environmental versus economic performance.

Users of BEES 2.0 that downloaded the software before July 2001 were asked by email to participate in an Internet-based survey. 566 partially or fully completed surveys (of 2875 delivered emails; equals 19.7% gross response rate) are used to evaluate: why they downloaded BEES; whether they applied the tool to a real-world decision; what type of building products need to be added; how much time they spent using BEES; what level of analysis they are most interested in; which degrees of transparency, complexity, and uncertainty analysis users want; what type of result presentation they would prefer; a.s.o. Although the survey was geared towards users of one specific tool (BEES 2.0), many results may apply as well to other similar tools that can be downloaded free from an Internet web-page.

A higher percentage of designers and a lower percentage of builders responded to the survey than were represented in the survey population (design: 32% of the respondents compared to 23% of the "downloaders", construction: 6% of the respondents compared to 16% of the "downloaders"). This was interpreted in two ways. First, BEES addresses the decision support needs of designers better than it does builders. Therefore, many builders that downloaded BEES never used it and many of the designers that downloaded BEES actually looked into it in more detail. Second, the work-load in the construction sector was so intense that they didn't have time to respond to email messages and surveys.

Only 13 % of respondents inspected or applied the BEES results, while an additional 30 % intend to do so in future. Forty-four percent wanted to educate themselves or others and another 6 % decided that they will not apply BEES to future projects.

Many respondents that downloaded BEES have so far not applied it to a specific decision. Only 9 % did so and of those who did so it was often used in real world situations (not hypothetical classroom problems). 16 % of all respondents have studied the tool in much

[19] Hoftstetter, P. et al.: User Preferences for a Life-Cycle Decision Support Tool: Evaluation of a Survey of BEES Users, NISTIR 6874, NIST, 2002

detail spending 5 or more hours with the software and most likely also with the manual. Another 48 % spent 1 hour to 4 hours, which allows one to get familiar with BEES. The remaining 36 % spent less than one hour with BEES.

Another goal was to determine how much the users value transparency. The first question presents the transparency issue as if no trade-offs would be involved: Indeed 82 % of respondents want more or most transparency. People from education&research and from consultancy want most transparency while builders are content with less. But also designers want more transparency. A minority is focused on results only or major assumptions only.

The next question dealt with the fact that transparency comes often at the expense of user friendliness. But only 50% prefer a tool that is easier to use at the expense of its transparency (more built-in assumptions).

Only 16 % (with a relatively high proportion of manufacturers) were satisfied analyzing buildings at the element level only. Most respondents preferred either the assembly or whole building level or a combination of all levels.

BEES calculates an Environmental Performance Score from the performance of ten impact categories to present the results of the comparisons. For 32 % of respondents this is the preferred outcome. Another 35 % felt that an “EcoProfile” (scorecard) without weighting of the impact categories would best serve their needs. 27 % of respondents felt that simple seals of approvals or information labels would be sufficient. The additional comments received revealed that compatibility with the U.S. Green Building Council’s LEED Green Building Rating System (2001), a more comprehensive yet less science-based system to evaluate buildings, was also an issue.

4.4.2 German architects’ survey, 2004[20][21][22]

The survey was carried out as a project of the German Network on life cycle inventory data supported by the German chamber of architects. The survey results were based on approximately 600 received feedbacks and 309 questionnaires duly completed. The distribution of respondents is representative of the German conditions with respect to the ageing and enterprise structure of the chamber of architects 95% of respondents were architects.

Approximately 24% of respondents declared always making decisions based on environmental protection aspects during planning, 70% partly – depending on the project. The large majority (75%) do it for personal conviction, while the percentage of clients

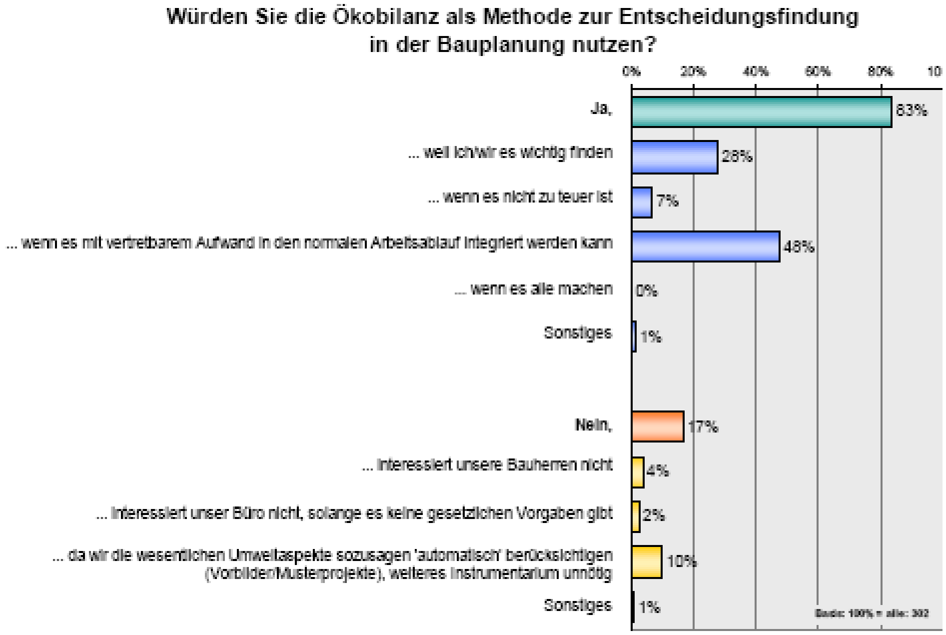
[20] Klingele, M., Jeske, U.; Umweltaspekte und Lebenszyklusdaten in der Gebäudeplanung. Kumulierte Ergebnisse aller Fragebögen, Band 1, 2007
[21] Starzner, S. et al.: Formulierung von Anforderungen an die Datenbereitstellung nach Art, Qualität und Aggregationsstufe [Formulation of data requirements concerning form, quality and aggregation level], Netzwerk Lebenszyklusdaten, 2007.
[22] Frankl, P., Fullana, P., Kreissig, J.: Communication of life cycle information in building and energy sectors. Reviewed final draft version 4.2, 2007

ordering services to consider environmental protection (against payment) is very limited, i.e. respectively 18% in the case of private builders, 10% of public authorities, 2% of enterprises and practically 0% of property developer investors.

The need to include the use phase into the planning of buildings is already understood by architects and energy is a focal point concerning environmental aspects in present planning. The survey indicates an overwhelming request for environmental declarations or certifications of building products for all building levels, ranging from building materials (wall construction, insulation, roofing), indirect materials (solvents, adhesives), finishing products (paints, floor coverings). This information is wanted by more than 90% of respondents. The request is slightly lower for technical installations (heating, ventilation, etc.- 80%), cleaning processes and agents (73%) and building elements (windows, doors – 70%). In principle this demonstrates the high potential of ISO-type III environmental product declarations in the building sector. As far as this is concerned the role of architects appears crucial because the decision of applying environmental aspects in planning is strongly under their control; independently of the client's desires. Architects express a high willingness to use LCA-data in decision making (82%), especially if integrated in usual workflow to reduce the workload to acceptable levels (as strong condition for 48% of respondents).It is worth noticing that they show a significant interest in life cycle costs, which is higher than the one in environmental life cycle information (see figure 4-6).

In contrast however at present there is only limited knowledge of existing LCA studies (25%) and little use of tools and guidelines already in existence. Moreover there is no clear preference with respect to the format of delivered information, e.g. with respect to the choice of indicators and/or a single score indicator (see figure 4-4).

There is an evident gap between the wishes and the current use of life cycle communication by German architects. What is clear is their request of life cycle cost and additional information (e.g. comfort, indoor air quality) beyond "conventional" LCA information (see figure 4-4).



Yes,

…because I/we consider this important

…if it is not too expensive

…if it can be integrated in usual workflow with acceptable additional effort

…if all other architects are using it,

…else

No,

…our clients are not interested,

…our company is not interested as long as there are no legal requirements

…since we anyway consider the most important environmental aspects (pilot/ demonstration projects) we don't need this instrument

…else

Figure 4-2 Answers to question: Would you use LCA as a method for decision making in the construction process? [own translation from Klingele, Jeske, 2007]

Concerning LCA, I would rather…

31%: …order it as a service of specialized engineers

63%: …do it myself with appropriate instruments and tools

6%: else:

- I have not decided yet

- I would like to use tables or lists

Figure 4-3 Answers to question: How would you prefer to conduct an LCA study? [own translation from Klingele, Jeske, 2007]

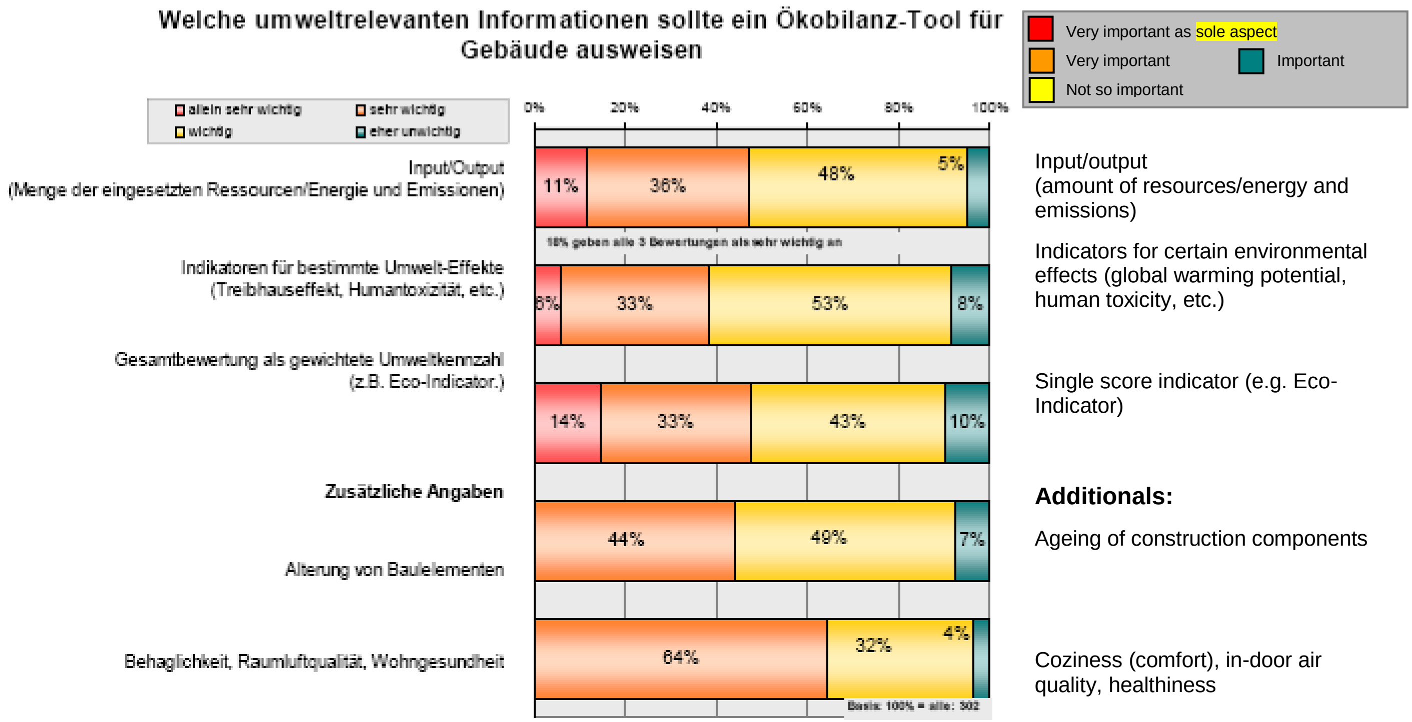


Figure 4-4 Answers to question: Which ecologically relevant information should be provided by LCA tools for buildings? [own translation from Klingele, Jeske, 2007]

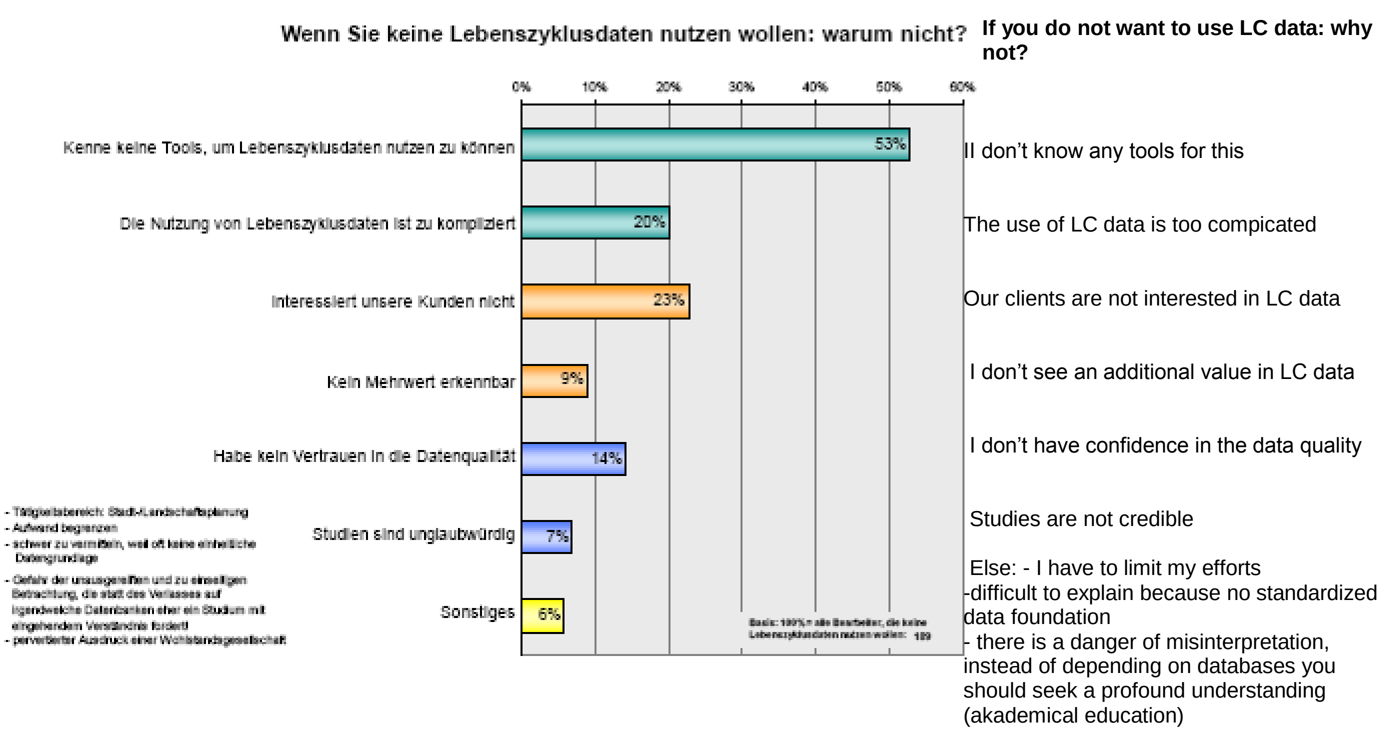


Figure 4-5 Answers to question: If you do not want to use LCA data, why not? [own translation from Klingele, Jeske, 2007]

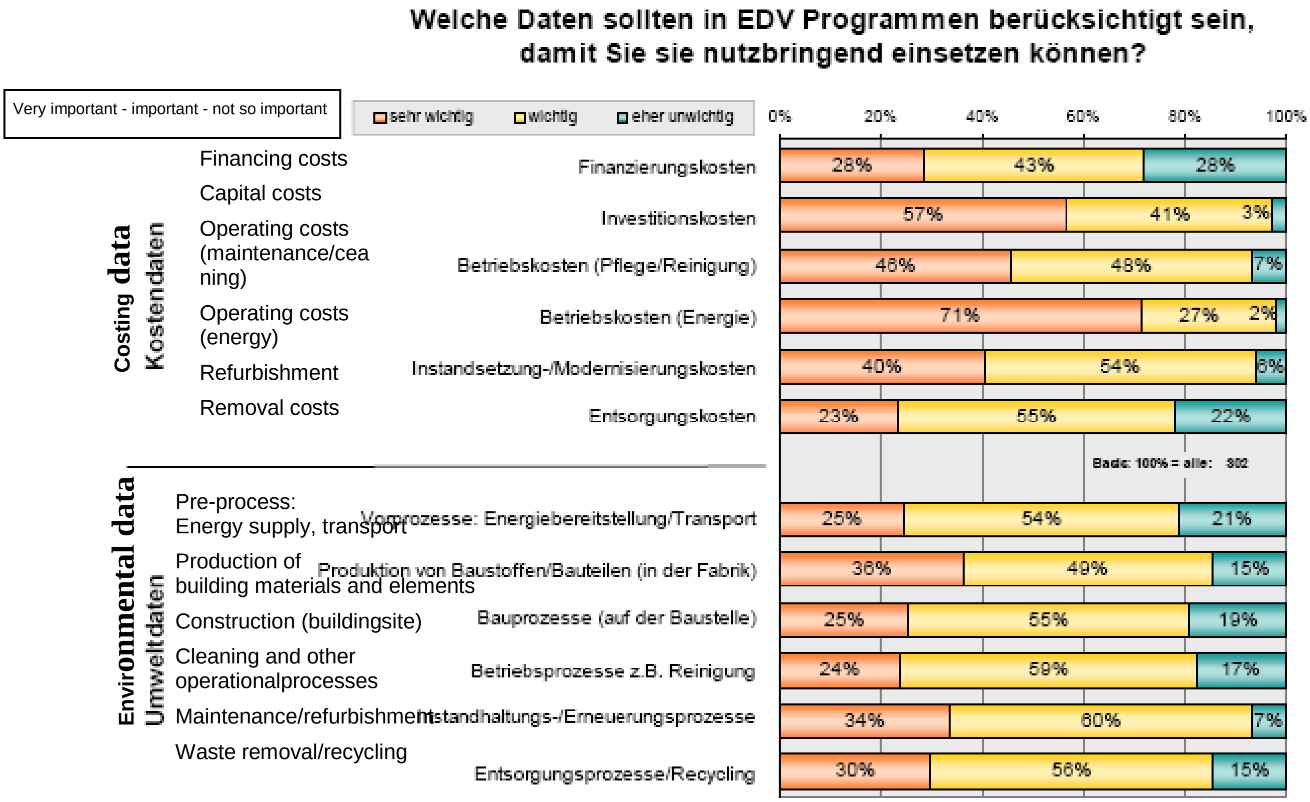


Figure 4-6 Answers to question: Which data should be included in the software to have a benefit for you? [own translation from Klingele, Jeske, 2007]

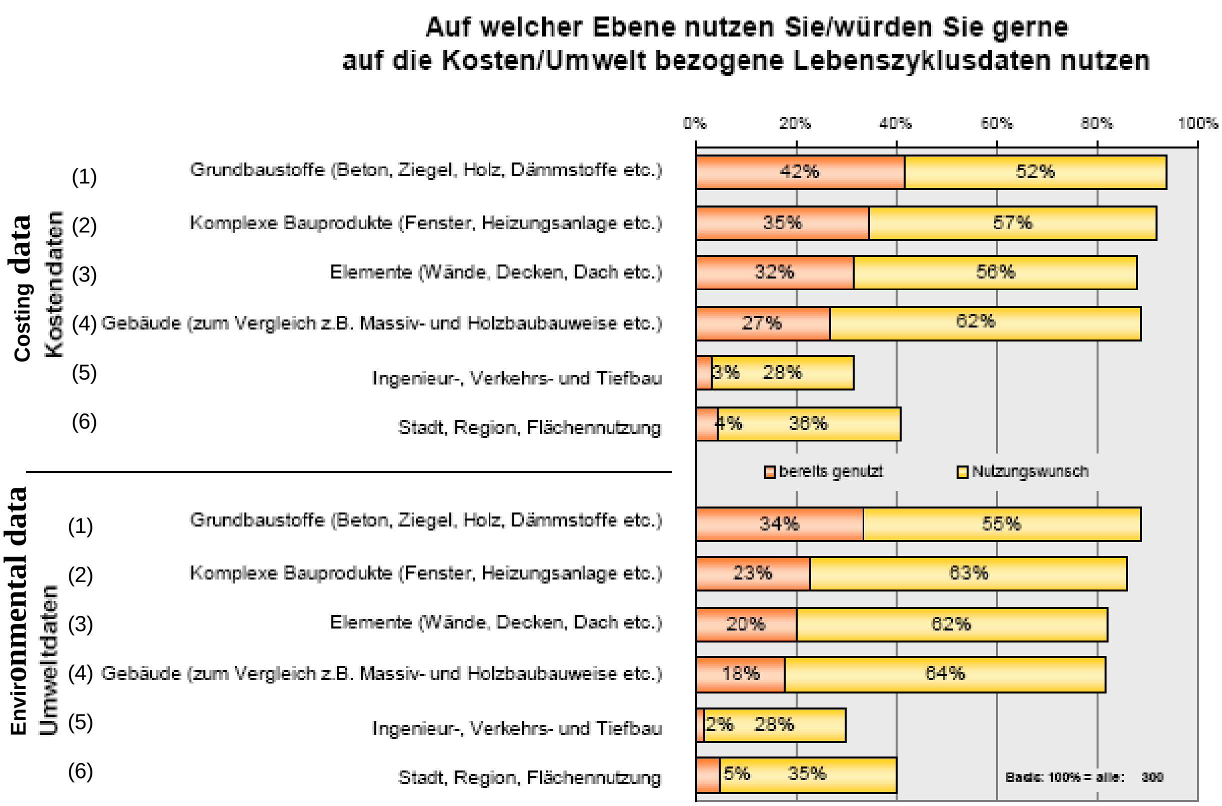


Figure 4-7 Answers to question: The life cycle data that you would like to use should be on what level? (listing from above) (1) Materials like concrete, bricks, wood, insulation, etc., (2) Assembed products like windows, heating system, etc., (3) building elements like walls, floor, roof, etc., (4) whole building (e.g. to compare massive buildings to timber frame buildings, etc.), (5) Other construction works (Roads, etc.), (6) urban and regional planning, zoning [own translation from Klingele, Jeske, 2007]

4.4.3 Survey on complex "green" messages among US architects, 2006,[23][24]

This study explores the mechanisms by which relevant actors in the building sector process environmental information resulting from LCA techniques. The results were built on the responses of 1,346 architects (21.5 response rate), all of which were members of the United States Green Building Council (USGBC). Individuals were randomly assigned to receive one of 8 insulation advertisements developed with support from an advertising/graphic designer and with input from the Communication Committee of the North American Insulation Manufacturing Association (NAIMA). The communication effectiveness of the different advertisements was rated and further analysed based on regression analyses and a structural equation model. Results indicate that advertisements with environmental messages were indeed more effective, however, only when environmental performance information was presented in a highly elaborated/disaggregated manner and not when it was aggregated in a simple slogan. Although the complexity of the ad does not help the ad appealing, the credibility gained through more elaborated environmental messages and this also influences in a positive manner the attitudes the buyers have toward the brand, the company and their intention to purchase the product. In summary it was concluded that when companies intend to communicate environmental messages, the inclusion of disaggregated LCA information is appropriate even though simpler messages performed more appealing. But with an increasing pressure from multiple stakeholders toward environmental and social responsible activities, the credibility gained might appear to be in the long term the more fruitful approach.

[23] Molina-Murillo, S.A., Smith, T.M., Environmental Communications with LCA Information: An exploratory Study within the Building Industry, 3rd Conference on LCM, Zurich, 2007
[24] Smith, T.M, Molina-Murillo, S.A., Exploring complex green messages in Advertisements within the building Industry, prepared for: North American Insulation Manufacturing Association (NAIMA), 2007

5 Description of information handling, information needs, tools and barriers

5.1 Awareness of Life cycle issues in the construction sector[25]

Life cycle thinking (LCTh) is one of the key principles of the Integrated Product Policy of the European Commission. To support the IPP for SME (small and medium sized enterprises) a study was carried out by TNO and other organisations to understand the specific needs of SMEs. The main objective of the study was to describe the status of the awareness of relevant target groups in the various industry sectors regarding LCTh. Among others the building sector was analysed:

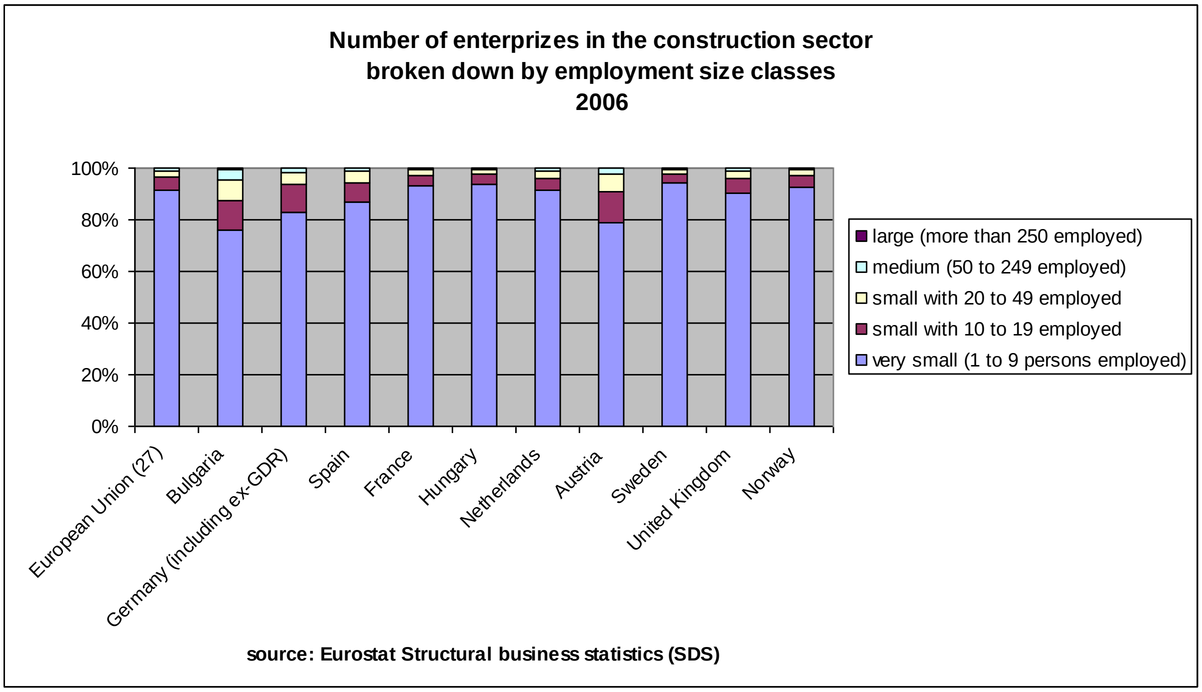


Figure 5-1: Structure of the construction sector in some European countries (Ansems et al., 2005)

The figure indicates the importance of the SMEs for the construction sector (not including manufacturing of building materials neither retail/wholesale of building materials, but including civil engineering) in many EU countries. Construction is traditionally a local activity that is dominated by SMEs and displays little export activity. The output of the sector divided into 4 main categories: private house building (2001: 24,9%), non-residential buildings (2001: 30,7%), renovation and maintenance (2001: 24,8%), civil engineering (2001: 19,6%).

[25] This chapter is partly a summary of the chapter 2.3.4 “Building sector” of the TNO-report „Making Life-cycle Information and interpretative tools available“ (Authors: Ansems, A., van Leeuwen, S., Guinée, J., Frankl, P.), prepared for the EU-IPP (Integrated Product Policy), 2005, p.60-62

Construction is a highly heterogenous sector depending on a large number of different professions. The structure of the sector can be viewed as a pyramid with project coordinating enterprises at the top, subcontracting out work to smaller, specialised enterprises in lower tiers. Transport aspects are very important, as construction is one of the most geographically dispersed sectors. Because of the society relevance also authorities and public administrations interfere with regard to LCTh oriented issues. The retail sector is less active in the delivery of new products (here: buildings). But in the situation of renovation and maintenance the retail sector is more important. Its customers are mainly self-employed enterprises and individual consumers (Do-it-yourselfers). Also consumer organisations are more active especially regarding specific products and health impacts.

The building sector is perhaps the sector in which LCTh first emerged. The oil crisis in the early seventies drew the attention to the heating energy consumption of buildings. Reduction measures such as insulation started to be used. Later on, the use of materials was also focussed on. Depletion of abiotic resources and the use of potentially toxic materials were items that emerged in the eighties. Sustainable construction has been an issue in Europe since the early nineties.

Considering the number of EPD programmes relevant for building and construction sector established in different countries, this sector is clearly ahead of other sectors in providing environmental performance information about its products. However, due to the relatively high costs the drawing up of EPDs is mainly commissioned by large (international) firms. For small firms the main drivers for incorporating LCTh comes from the branch organizations of these small firms; of one’s own accord the small firms are less active.

Some of the large retailers pay attention to the environmental aspects of building materials and provide the customers with information on sustainable Do-it-yourself. Consumer organisations occasionally test building products and include environmental aspects in these tests.

5.2 Evaluation of the project partners’ expertise

In the following a summary and evaluation of answers from the project partners and of some experts in the project partners’ countries to a questionnaire in Summer 2009 are compiled. The contacted persons were asked to give

- (Background) information to each question
- His/her opinion to each question
- Other perspectives (of construction companies, architects, clients, etc.) – optional if he/she is familiar with one or another to each question

The partners were advised to think also on non-building constructions (highway and street construction; bridge, tunnel & elevated highway; water, sewer and utility lines) and related issues.

The questionnaire was divided into 4 sections dealing with

- Construction practice with respect to aspects related to LCA and/or Life cycle thinking (LCTh)
- Use of LCA looking at various stakeholder groups and their benefits, needs and barriers
- Tools for LCA that are spread in practice
- A short conclusion in 1-3 sentences.

The questionnaire to the project partners is given in annex 1 and to the external experts in annex 2 of this report. All in all 15 questionnaires were received and evaluated.

5.2.1 Current situation of the construction practice in European countries concerning LCA and LCTh

Legislative and other requirements based on LCA data / LCTh (life cycle thinking)

It was already stated in the chapter 1 (Introduction) there is not only the ISO-conform LCA that is of interest for this report. But there are several approaches that take into account environmental impacts attributed to buildings or part of a building (e.g. building envelop or interior works and materials) during its life cycle or part of it. To mention some: procurement strategies, environmental impact assessment, environmental risk assessment, certificates. They are often restricted to only some of the impact categories, or address their own like monetary categories. And they are often limited to a period of the building’s life cycle.

There are no legal requirements for buildings in the countries that are LCA-related or LCTh-related in a comprehensive meaning; this means covering several impact categories and the whole life cycle. LCTh in this report is used as a synonym for a less “analytic” way than LCA to deal with the same issue.

Requirements for the building permit are posed by the implementation of the EPBD in national building regulations, demanding an energy certificate for new buildings and refurbishments. The energy certificate includes the calculated energy consumption for heating and hot water, as well as for cooling and lighting (for non residential buildings only). Only energy and only the use phase of the building is affected, the annual energy consumption is reported, not the consumption assumable for the building’s service life.

In Spain, the designer (architect or engineer) has to sign the certificate for the proceeding of the design phase. After construction, the project manager has to sign the final version. And finally, the investor or building owner has to present it to the buyer or building user. Thus there are a lot of people getting into contact and identifying (signing) with it.

In Catalonia (Spain), the Eco-efficiency Decree also goes one step further and obliges all new buildings and all refurbishments to reach a minimum ecological standard. This can be achieved either by additional water saving equipment or by facilities for waste separation, etc.

In Bulgaria, the EnergyEfficiency Act of 2004 provides a calculation method sets requirements for energy performance of the building during use and promotes energy efficiency measures and renewable energy by CO_2 benchmarks for buildings.

In all countries further regulatory requirements certainly do exist, concerning health, hygiene, comfort of the building, e.g. as part of the building code. But they are by far not as thoroughly described and are usually not requested to calculate. Also water and (raw) material consumption remain on a general level with the exception of some local authorities in Spain that impose an obligation to recover rain-water, gray-water and/or pool-water. Waste at the construction site is often separated as long as economic calculations considering the disposal fee favours it. Demolition waste is relevant not before the building has reached the end of its service life and a dismantling / demolition permit is needed. In Spain the Royal Decree 105/2008 on the production and management of construction and demolition waste covers both aspects and sets forth a management programme and management model promoting prevention, reuse, recycling and contributing to sustainable construction.

For certain cases (buildings in protected areas, industrial buildings, etc.) environmental impact assessment has to be performed involving criteria like land use and impact on the local ecosystem. Cultural conservation can also pose instructions on materials, workmanship techniques and preservation of characteristics of the building. If the ground water level is reached during construction, there are special requirements for the construction works.

Besides the regulation in many countries voluntary assessment schemes are implemented either national or international ones. These have a wider scope of environmental impacts and aspects. In specific there was mentioned the HQE (“high environmental quality”)-label of France, the DGNB-Gütesiegel of Germany, the “klima:aktiv Haus” of Austria and the “Miljöklassad byggnad” in Sweden. These assessment schemes often address issues like durability aspects and resources consumed by transport during the production and construction phases. However, these issues are often tedious to evaluate or calculate and are by far not so popular as the nergy and climate related ones.

Housing subsidies are mentioned as an important driver for LCA assessments in Austria. Subsidies require a simplified LCA of the building envelop materials based on the “Ecosoft-Tool” and aggregated to the so called “OI3-Index”. This is a rating composed of the primary energy use from non-renewable sources (PEI_{ne}), the global warming potential (GWP) and the acidification potential (AP).

Some clients have own demands on special LCA-related qualities like CO_2 reduction goals or have own checklists of hazardous products, this was mentioned for Sweden and Germany. Of course, ecological demonstration buildings are very well evaluated in all countries, with the aim to minimise environmental disadvantages and to optimise the benefits. A LCA evaluation is also sometimes performed for prefabricated houses – justifying the efforts by multiplying the benefits due to the standardized design, e.g. in Germany.

Producers of building materials and components use LCA to gather environmental information on their products like EPDs and to improve the design and process.

Requirements on operational costs as a step towards life cycle costing

There are no requirements either by regulation or by subsidy schemes on maximum operational costs in any country. A maximum energy consumption threshold is required by the thermal regulation in all countries. Some clients begin to include LCC in their planning but this is only emerging.

In Austria, public clients have articulated a strong interest in this and are attempting to integrate operational cost aspects in architectural competitions and tendering activities of construction work for their building (schools, nurseries, offices, etc.). But they have no suitable instruments (tools) for the integration of LCC aspects. Thus requirements for operational cost aspects are stated in a very common, simplified way, which hardly enables to prove entries (e.g. in architectural competitions).

An interesting strategy for the implementation of LCC aspects in tendering is related to energy performance contracting. In Austria, an LCC model was used for the campus building of St. Pölten University of Applied Sciences in Lower Austria. Bidders had to offer besides construction costs, also costs for operation (maintenance, technical operation management, energy consumption) within a period of 25 years. This forced bidders not only to account for the investment costs but also to optimise life Cycle Costs. The effect of this procurement model was a higher quality of construction products and HVAC – systems, because bidders calculated their offers based also on durability and lower maintenance costs.

Sporadically private clients start to require prognosis about the prospective cleaning costs or heating costs but as a matter of fact human resources cost much more and thus are more important. Also clients are more interested in new technologies and neglect (their) operating costs, as pointed out for Hungary. There is also a difference between developers who build for their own – they often pose higher demands on operational costs – than developers who build for selling. In Sweden, for instance, it is quite common today that housing cooperatives no longer coordinate the construction of their residential estates but to buy it from a developer. In this case, the usual requirement is solely to comply with the building standard.

In a Swedish project regarding development of LCC tools for the building and construction sector, the questionnaire and interviews in this project did not show that influential customers posed such demands in procurement (Noring, 2009). It was instead mentioned to be a main barrier that there were no such requirements in procurements.

Durability as a LCA related topic

In all countries consumer protection and product liability are established by accordant laws. These laws apply to products, to but also to services like construction works or design of construction details.

In Austria, on product level, manufactures of building product give guarantees for durability and operability for their products (e.g. 20 years for flat roof foils). Architects and construction firms are liable for defects caused by their work for 30 years.

In Bulgaria, there are requirements for the structural parts of the buildings, the minimum guarantee is 10 years. For other elements of the buildings the guarantees are from 1 to 5 years.

In France, durability as such is not addressed beyond the common 10 years guarantee. But it is gaining importance in PFI (public finance initiative) projects.

In Germany, civil codes' warranties protect the consumers for 5 years. A special case is the PPP (Public Private Partnership) agreement. A PPP agreement arranges usually a determined operating life expectancy contractually to ensure the building quality and the usability after the contract end.

The Spanish Technical Building Code sets only some durability criteria for the building structural elements (steel, wood, etc.), but the durability of the whole building is not usually considered.

In the Swedish social housing part (still constituting large parts of multi family buildings in Sweden) there used to be a practice with standardised intervals for renewing or changing internal equipment and surface layers. This has changed gradually towards more of a client-driven upgrading of the apartments. Moisture control and mould prevention are other topics related to the discussion of durability in Sweden.

Durability is rather a criterion that clients require for their buildings, in specific for buildings they intend to own and use themselves in all countries (Bulgaria, Hungary). In Spain there are examples of eco-city buildings that fulfil certain conditions about the type of building materials to use and/or its durability.

Waste management is mandatory for the demolition waste in all countries. However, there are big differences in the extent of the materials that go into recycling or re-use. In Austria, e.g., recycling is a general aim of the solid waste management law. If economically feasible clients and construction companies are obliged to recycle construction waste. If recycling is not possible the materials have to be offered to the Austrian recycling exchange in Vienna (RBB). Recycling has to follow requirements stated in a directive of the Austrian construction recycling alliance. However, in Austria recycling material substitute only about 2% of building materials, whereas non building related construction sectors (highway and street construction; bridge, tunnel & elevated highway; water, sewer and utility lines) have higher recycling rates.

In Spain, 1.1 tons of construction waste was generated per inhabitant and per year in the last years. Most of the construction and demolition waste can be considered equivalent to inert or inert. Most of would be reusable, generally, for other uses in the construction sector. Only some previous operations of cleaning and preparation (not very complicated) would be required. At present, in Spain most of these wastes go to landfills (more or less controlled) and the percentages of recycling/reuse of construction waste (<10%) are the lowest in Europe.

Communication and information flow

Communication and documentation of LCA subjects like energy consumption, durability of structure and materials and maintenance required, disassembly, construction related transport is currently dispersed to various legislative matters, in heterogenous formats or documents. Different formats are generated by different building experts (architects, civil engineers, etc.) for different purposes (submission planning, energy and LCA calculations). There is no consensus on a consolidation of this situation. Currently every member of the design team (architect, civil engineer, energy expert, ecological experts) is responsible for “his”/”her” LCA data. This makes it difficult to put together all generated information to a building’s LCA.

One of the core problems of communication and documentation on LCA subjects is the fact, that in the first design phases of a building (preliminary design until building permit) on the one hand there are no sufficiently easy and necessarily imprecise LCA instruments and tools at hand giving nonetheless significant information and guidance to the designer. In the questionnaires it was stated several times that the use of LCA/LCTh would be most beneficial during the design process. On the other hand designers are often reluctant to specify a building, the materials and the constructions in an early planning stage probably still subjected to major changes. So a lot of LCA studies are done after the early planning phases, leaving less opportunity to ecological optimisation. In general in Europe most LCAs are done for building already constructed, e.g. LCAs within the scope of a certification.

Energy certificates were the first broadly implemented common format of building information. That was also pointed out by all partners. But it was also stated that the objective of building energy assessment should be to valuate the overall energy impact of the building including also the embodied energy of the materials and equipments implemented in the building through their manufacturing, transport, implementation and final disposal processes. This requires a LCA approach. It becomes more critical as building operational energy efficiency is increased, since under these circumstances the embodied energy adopts a higher relative weight in the life cycle energy consumption.

Complaints about attempts to establish further requirements

In Spain, the architects are complaining most about LCA-like requests. As a result of the transposition of the EBPD, last years there has been a strong change of Spanish legislation. It has involved the development of a new Technical Building Code (Royal Decree 314/2006), a new Regulation of Thermal Installations in Buildings (Royal Decree 1027/2007), and a new Energy Certification Procedure for new buildings (Royal Decree 47/2007). Furthermore a new Energy Certification Procedure for existing buildings is expected. Hence, the architects say that there is not enough time to understand the new legislation and to implement all the new requirements. But also other stakeholders like property developers, builders, technicians, workers, etc. perceive the legislative changes as complicated.

In Austria, many architects, parts of the building industry and parts of the public administration are complaining most. Their disaffirmation is based on different causes: Architects fear to have more unpaid efforts, they can not see the benefits of LCA and they have marginal knowledge on this topic, as in the education of architects in Austria LCA is no topic. Manufactures thinking to have disadvantages for their products (e.g. PVC, cement and concrete industry, etc.), are complaining most. On the other hand some manufactures (especially of ecological building materials) are showing an increasing interest in the EPD, seeing market competition benefits through EPDs. Officers of the public administration criticise the difficulties by the practicable implementation of LCA aspects in their daily work, they are missing easy to handle, verifiable LCA instruments. Private clients are confronted with a vast quantity of labelled products and building certificates, not knowing the quality and reliability of the data provided.

In Sweden, there is a confusion and perception of stress regarding that there are so many different environmental rating/labelling schemes – on product, building element, building, city district levels, covering different issues; only energy related or more, LC related or not, driven by consultants, authorities, standardisation, etc. Many actors find it difficult to relate to this flora of tools and schemes and also find it difficult to understand which ones are the ones to learn about and apply. Regarding EPD´s and BPD´s (building product declarations of a standardised format developed by the Swedish Eco cycle council for the building industry), the manufacturers of the building products are the ones who complain most and find the data need to demanding. As a compromise, the latest version of Swedish BPD´s therefore includes life cycle inventory data only on voluntary level.

Barriers for a broader uptake of LCA

One of the main problems is the high amount of energy and material flows in all life cycle stages of a building, which causes enormous efforts (time) to handle LCA. Wherever there are efforts, e.g. from public administration, to implement LCA and LCC aspects in procurement policies, etc. they are facing several problems for the practical implementation. On one hand national data bases are still missing and the quality of information of these data bases is perceived as still not sufficient. LCA tools are familiar to a small LCA community only, thus are not viewed as practicable and commonly accepted by many stakeholders in the construction sector.

Besides energy consumption during the use stage of the building, there are no further aspects of LCA that are as popular. In specific end-of-life-waste is not as attractive, using recycled materials, etc.

According to a large survey about environmental practice in the Swedish building and construction sector in 2006, the largest barrier to improved environmental practice is limited market demand on green products/services (Gluch et al., 2007). A case study (ENSLIC project) with Sollentuna municipality aimed at finding ways to start posing demands for new exploitations that are based on LCA. The main reason why there are still no requirements is, that simple, hands-on evaluation tools that are tailored for individual user groups still are absent. Without such tools – no demand or requirements. The cooperation with Sollentuna municipality shows this fact obviously since they are demanding a tool they can rely on first. After that they can start posing requirements for the new exploitations in the municipality. More information is given in annex 1.

With respect to LCC as a barrier it was mentioned, that architects will not guarantee for the life cycle costs of their design (since in general they can give guarantees only for their work). Architects' main interests are strongly design related, energy consumption and not to mention LCC aspects play an inferior role in their daily work. But LCC is also seen as attractive for architects as they can provide figures as an added value to their clients.

Concerning an energy performance contracting approach or more general a PPP/PFI approach, a hurdle of broad dissemination is the fact, that only big companies can offer a turn-key project with guarantees for operational costs. In most European countries however the construction firms are dominated by small and medium size companies (see fig. 5-1).

At present LCA of building materials and of construction products is rather in the focus of the construction sector than LCA of buildings.

5.2.2 Summary table on the present use of LCA in the countries

In the table 5-1 a summary of all answers to question 2 of the questionnaire (see annex 1 and 2) is given. The respondents were asked to give information on their company's or institution's and the sector's use of LCA/LCC. The leftmost column specifies the actor (or group of actors) who could use LCA (or LCTh life cycle thinking) for their business. In the next column the life cycle stages of a building or a construction work are listed each actor's work is concerned with. The respondents should specify which life cycle stages of the building/construction would be most relevant for the actor. The life cycle stages were:

- Manufacturing of building products (raw material acquisition and processing, transports, manufacturing processes)
- Transport to building site and construction
- Interior: painting, flooring, "fixtures and fittings"
- Operation and use, servicing and maintenance
- End of use of the building: disassembly and disposal (including transport)

The level of detail appropriate for the actor should also be specified. It was pre-described as:

- No LCA, life cycle thinking only
- Simplified with respect either-or/and

  a) to the input data (e.g. estimated or representative of commonly used materials or processes),

  b) to the "modelling" (e.g. qualitative),

  c) to the building (e.g. covering only major elements of the building like the structure, or a very detailed description)

  d) to the output (only few categories or single score indicator),

  e) to the user interface

  f) other

- Detailed, including all materials and flows during the buildings life cycle, in specific considering the use phase and resource consumption within the use phase of the building, data collection on the whole building

	Life cycle stages of building/ construction important for the actor	Level of detail of LCA appropriate for actor	Relevance of LCC of building/construction for actor	Fields of business which could profit from LCA	Barriers concerning LCA
Producer of building products (either big / SME, national / internat.)	Manufacturing of building products, but also use phase of building (in specific servicing&maintenance) and end of life	Different opinions: simplified vs. detailed	low; but if product saves energy: medium	-Improve the manufacturing process, -reduce environmental impacts, -marketing activities (information about product quality, branding,..), -eco-label	- Complicated methodology - Additional costs for LCA studies - Results might be negative for product - Low demand (but this is changing) - Lack of technical experts in LCA - Lack of interest
Producer of prefabricated homes	All stages, in any case manufacturing and transport to building site	Simplified, use could be detailed	low to medium	Same as above. In addition: Improve construction process, assistance with selection of materials or products. Specially important: market shares might rise (eco-label)	- Lack of interest, resources - Users do not usually appreciate the effort to achieve a low impact building - Lack of access to simplified tools - No or only few requirements by law&subsidies
Client: investor	Manufacturing and use; but all other stages also relevant	Life cycle thinking is sufficient, certification	medium	Marketing and possibilities for new market segments	- No or only few requirements by law&subsidies - Lack of interest of most tenants - Lack of awareness of relation between value and green building - No benefits are seen for lower impacts - Additional costs for LCA studies - Missing of standards (norms) - Comparability of LCA results
Client: own use, also public administration	Most important is use; manufacturing is next, then interior parts (paint, floorings) and end of life	Simplified; for manufacturing life cycle thinking may be enough	high	- Lower life cycle costs, - better management of e.g. energy and water saving, -better long-term perspective decisions on investments	- Lack of awareness and knowledge on LCA - Users do not usually appreciate the effort to achieve a low impact building, - Missing of standards (norms) - Lack of specialists offering LCA
Architect, consultant, engineer	All stages	Rather simplified (use could be detailed, end of life: life cycle thinking is enough, else: simplified)	depends on conditions (low–medium–high)	- Reach targets set by local authorities or client, -better design solutions, - demonstration buildings, - inform client	- Lack of legal requirements - No demand by clients, targets - Lack of awareness&knowledge - Complexity, no simple tools - LCA often is a voluntary, unpaid work - Missing of standards (norms)
Construction company	Most important transport to building site, less: manufacturing	life cycle thinking or simplified	low to medium (transport)	- Marketing activities&competitive advantages. - Design or refurbishment of demonstration buildings. -Selection of architectural solutions and cheeper solutions.	- Lack of requirements (law, clients, etc.) - Complexity and costs - Lack of specialists
(Local) authority, public	All stages, in specific also end of life	Simplified	low to medium	- Raising awareness, - implementation of targets (European or national), - demonstration buildings. - Tools for giving building permits, land assignments, architectural competitions, urban developments. - System perspective on local and regional developments.	- Lack of knowledge, perception of LCA as a method of product system level - Lack of technical experts within institution - Lack of access to simplified and trustworthy tools - Lack of standardisation and comparability
Research Center, University, LCA specialist (construction related)	All stages	Full; but parts may be simplified.	medium or high	- Research and training purposes - Dissemination - Provide LCA tools - Elaborate building concepts	- Lack of data from the industry - Lack of contributions from public sides (national) - Lack of funding - Little demand for scientific LCA studies by the building sector - Certification business as competitor

Table 5-1: Summary of answers of important life cycle stages and LCA and LCC for the actors in the building and construction sector.

As a conclusion it can be stated that all life cycle stages are relevant in practice. Manufacturing of products and use (including maintenance) are important for all actors in the building sector; other life cycle stages vary in importance, e.g. transport is an issue for construction companies, interior materials and products are interesting for clients who want to use the building for themselves, end of life is important for local authorities, but also for producers and clients.

On the whole all respondents said that in practice a simplified LCA will be adequate; simplified with respect to the input data, to the modelling and the output (only few categories or a single score will be sufficient for the majority).

The attractiveness of LCC seems to be quite varying. In general it is rather high for clients (own use), for consultants and specialists and for energy consuming/ generating processes, but the perception of the respondents varies.

The fields of business for each actor group are in all countries the same, as given in the table 5-1.

Barriers are more country-specific. Whereas in some countries still methodological problems or lack of knowledge are seen foremost, other countries address missing data bases. Complexity and awareness are mentioned for many actors in almost all countries.

5.2.3 Tools used in practice for building/construction assessment

	First tool	**Alternative tools**
Austria	**Ecosoft** Developed and distributed by IBO, Austrian Institute for Healthy and Ecological Building, www.ibo.at With national database from IBO, adapted from ECOINVENT Calculation method in line with SimaPro/CML baseline 2001 Building materials from cradle to gate, no transport to site, but service life time of elements considered, no use phase, no end of life szenario.	Subsidy schemes: OI3-Index (derived from Ecosoft) Research/Professionals: also use SimaPro, LEGEP Building assessment schemes: Total quality (www.arge-tq.at), klima:aktiv Haus (derived from TQ, with emphasis on energy use)
Bulgaria	-	Energy certification: E-TOOL, Key Factor The data base for these tools includes only entries relevant for energy certification

France	**ELODIE** with INES database: does not include use phase **EQUER**: simplified life cycle simulation tool with contextualized Ecoinvent data	There are some widely used or relevant in practice by the actors to provide information on the building downstream or to the client or to the public, e.g. building assessment schemes, energy certificate, etc.: 3CL Energy certificate with annual balance COMFIE dynamic building simulation software
Germany	**GABI** **LEGEB**	EPIQR Energy Performance Certificate (Energieausweis) ecopro
Hungary	-	Building energy certificate calculations EnergyPlus for buildg simulation
Spain	**SimaPro** **GABI** Both with general Ecoinvent or IVAM database National database: ITEC database (Catalonia Institute of Construction Technology) www.itec.es/nouBedec.e/presentaciobedec.aspx.	CENER tool (National Renewable Energies Centre) : environmental quality guarantee that involves an energy consumption analysis and a life cycle assessment of the construction materials with own software. Energy certification: CALENER VYP (for residential or small commercial buildings), CALENER GT (for medium and large tertiary buildings) Basque Country tool: guide for sustainable building containing an extensive catalogue of good environment practice in the construction sector applied throughout all its life cycle General: EnergyPlus, Design Builder, Ecotect.

Sweden	**Environmental Load profile** ELP, is used by the City of Stockholm, e.g. in Hammarby sjöstad **Anavitor** (www.anavitor.se) is a commercially available LCA tool. It is used to generate climate declarations for all buildings of NCC, a property developer.	Building products: Byggvarubedömningen - tool focused on hazardous contents but includes a life cycle thinking in the assessment. Criteria document at: http://www.byggvarubedomningen.se/documents/public/bedomningskriterier/Byggvarubedomningencriteria090528english.pdf Building assessment systems: Miljöklassad byggnad, Miljöstatus Indoor air quality assessment: MIBB, P-märkning, EcoEffect

Table 5-2: Tools used in (some) European countries for building and construction assessment in practice.

5.2.4 Conclusions concerning the European situation of LCA approaches in construction practice

In all countries the use of LCA is still rather limited. In some countries the project team predicts a progressing importance. In France the future version of HQE label will also foster LCA approaches. It is supported by the national "Grenelle" environmental policy and its forum. In Germany, the government aims at providing LCA in the building construction practice. At the moment LCA is only used for designated sustainable building projects in Germany. In Spain, LCA studies applied to buildings are mainly carried out by R&D centres, universities and some specialized consultants. Only in some specific buildings, a company or a local authority (e.g. a City Council) could require the development of a LCA study. In such cases, this study is sometimes developed by the building designer (architect/engineer), but usually it is subcontracted to a specialized consultant. In Sweden case studies are performed by university institutes and by consultants. In all other countries LCA is still very rudimentary. With the broader diffusion of passive houses and of climate certifications LCA will become more important.

Another important driver for LCA or LCTh is procurement guidelines. In Sweden national guidelines for environmental construction are currently developed. They will be used as a procurement tool and will include elements of life cycle thinking.

Dissemination and LCA platforms:

In the Eastern European countries dissemination of LCA proceeds by the participation in EU research projects like LCCA or ENSLIC (Bulgaria, Hungary). Centred around these projects there evolves mostly a scientific discussion. Sometimes also training sessions of interested people in practice are organised. In Hungary, a national LCA platform was founded in 2007, which has members from many different fields. LCA conferences are organised annually (www.lcacenter.hu Magyar életciklus-elemzök szakmai Egyesülete).

In France, a LCA platform is organized by the energy and environment agency, but it is not specialised in buildings.

In Germany the “Netzwerk Lebenszyklusdaten” is the most influential LCA platform, but there are some more networks (www.netzwerk-lebenszyklusdaten.de)

In Spain there are 2 thematic network related to life cycle assessment: “Spanish LCA Thematic Network” (www.usc.es/biogrup/redciclovida.htm) and “Catalan Thematic Network for LCA” (www.acv.cat). The aim of these networks is to facilitate the contact and exchange of opinions and research works within a framework of collaboration between agencies, institutions and companies interested in knowledge and application of Life Cycle Assessment.

Furthermore a national project is funded on the analysis of energy and emissions during extraction and manufacture of materials (coordinator: www.imat.cat) and another one is proposed for a database (coordinator: CIRCE).

- “Spanish LCA Thematic Network” is coordinated by Prof. Gumersindo Feijoo, University of Santiago de Compostela - School of Engineering - Department of Chemical Engineering; +34.981.563.100; Gumersindo.feijoo@usc.es
- “Catalan Thematic Network for LCA” is coordinated by Prof. Joan Rieradevall, Universitat Autònoma de Barcelona - Department of Chemical Engineering; +34.93.581.37.49 Joan.Rieradevall@uab.cat

In Sweden LCA in the building and construction sector is closely linked to calculations with the tools ELP (was used by the City of Stockholm) and EcoEffect (research project) and work done by Martin Erlandsson at IVL (Swedish environmental research institute). Also some industry branch organisations are working with LCA in Sweden.

Barriers

Lack of awareness is one of the major barriers, mentioned by all partners. Not enough clients presently integrate environmental targets in building programming. The other barrier is lack of requirements in the legislation. So, LCA is an “extra” work, for the expert. Knowledge of the LCA methodology is limited to some specialists. Architects, engineers, urban planners, property developers and clients happen to have heard about LCA but don’t know what the benefits are. There is neither an economical incentive nor requirements by law nor a tradition for LCA.

LCA is known to be complex and costly caused by the specialized tools and the amount of information needed:

There is still the barrier that due to the various sources (different regions, producers or countries) of materials the data base is actually not very reliable. In addition, the uncertainties in the application of the LCA methodology to buildings can lead to different results and interpretations. Further research and subsequent stakeholder processes will be necessary to agree on key questions like the functional unit, the system boundaries, appropriate data and standard situations, a standardized impact matrix, etc.

Simplified versions of LCA tools would be needed that also are more adapted or adaptable to individual users. The best option would probably be if it was possible to integrate an LCA-module to the tools already used for instance by architects.

Summary of barriers:

- Limited customer demand
- Limited knowledge and competence
- Limited experience of usefulness
- Lack of simplified and easy-to-use tools
- No easy short cuts for acquiring simplified input data
- Lack of accessible and consensus data for calculations

Suggestions to foster a broader uptake of LCA in practice

The following suggestions were extracted from the experts' interviews and were discussed in detail by the LoRe-project group. They also serve as a starting point/ an input for the other workpackages of the LoRe-project.

- Integration of LCA issues in future revisions of the Directive on Energy Performance in Buildings (EPBD):
  The aim should be to include LCA issues in the energy certification procedures. To be practical not more than 3 to max. 5 indicators should be considered. It has to be clarified which parts of the building will contribute to the calculation and which life cycle stages will be considered. There is an example of the Austrian Wohnbauförderung (housing subsidy scheme). All provincial schemes relate to the "OI3-Index" comprising the GWP, the AP and the PEI of the façade materials of the building at hand from "cradle to gate". This has arisen some critics – in future also the building materials of the cellar will be part of the calculation.
  As a first step we suggest a test on a broader scale. Further research requirements and adequate settings and means (within a research action, which nations, test building(s) or case studies, barriers) have to be considered in the next workpackages.

- Development of simplified LCA-guidelines or of simplified tools to facilitate the stakeholders' use (architects, engineers, urban designers, property developers, etc) of LCA in buildings:
  Stakeholders have different purposes why they could use LCA and/or LCC-calculations. Guidelines have to reflect the main scopes and the main use areas of the addressee as well as its "language"/terms. The ILCD handbook distinguishes 3 basic situations for LCA studies according to the 3 main types of questions that are

addressed within the study[26]. An application to the buildings and construction sector thus gives a differentiation between LCA giving:
- micro-level decision support on building products (materials and components), on buildings and on single construction projects (situation A),
- meso/macro-level strategies, like certification and policy options (situation B),
- accounting information and documentation, which is used for certification and for EPDs (situation C).
ILCD sets the rules and gives guidance for these situations, e.g. with respect to data acquisition and to LCI modelling which allow to conclude how to deal with simplifications or lack of accuracy.
Based on the results of WP3 further suggestions will be considered in WP 4.

- Adaptation and harmonization of the methodology and of existing inventory databases for building processes and materials to specific aspects of the building industry in each country:
  The LoRe-project tackles these requests in specific within the WP 3. The WP 3 will define further research needs. WP 2 will come up with policy recommendations (deliverable D2.4).

- Development of awareness raising activities for audience actor groups to highlight the importance of the life cycle of a building:
  It is essential to show clearly the influence of the building design in the building energy consumption (and therefore the building operational costs) throughout the whole span life. The main audience groups are national institutions, local authorities, architects, building owners and building occupants (users). Campaigns have to be tailored to achieve an optimal impact. Other awareness raising measurements like case studies. Many members of the mentioned actor or audience groups are not interested in the detailed numbers LCA is providing but want a simple guidance or solution that they can take over.

- In specific, dissemination among municipalities and owners of large building stock (e.g. social housing, public buildings…), promoting the integration of environmental targets in building programmes could be promising actions. Integration could work especially for green (public) procurement.

- Development of specialized training activities for all stakeholders about the application of LCA in buildings is partly the objective of LoRe-LCA WP 6. It is adequate to emphasis courses on universities as raising awareness about the possibilities that LCA provides should start with multipliers like teachers.

- Subsidy systems could play an important role if credits for the use of LCA would be given. Strategies for subsidy systems often plan a gradually tightening of the requirements in specific if the budget is decreased. LCA can be argued convincingly to achieve acceptance. A pre-condition is the development of a method to set targets

[26] European Commission/ Joint research center, institute for environment and sustainability: ILCD Handbook (International reference life cycle data system). General guide for Life cycle assessment – detailed guidance. 1st edition 2010

and to document the calculations. The stakeholders would not be interested to give credits for only performing a LCA calculation. Further suggestions have to go into details of each subsidy system.

Examples for the adoption of LCA in practice

5.3 *"Details for Passive Houses", Austria*

Passivhaus-Bauteilkatalog | Details for Passive Houses
Ökologisch bewertete Konstruktionen | A Catalogue of Ecologically Rated Constructions

IBO – Österreichisches Institut für Baubiologie und -ökologie (Hrsg.)
3. Aufl., 2009, X, 347 S., Springer

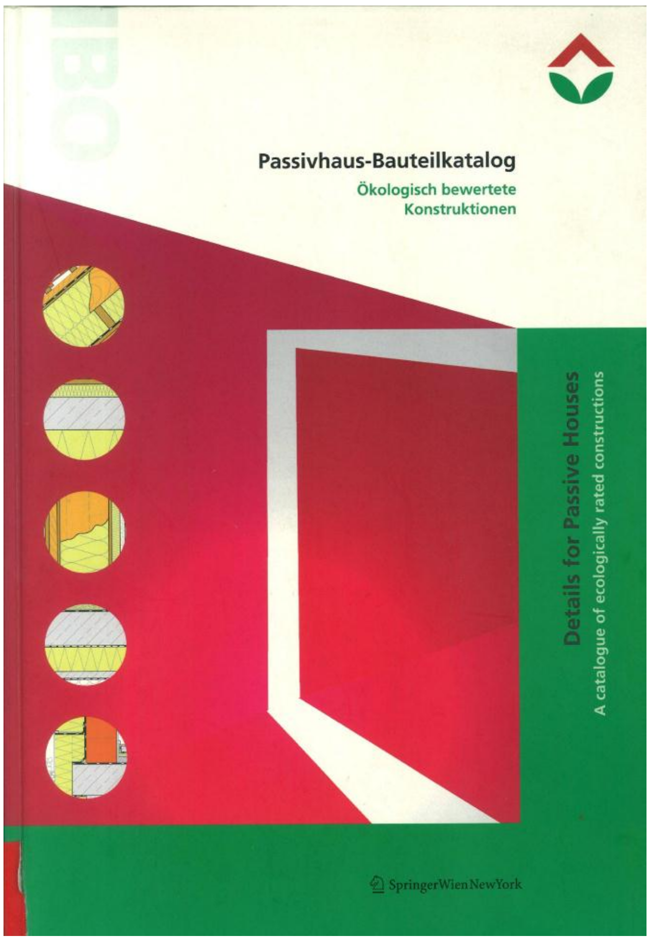


Fig. 6-1: Titel of "Details for Passive Houses"

The first edition of the catalogue of ecological building elements appeared in German in 1999, and soon became an unrivalled classic in its field due to the obvious need for a collection of ecological evaluations, practiced constructional guidance and indicators with regard to the physics involved. For the second edition, the publicised construction solutions now conform to passive house standards and the ecological evaluation is brought up-to-date and presented more clearly.

Planners, architects and commissioners are thus given reliable construction details for the passive house standard, criteria for the proof of ecologically optimized planning, information on building materials, tender criteria and, of course, a competent work of reference. The third edition provides minor corrections.

Target audience: Architects, planner, developer, engineers

Key-words: Building Physics, Catalogue, Ecological, Passiv House Standard

5.3.1 Addressed subjects

The main part of the catalogue is a collection of construction solutions (cross-sections and connection details). Commonly used building components like windows, or layered structures like plaster insulation facades are presented with detailed information allowing for ecological comparison of variants. A list of building materials with their properties and environmental impacts (based on LCA CML 2001) form the last part (and the basis) of the catalogue.

The standard cross-sections and connection details are sized to meet passive house requirements (U-value, airtightness, safe moisture behaviour, etc.). An alternative ecologically favorable solution is compared to the standard variant.

The ecological profile of the two solutions is comprised of the GWP (100a), the acidification potential and the non-renewable primary energy content (cradle to gate). The service life time of different materials and components is taken into account and is normalized to 100 years. A qualitative description illustrates effects on human health and eco-toxicity. Special attention deserves the assessment of recycling /disposal. A semi-quantitative evaluation method has been developed by IBO to account for the end of life of a construction solution. 3 characteristic values are given for its rating:

- the Disposal index, rated from 1 to 5 based on the expertise of the editors (IBO). The Disposal index is also shown disaggregated into all materials used („weighted waste volume“)
- the waste fractions, divided into organic/mineral/metallic and providing better ratings for solutions made of primarily of one fraction
- the number of layers considering fastening materials, primers, reinforcement, etc.

In the Disposal index are entering:

- the accruing volume to be disposed of for each material used in the construction solution,
- the disposal rating of each material used; it is given as a number (1 to 5), based on the expertise of IBO, considering the current disposal procedure
- the utilisation potential of each material; given as a number (1 to 5), based on the expertise of IBO, considering the (theoretical) utilisation potential with best economic and technical framework conditions

A technical description is included for all construction solutions and building components. Checklist information is provided on the suitability, on requirements during construction and on maintenance.

5.3.2 Example of an ecologically rated construction

Fig 6-2: Reinforced concrete outer wall with insulation system and alternative (corc insulation) – information in the "Details for Passive Houses":

5.4 Application of LCA in the design: French office building with ¼ environmental impacts

In a building programme regarding the construction of a tertiary building in the South of France, a client required to divide by 4 the main environmental impacts of this building compared to a standard construction. LCA has been used in order to help the design team answering this requirement.

In the following the considerations concerning the basis of comparison (functional unit), the appropriate system boundaries in general and the criteria of the environmental load profile are outlined. A comprehensive analysis of these topics – in specific detailed for energy, transport, recycling, building materials and domestic waste – are contained in annex 3. Also the results of a case study in France are presented there.

5.4.1 Definition of the functional unit

The functional unit has to be defined so that the compared design alternatives provide the same services, over a similar duration.

We consider as the functional unit the whole building, placed in the specified site and planned for the required use (number of offices, meeting room etc.). This building is assumed comfortable and healthy. Its comfort is defined by a given set point temperature (possibly varying in the time), for heating and if needed for air conditioning, and by sufficient illumination, ventilation and noise protection. A sufficient inside air quality is necessary for sanitary reasons. Also a unit of heated area (one m^2) can be used as functional unit under the same conditions as above. This will then allow the comparison of the project with a standard or best practice ratio on a homogeneous basis.

5.4.2 System boundaries

The system boundaries define which fluxes (e.g. materials and energy used, emissions) are taken into consideration and if the impacts due to infrastructure (construction, maintenance,...) are assigned to the studied system in a certain proportion.

Processes could take place inside or outside a building. We take into account direct flux caused by external processes (e.g. impacts related to the incineration of materials), but the effects created by making available their infrastructure are in general negligible (e.g. the impacts corresponding to the construction of the incinerator are negligible compared to the impact of the combustion process over the whole service life of the equipment). External processes are for example the fabrication of building components, their transport and recycling processes and waste treatment. Daily transport of occupants and urban waste processing may be included according to the purpose of the study, e.g. if differences between building sites and the possibility of sorting urban waste is studied. But this is not the case in the present study.

For processes which could also be localised in a building (e.g. water treatment) making their infrastructure available is taken into account. This allows a comparison between an external system and a system integrated in the building, for which the construction impact is accounted for. This approach is applied to energy production and water processing. Thus we can study local electricity production by photovoltaic, solar space heating, passive cooling, reuse of grey water, rain water collection, etc. An example of this approach is the production of domestic hot water which can be done either by using a solar collector or a fossil combustion process. All the fabrication processes of the collector are attributed to the building, as well as its maintenance and dismantling. This represents the infrastructure for the used solar energy. Therefore, to be homogeneous when comparing both systems, the infrastructure of the used energy for hot water production by fossil combustion (for example for fuel oil, oil production, transport and refinery) has also to be taken into account.

5.4.3 Environmental profile

The first quantitative output of the environmental assessment is an inventory. It contains usually a large amount of data, up to a few hundreds of substances. Comparisons between products are hardly possible by using such inventories. Hence, data is usually aggregated on environmental themes in order to present the final output under the form of an environmental profile. The definition of the profile considered here (cf. table 1) is partly based on a classification method published by CML (Heijungs, 1992). For some of the themes (e.g. energy or water consumption) an absolute value is calculated. On the other hand, themes like global warming or acidification can only be assessed by a potential, expressed as an equivalent quantity of a reference substance (e.g. kg CO_2 for global warming). The list of environmental themes and aggregation methods is still in evolution: e.g. the use of damage oriented indicators is being studied.

Table 6-1: Environmental indicators considered:

environmental theme	**Profile name**	**unit**
energy consumption	ENERGY	MJ
water consumption	WATER	m^3
depletion of abiotic resources	RESOURCES	10^{-9}(1/1 billion), dimensionless, calculated by dividing used resources by known resources
waste creation	WASTE	tons
radioactive waste creation	RAD-WASTE	dm^3
global warming	GWP100	ton CO_2 equivalent
depletion of the ozone layer	ODP	kg CFC-11 equivalent
acidification	ACIDIFICA-TION	kg SO_2 equivalent
eutrophication	EUTROPHI-CATION.	kg PO_4^{3-} equivalent
aquatic ecotoxicity	ECOTOX-W	m^3 of polluted water
human toxicity	HUMAN-TOX	Kg, human weight

photochemical oxidant formation	O_3-SMOG	kg C_2H_4 equivalent
malodorous air	ODOUR	m^3 of contaminated air (ammonia is used as a reference)

5.4.4 Limits of the approach

There are still many uncertainties and limits to the present state of the art of LCA. The uncertainties concern both the data (inventories) and indicators: for instance, the global warming potential (GWP) of other gases than CO_2 is known with 35% uncertainty (IPCC, 1994). Indicators related to human or eco-toxicity are doubtful because the location of the emissions is not considered: air pollution inside buildings might have a much larger effect than diluted external emissions. Also, the processes occurring at the end of the building life cycle are difficult to foresee, particularly because buildings are generally long lasting (though it may be assumed that mixing materials -concrete with polystyrene or wood for instance- will make the future waste management more difficult). Variation of the physical properties of materials in time are not considered (e.g. thermal conductivity of insulation materials).

The method developed is not assessing internal environmental quality (e.g. air quality, acoustic or visual comfort), but the related constraints have to be respected (cf. definition of the functional unit). Accidental risk analysis is not included as we assumed that this topic is accounted for in safety and work legislation. Esthetical aspects are neither included.

The energy loads for heating and if needed for air conditioning during a building's use phase have to be calculated. Thus we created links between a thermal simulation tool, COMFIE, and the described environmental evaluation method. We use simulation rather then correlation so that solar heating and passive cooling can be evaluated on a dynamic basis, accounting for energy collection, storage and distribution, and allowing the assessment of thermal comfort.

Coupling LCA and energy calculations simplifies the use of the tool, and makes the comparison of design alternatives easier. The heating/cooling loads calculated by COMFIE are integrated as input of LCA, together with data from libraries concerning environmental impacts of materials, and other parameters like the water consumption and waste generation in the use phase.

The different phases of a building life cycle are considered (figure 6-3).

The output of the method is an eco-profile including the different impact indicators (see table above). These indicators are given either for the different phases or for different alternatives or projects.

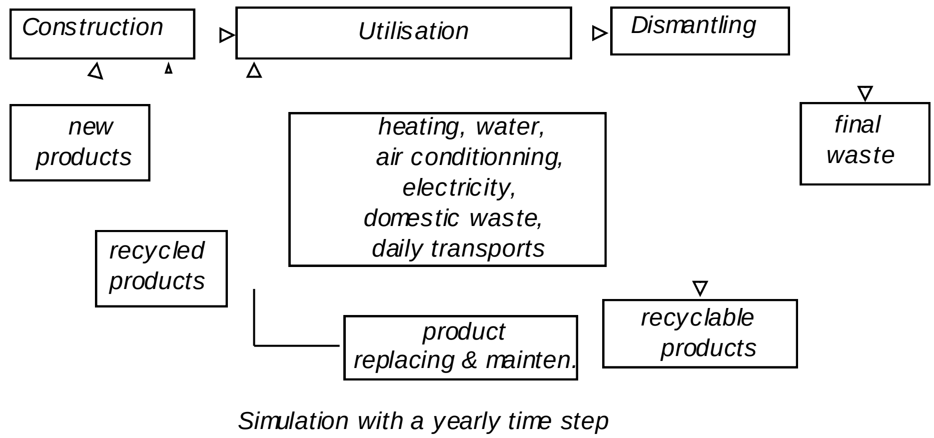


Fig. 6-3: Principle for calculating the inventory of the whole building

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Appendix 1
Questionnaire to partners

LoRE-LCA
("Low resource consumption buildings and constructions by use of LCA in design and decision making")

Questionnaire for project partner (Version 2)

Template to collect information for:

- Report on use of LCA and on general information concerning life cycle approaches in practice

- Report on use of EPD in practice

of WP 2 ("LCA use and barriers")

1.) Please describe the current situation of the construction practice in your country (give information and your opinion on the following topics, please indicate if you cannot comment on topics/subtopics)

Where could LCA tools help in construction practice[1]?

Please give:
- Your opinion
- Different perspectives (of construction companies, architects, clients, others)

Are there any requirements (to be <u>proven or documented</u>) that have to be met and that are related to life cycle thinking (or LCA, LCC)?

Either in building acts, in building permit or subsidy schemes on the one hand or in procurement practice of influential clients on the other hand during the life cycle stages of a building/construction

Please give:
- Information
- Your opinion
- Different perspectives (of construction companies, architects, clients, others)

Consider current/envisaged legislation in the construction sector (products, works and building/construction) concerning life cycle issues.

Examples of life cycle issues are: EPD, CPD/CPR, labelled products, environmental impact assessment, waste management, etc. Is legislative situation perceived as complicated? Who is complaining most?

Please give:
- Information
- Your opinion
- Different perspectives (of construction companies, architects, clients, others)

What are common (formal and informal) ways and types of communication on a building?

Communication and documentation on subjects like e.g. energy consumption, durability of structure and materials, disassembly, construction related transport.

Please give:

[1] Please mind that we are also talking about non building related issues (highway and street construction; bridge, tunnel & elevated highway; water, sewer and utility lines)

LoRE-LCA
("Low resource consumption buildings and constructions by use of LCA in design and decision making")

Questionnaire for project partner (Version 2)

- Information
- Your opinion
- Different perspectives (of construction companies, architects, clients, others)

Regarding the operational costs of a building/construction: how important is it in practice?
Are there requirements by regulations, subsidies, clients, etc. in your country? E.g. maximum heating energy consumption, maximum cleaning costs, etc.

Please give:
- Information
- Your opinion
- Different perspectives (of construction companies, architects, clients, others)

Regarding the working life/durability of buildings/constructions and its components: how important is it in practice?
Are there requirements by regulations, subsidies, clients, etc. in your country? E.g. waste management, etc.

Please give:
- Information
- Your opinion
- Different perspectives (of construction companies, architects, clients, others)

2.) Please complete the table below on the present use of LCA in your country

- What are relevant user-groups of LCA (in a general meaning: life cycle thinking)?
- What for (field of application, business reasons) does he/she need it?
- Which life cycle stages **of the building/construction** should be covered:
    - Manufacturing of building products (raw material acquisition and processing, transports, manufacturing processes)
    - Transport to building site and construction
    - Interior: painting, flooring, "fixtures and fittings"
    - Operation and use, servicing and maintenance
    - End of use of the building: disassembly and disposal (including transport)
- Level of detail required:
    - No LCA, life cycle thinking only.
    - Simplified with respect either-or/and
      - a) to the input data (e.g. estimated or representative of commonly used materials or processes),
      - b) to the "modelling" (e.g. qualitative),
      - c) to the building/construction (e.g. covering only parts of the building like the construction materials or the thermal insulation of the façade
      - d) to the output (only few categories or single score indicator),
      - e) to the user interface
      - f) other (Which?)

      Please specify simplification in the table according to these categories!

LoRE-LCA
("Low resource consumption buildings and constructions by use of LCA in design and decision making")

Questionnaire for project partner (Version 2)

- Full/Detailed, including all materials and flows during the building/construction life cycle, in specific considering the use phase and resource consumption within the use phase, data collection on the whole building/construction.

Is there another actor / user group you might highlight? Please add a row to the table then!
If possible, incorporate not-building-related-construction-works, too.

LoRE-LCA
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Questionnaire for project partner (Version 2)

actor / user group	**Life cycle stages of building/ construction important for the actor**	**Level of detail of LCA appropriate for actor (please refer to categories described in the text above)**	**Relevance of LCC of building/construction for actor**	**Fields of business which could profit from LCA**	**Barriers concerning LCA**
Producer of building products (either big / SME, national / internat.)					
Producer of building products (either big / SME, national / internat.)					
Producer of prefabricated homes					
Client: investor					
Client: own use, also public administration					
architect, consultant, engineer					
construction company					
(local) authority, public					
Research Center, University, LCA specialist (construction related)					

LoRE-LCA
("Low resource consumption buildings and constructions by use of LCA in design and decision making")

Questionnaire for project partner (Version 2)

3.) Tools used in practice for building/construction assessment

Best known LCA tool(s) available with national database:

Alternative tools and methods that are widely used or relevant in practice by the actors (see table above) to provide information on the building downstream or to the client or to the public, e.g. building assessment scheme, energy certificate, etc.:

Could you provide a concrete example (to be used as a short case study in the report) too? Please give a header/reference; we will contact you separately.

4.) Your conclusions concerning the national situation

What is the current status of LCA use in practice?

Have there been initiatives to introduce LCA? Are there LCA platforms or networks in your country? (Please provide information)

What barriers (technical, social, economic, by law) do exist in general and in particular concerning the LCA tool you mentioned above?

How could barriers be overcome? Which priorities, which strategies (cooperation with ..., etc.)?

5.) EPD in practice

The ISO-standard 21930 "Sustainability in building construction -- Environmental declaration of building products" sets the criteria for EPDs of building products. But only few EPDs according to this standard are available. Information on products is also published in environmental labels and declarations of products. Reliable information should comply with the ISO-standards 14020 ff[*] on environmental labelling and declarations. Information on a general level is issued in sector specific environmental reports. However, usually it is not possible to relate environmental impacts to certain products then.

What is the current status of environmental information on building/construction products in your country?

What is the number of EPDs available? What other information is available? Who is dealing with environmental information? Are there requirements (of administration etc.) by now?

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[*] ISO-standards 14020 (Environmental labels and declarations -- General principles), 14021 (Environmental labels and declarations -- Self-declared environmental claims - Type II environmental labelling), 14024 (Environmental labels and declarations -- Type I environmental labelling -- Principles and procedures), 14025 (Environmental labels and declarations -- Type III environmental declarations -- Principles and procedures)

LoRE-LCA
("Low resource consumption buildings and constructions by use of LCA in design and decision making")

Questionnaire for project partner (Version 2)

What are prospective activities concerning environmental information on building products?
What are the actors in this field? Are there any programmes?

What are the barriers related to EPDs or to provide EPDs?
What are the actors in this field? Are there any programmes?

Can you provide an example of an EPD of your country?
In your language, for illustrating the report.

For questionnaires you want to send to experts yourself please use: Questionnaire for external experts
Please insert contact data of possible interview partners (IFZ telephone interviews):

Name	**Position and/or function** ***(e.g. research)***	**Company and division**	**Address** ***(Please give phone number and e-mail address!)***	**Field of expertise**	**Knows situation in ... (country)**	**Further remarks** ***(good to know when contacting him/her)***	**Provided by (partner + name)**

Appendix 2
Questionnaire to external experts

LoRE-LCA
("Low resource consumption buildings and constructions by use of LCA in design and decision making")

Questionnaire for external experts

LoRe-LCA ("Low Resource consumption buildings and construction by use of LCA in design and decision making") is a project within the EU-FP 7. **The aim** is to contribute to an increased use of Life cycle analysis (LCA) as a method to gather, analyse, evaluate and document comprehensive information on buildings and constructions. **The specific focus** of LoRe-LCA is on building's resource consumption (water, primary raw materials, energy, land) and waste generation. **This questionnaire** is dedicated to collect and compare various practices of assessing environmental performance of buildings used in different countries. From this evidence should derive:

- Is LCA meaningful and useful for practice in the construction sector,
- What are chances and barriers for a broader uptake of LCA.

Questionnaire

on the use of LCA and EPD in your practice

1.) Please assess the current situation of life cycle assessment in your construction practice

Where could LCA tools help in your construction practice?

Are there any requirements that have to be met and that are related to life cycle thinking (or LCA, LCC[1])?

Either in building acts, in building permits or subsidies or in procurement practice of influential clients during the life cycle stages of a building or of construction works (highways and streets, etc.)

Describe current/envisaged legislation in the construction sector (products, works and building/construction) concerning life cycle issues.

Examples of life cycle issues are: EPD[2], CPD/CPR[3], labelled products, environmental impact assessment, waste management, etc. Is the legislative situation perceived as complicated?

Besides the requirements (mentioned above) are there any other common (formal and informal) ways involving life cycle-information on a building/construction (like documentation or transfer)?

Communication on subjects like e.g. energy consumption, durability of structure and materials, disassembly, construction related transport.

Regarding the operational costs of a building/construction: how important is it in practice?

Are there requirements by regulations, subsidies, clients, etc. in your country? E.g. maximum heating energy consumption, maximum cleaning costs, etc.

Regarding the working life/durability of buildings/constructions and its components: how important is it in practice?

Are there requirements by regulations, subsidies, clients, etc. in your country? E.g. waste management, etc.

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[1] Life Cycle Cost
[2] Environmental Product Declaration
[3] Construction product Directive / Construction Product Regulation

LoRE-LCA
("Low resource consumption buildings and constructions by use of LCA in design and decision making")

Questionnaire for external experts

2.) Please select your row in the table below and insert information on your company's/institution's and sector's use of LCA

Please add a row if none is appropriate.

- Which life cycle stages **of the building/construction** should be covered:
    - Manufacturing of building products (raw material acquisition and processing, transports, manufacturing processes)
    - Transport to building site and construction
    - Interior: painting, flooring, "fixtures and fittings"
    - Operation and use, servicing and maintenance
    - End of use of the building: disassembly and disposal (including transport)
- Level of detail required:
    - No LCA, life cycle thinking only
    - Simplified with respect either-or/and
      - a) to the input data (e.g. estimated or representative of commonly used materials or processes),
      - b) to the "modelling" (e.g. qualitative),
      - c) to the building (e.g. covering only major elements of the building like the structure, or a very detailed description)
      - d) to the output (only few categories or single score indicator),
      - e) to the user interface
      - f) other
    - Detailed, including all materials and flows during the buildings life cycle, in specific considering the use phase and resource consumption within the use phase of the building, data collection on the whole building

Do you know the situation of any other actor / user group? Please complete also these rows or add row.

LoRE-LCA
("Low resource consumption buildings and constructions by use of LCA in design and decision making")

Questionnaire for external experts

actor / user group	**Life cycle stages of building important for the actor**	**Level of detail of LCA appropriate for actor (please refer to categories described in the text above)**	**Relevance of LCC of building for actor**	**Fields of business which could profit from LCA**	**Barriers concerning LCA**
Producer of building products (either big / SME, national / internat.)					
Producer of prefabricated homes					
Client: investor					
Client: own use, also public administration					
architect, consultant, engineer					
construction company					
(local) authority, public					
Research Centre, University and LCA specialist (construction related)					

LoRE-LCA
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Questionnaire for external experts

3.) Tools used in practice for building/construction assessment

Best known LCA tool(s) available with national database:

Alternative tools and methods that are widely used or relevant in practice by the actors (see table above) to provide information on the building downstream or to the client or to the public, e.g. building assessment scheme, energy certificate, etc.:

Could you provide a concrete example (to be used as a short case study in the report), too? Please give a header/reference; we will contact you separately.

4.) Your conclusions concerning the national situation

What is the current status of LCA use in practice?

Have there been initiatives to introduce LCA? Are there LCA platforms or networks in your country? (Please provide information)

What barriers (technical, social, economic, by law) do exist in general and in particular concerning the LCA tool you mentioned above?

How could barriers be overcome? Which priorities, which strategies (cooperation with …, etc.) are needed?

5.) EPD in practice

The ISO-standard 21930 "Sustainability in building construction -- Environmental declaration of building products" sets the criteria for EPDs of building products. But only few EPDs according to this standard are available. Information on products is also published in environmental labels and declarations of products. Reliable information should comply with the ISO-standards 14020 ff[*] on environmental labelling and declarations. Information on a general level is issued in sector specific environmental reports. However, usually it is not possible to relate environmental impacts to certain products then.

What is the current status of environmental information on building/construction products in your country?

How many EPDs are available in your country? Which other information is available? Who is dealing with environmental information? Are there already EPD requirements (of administration etc.) in place by now?

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[*] ISO-standards 14020 (Environmental labels and declarations -- General principles), 14021 (Environmental labels and declarations -- Self-declared environmental claims - Type II environmental labelling), 14024 (Environmental labels and declarations -- Type I environmental labelling -- Principles and procedures), 14025 (Environmental labels and declarations -- Type III environmental declarations -- Principles and procedures)

LoRE-LCA
("Low resource consumption buildings and constructions by use of LCA in design and decision making")

Questionnaire for external experts

What are prospective activities concerning environmental information on building products?
What are the actors in this field? Are there any programmes?

What are the barriers related to EPDs or to provide EPDs?
What are the actors in this field? Are there any programmes?

Can you provide us with a copy (file or hard-copy) of a particular EPD in your country?
In your language, for illustrating the report.

Information on respondent:
Name:

Company/institution and division:

Position and/or function (e.g. research):

E-mail and telephone number:

Field of expertise:

Country:

Date:

Appendix 3
Application of LCA in the design of an office building in France

In a building programme regarding the construction of a tertiary building in the South of France, a client required to divide by 4 the main environmental impacts of this building compared to a standard construction. LCA has been used in order to help the design team answering this requirement.

Definition of the functional unit

The functional unit has to be defined so that the compared design alternatives provide the same services, over a similar duration.

We consider as the functional unit the whole building, placed in the specified site and planned for the required use (number of offices, meeting room etc.). This building is assumed comfortable and healthy. Its comfort is defined by a given set point temperature (possibly varying in the time), for heating and if needed for air conditioning, and by sufficient illumination, ventilation and noise protection. A sufficient inside air quality is necessary for sanitary reasons. Also a unit of heated area (one m2) can be used as functional unit under the same conditions as above. This will then allow the comparison of the project with a standard or best practice ratio on a homogeneous basis.

System boundaries

The system boundaries define which fluxes (e.g. materials and energy used, emissions) are taken into consideration and if the impacts due to infrastructure (construction, maintenance,...) are assigned to the studied system in a certain proportion.

Processes could take place inside or outside a building. We take into account direct flux caused by external processes (e.g. impacts related to the incineration of materials), but the effects created by making available their infrastructure are in general negligible (e.g. the impacts corresponding to the construction of the incinerator are negligible compared to the impact of the combustion process over the whole service life of the equipment). External processes are for example the fabrication of building components, their transport and recycling processes and waste treatment. Daily transport of occupants and urban waste processing may be included according to the purpose of the study, e.g. if differences between building sites and the possibility of sorting urban waste is studied. But this is not the case in the present study.

For processes which could also be localised in a building (e.g. water treatment) making their infrastructure available is taken into account. This allows a comparison between an external system and a system integrated in the building, for which the construction impact is accounted for. This approach is applied to energy production and water processing. Thus we can study local electricity production by photovoltaic, solar space heating, passive cooling, reuse of grey water, rain water collection, etc. An example of this approach is the production of domestic hot water which can be done either by using a solar collector or a fossil combustion process. All the fabrication processes of the collector are attributed to the building, as well as its maintenance and dismantling. This represents the infrastructure for the used solar energy. Therefore, to be homogeneous when comparing both systems, the infrastructure of the used energy for hot water production by fossil combustion (for example for fuel oil, oil production, transport and refinery) has also to be taken into account.

Energy

As the boundaries for the energy processes have already been shown in the above paragraph, only the model of energy recovery for waste incineration is explained here. If waste, either of building components or domestic waste, is burnt in an incinerator its intrinsic energy can be recovered and used for heat generation and/or electricity production. We consider that the avoided impact has to be credited to the building inventory which in all cases (with energy recovery or not) will be charged with the pollution due to waste incineration. Therefore the amount of replaced fuel and its emissions, corresponding to the recovered energy, will be counted negative. Seasonal variations in heat or electricity demand may reduce the efficiency of the energy recovery and should thus be taken into account. Accounting for waste treatment allows the comparison of possible building sites, for instance one with heat recovery and another one with combined heat and power systems.

Transport

We distinguish four means of transport: truck, railway, ship and aircraft. A building component can be transported successively by different means. Building components differ much in density. We propose therefore an approach based on the load of a transport mean. According to the density of a transported good the load is either expressed by the weight or by the volume which can be transported. The inventories for a transport over 1km correspond to a full load. The part attributed to a building component is evaluated by the weight or volume ratio based on the full load.

We suppose that railway carriages, ships and aircrafts will make a one way travel to deliver the goods and will return with other goods. Hence the impacts of the return tour is not accounted for. We suppose also that a truck transports another good at least on a part of its return travel as the haulage firms limit empty tours. Due to this fact, we count only the impacts of half of the return distance.

The daily transport of the building occupants is supposed to be done by car or collective transport (e.g. bus). Average data on the use of the transport types are proposed as default values. They depend on the type of building site (urban, suburban, rural, remote) and the distances to the next transport station, to the working place and to the next shopping centre.

Recycling

Recycling products reduces in general environmental impacts, particularly the use of resources and waste creation. For example, the fabrication of steel from recycled material needs about half the energy used to produce steel from iron ore (Haberstatter, 1992). The former releases as well only about half of CO2 than the later and creates about 280 kg less waste per ton of steel. Concrete can also be mentioned as a relevant example. Its recycling process gives granules which can be used in road construction avoiding the use of other resources, like gravel.

These two examples allow to distinguish two different recycling types for building materials. Steel is an example of a material which after recycling can be reused for the same application. This is called closed loop recycling. In opposite to this, concrete is a material (or more exactly a composition of different materials) which can hardly be reused for the same application. The corresponding recycling process is called downcycling or open loop recycling. It concerns materials which were degraded during their use or recycling process, or compositions where the materials can not be separated.

Reusing a building material is handled like closed loop recycling. We define as reuse a process where a material is not transformed between two cycles, whereas it is transformed temporarily into another state during the recycling process (e.g. melted).

We identified as another recycling aspect the recycling of domestic waste, which will be treated separately.

Building materials

There is a rising demand nowadays that architectonic solutions should favour the use of recycled materials for building construction, including the fabrication of building components. But they should also allow the recycling of building components at the end of their life cycle or after a building's dismantling. The recycling model should thus take both ends into consideration in order to promote also design for dismantling.

The positive effect of recycling, being considered as a negative or avoided impact, can be expressed by the material's recycling inventory I_r minus its new fabrication inventory I_n (which would be counted if there was no recycling) for the recycled part r. This positive effect occurs only once during the life cycle of a material (corresponding to one recycling run). It must therefore not be counted twice, for both fabrication and treatment after use. As recycling should be favoured at the beginning and at the end of a building's life cycle, we decided to share the avoided impact equally between these two phases. Hence, the following equations are applied for theses phases:

$$I_f = I_n + (r_f / 2) \times (I_r - I_n) \qquad (1)$$

$$I_t = i \times I_i + d \times I_d + (r_t / 2) \times (I_r - I_n) \qquad (2)$$

If represents the fabrication inventory, It the treatment after use inventory, Ii the incineration inventory and Id the dumping inventory. The recycled part at the fabrication level is represented by rf whereas rt represents the recycled part at the treatment after use level. For the later, the incinerated part is i and the dumped one is d. Equations (1) and (2) are applied for closed loop recycling processes.

In this case, the recycling and new fabrication inventories I_r and I_n are the same for a material fabrication and treatment after use because the same processes are used. But these processes are not the same for open loop recycling. Nevertheless, equation (1) can be applied for the fabrication of a building material in an open loop recycling process. In this case, I_r represents the recycling inventory of a material becoming after downcycling the building material and I_n represents the new fabrication inventory of the building material. For the treatment after use of the building material the last term of equation (2) has to be replaced because the processes involved are not the same as for fabrication. The term is replaced by $(I_{r'}-I_{n'})$ where $I_{r'}$ represents the recycling process of the building material downcycled to another material and $I_{n'}$ represents the new fabrication process of a material to be replaced by the downcycled building material.

In general, the number of cycles is limited, even in "closed" loop recycling. If n is the maximal number of recycling runs, the maximal recycling rate r_m is n/(n+1). If the average recycling rate for a material of the studied building $(r_f+r_t)/2$, exceeds r_m, then pollution is displaced into another building. A penalty term is thus added to equation (1), depending on the sum of the material's incineration and dumping rates.

This term expresses the impact of the fabrication and treatment after use, related to the recycled part and distributed on the recycling runs. The above defined condition is only applied to closed loop recycling, as there is no theoretical maximal recycling rate in an open loop. The recycling rate in open loops can be limited by downwards applications (e.g. recycled PVC) or upstream production (e.g. gypsum from flue gas treatment in power plants), but we have not considered this aspect in the present step of our work.

Domestic waste

The model for the recycling of building materials, which shares the positive effects of recycling between fabrication and treatment after use, is not used for domestic waste. This is due to the fact that the building sector has no influence on the fabrication of the goods becoming waste. Thus, we consider a fixed inventory If for this fabrication. But decisions can favour the sorting of urban waste and hence reduce the impact of waste treatment. Therefore we decided to attribute completely the avoided impact, due to recycling, to the treatment of urban waste. This leads for this phase to the following equation:

$$I_t = i \times I_i + d \times I_d + r_t \times (I_r - I_{n'}) \qquad (3)$$

I_r represents the inventory of the recycling process of domestic waste and $I_{n'}$ represents the new fabrication inventory of the goods which are replaced by the recycled waste.

Environmental profile

The first quantitative output of the environmental assessment is an inventory. It contains usually a large amount of data, up to a few hundreds of substances. Comparisons between products are hardly possible by using such inventories. Hence, data is usually aggregated on environmental themes in order to present the final output under the form of an environmental profile. The definition of the profile considered here (cf. table) is partly based on a classification method published by CML (Heijungs, 1992). For some of the themes (e.g. energy or water consumption) an absolute value is calculated. On the other hand, themes like global warming or acidification can only be assessed by a potential, expressed as an equivalent quantity of a reference substance (e.g. kg CO_2 for global warming). The list of environmental themes and aggregation methods is still in evolution, e.g. the use of damage oriented indicators is being studied.

Environmental indicators considered

environmental theme	Profile name	unit
energy consumption	ENERGY	MJ
water consumption	WATER	m^3
depletion of abiotic resources	RESOURCES	10^{-9}(1/1 billion), dimensionless, calculated by dividing used resources by known resources
waste creation	WASTE	tons
radioactive waste creation	RAD-WASTE	dm^3
global warming	GWP100	ton CO_2 equivalent
depletion of the ozone layer	ODP	kg CFC-11 equivalent
acidification	ACIDIFICA-TION	kg SO_2 equivalent
eutrophication	EUTROPHI-CATION.	kg PO_4^{3-} equivalent
aquatic ecotoxicity	ECOTOX-W	m^3 of polluted water
human toxicity	HUMAN-TOX	Kg, human weight
photochemical oxidant formation	O_3-SMOG	kg C_2H_4 equivalent
malodorous air	ODOUR	m^3 of contaminated air (ammonia is used as a reference)

Limits of the approach

There are still many uncertainties and limits to the present state of the art of LCA. The uncertainties concern both the data (inventories) and indicators : for instance, the global warming potential (GWP) of other gases than CO_2 is known with 35% uncertainty (IPCC, 1994). Indicators related to human or eco-toxicity are doubtful because the location of the emissions is not considered : air pollution inside buildings might have a much larger effect than diluted external emissions. Also, the processes occurring at the end of the building life cycle are difficult to foresee, particularly because buildings are generally long lasting (though it may be assumed that mixing materials -concrete with polystyrene or wood for instance- will make the future waste management more difficult). Variation of the physical properties of materials in time are not considered (e.g. thermal conductivity of insulation materials).

The tool developed is not assessing internal environmental quality (e.g. air quality, acoustic or visual comfort), but the related constraints have to be respected (cf. definition of the functional unit). Accidental risk analysis is not included as we assumed that this topic is accounted for in safety and work legislation. Esthetical aspects are neither included.

The energy loads for heating and if needed for air conditioning during a building's use phase have to be calculated. Thus we created links between a thermal simulation tool, COMFIE, and the developed environmental evaluation tool. We use simulation rather then correlation so that solar heating and passive cooling can be evaluated on a dynamic basis, accounting for energy collection, storage and distribution, and allowing the assessment of thermal comfort.

Coupling LCA and energy calculations simplifies the use of the tool, and makes the comparison of design alternatives easier. The heating/cooling loads calculated by COMFIE are integrated as input of LCA, together with data from libraries concerning environmental impacts of materials, and other parameters like the water consumption and waste generation in the use phase.

The main classes are the products (building materials and finishes), the components (manufactured set of products like windows, shading devices,...), the subsystems (on-site built set of products and components like walls or zones), the whole building and the building site. A zone is here meant as a thermal zone, i.e. a part of the building with an homogeneous thermal behaviour. It can include several rooms with the same occupancy schedule, orientation, internal heat gains. The whole structure of the thermal model is presented hereunder.

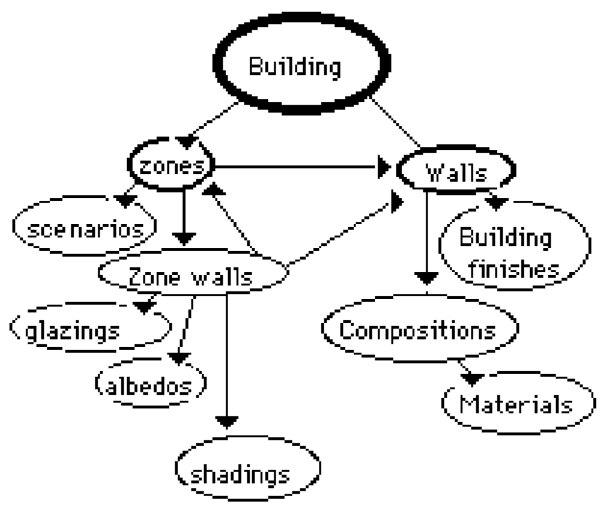

Figure: Building model, structuration of the data

The different phases of a building life cycle are considered (figure hereunder).

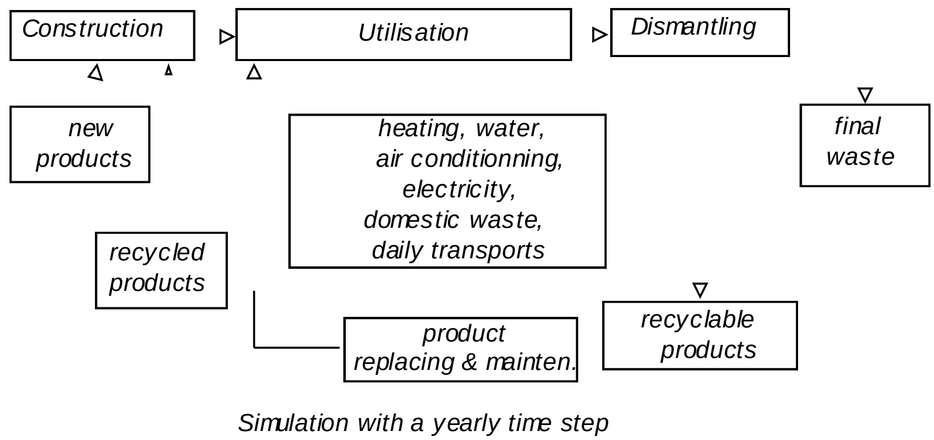

Figure: Principle for calculating the inventory of the whole building

The output of the software is an ecoprofile including the different impact indicators (see table above). These indicators are given either for the different phases or for different alternatives or projects. We have used this last option in this document.

Case study, description of the building

The general shape of the building is a curve from south east to south west, allowing collection of light and solar gains. A south-oriented sunspace is situated in the eastern side of the building. The entrance hall forms a buffer zone in the north facade, see figure hereunder.

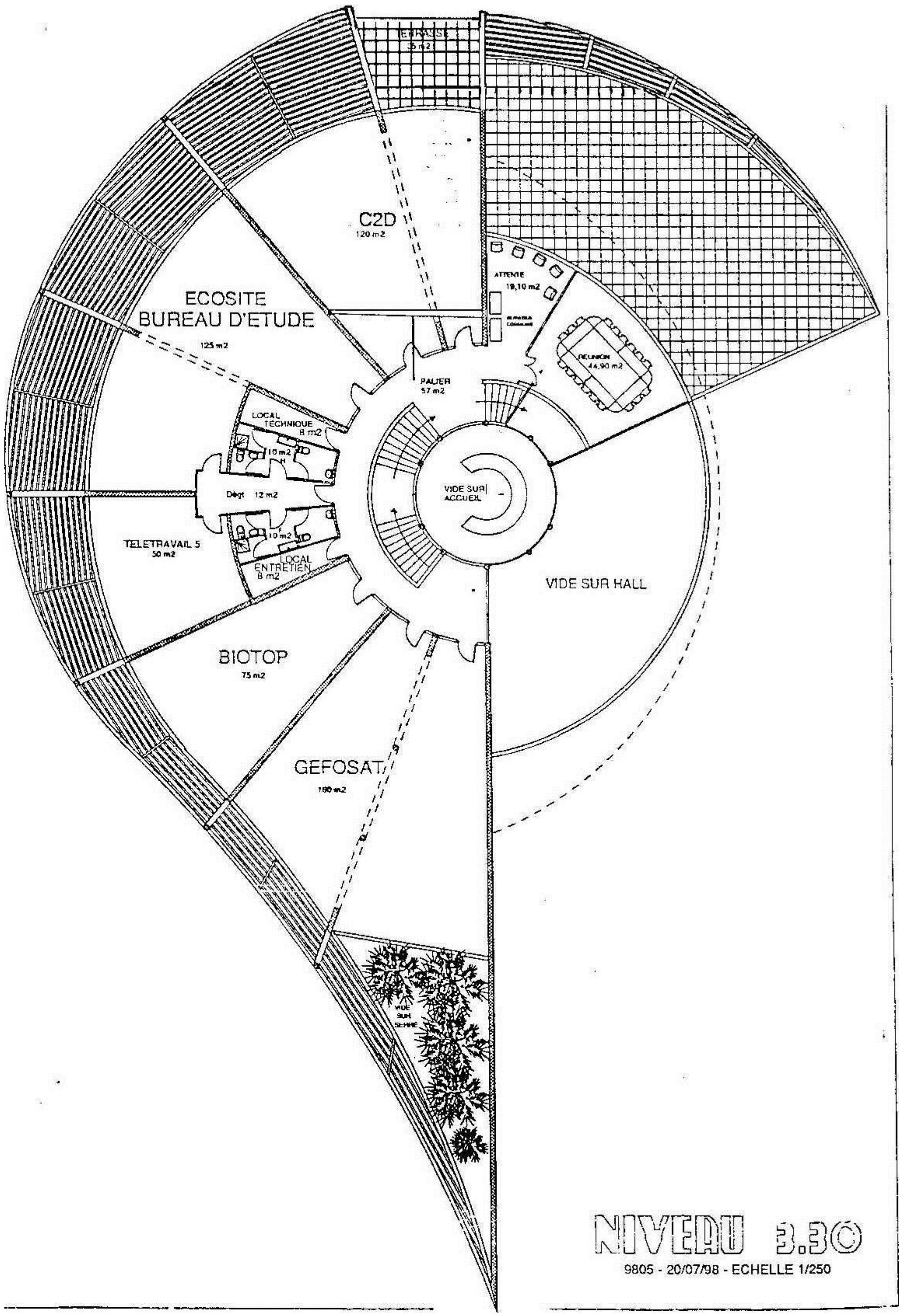

Figure: Plan of the office building "Nautile", Architect : Gilles CHICAUD, Client : SEMABATH, Mèze

The glazed areas (low emissivity double glazing) are protected from summer radiation by large overhangs. A higher ventilation flow rate is considered during night to cool the building : 6 ach, compared to 1 ach during the day in offices. The heating and cooling loads have been calculated using COMFIE and TRNSYS. Both models provided similar results : 2% discrepancy has been found regarding the heating load, 9% for the cooling load. The data input has been performed by two different thermal engineers, and the consistency of both descriptions has been checked only for the heating load calculation.

This project, called "Nautile" has been compared to a typical office building having the same area, concrete walls, internal insulation (8 cm polystyrene), and standard double glazing. The heating and cooling loads are given in the following table.

Case study, energy performance

	Heating load, kWh/year	Cooling load, kWh/year
Reference	68000	93000
Nautile	29000	11000

The building model has been complemented with data about the fabrication of materials. The north oriented facade, where thermal mass is not needed, is made of wood. As it can be seen in the following graph, the indicators are much lower for the Nautile project than for the reference building, i.e. the potential environmental impacts are reduced.

It is interesting to note that in this case, such a bioclimatic design allows a reduction by a factor 2.5 of various indicators (use of primary energy, GWP, radioactive waste,…). The legend of the axes in next figure correspond to the names given in the indicators table.

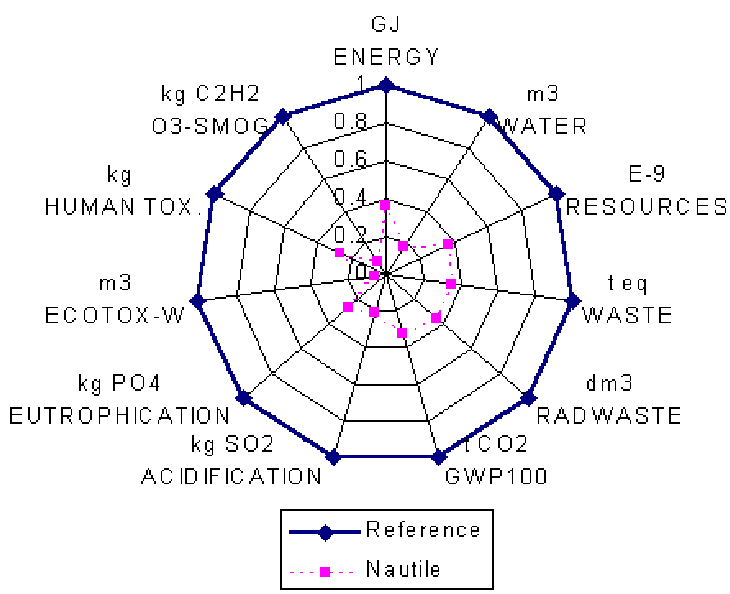

Figure: Example comparative eco-profile

Some ratios per square meter have been derived.

Case study, environmental performance

Indicator	Nautile	Reference
Primary energy (MJ/m^2/year)	520	1720
Use of materials (kg/m^2/year)	5.7	15.5
GWP (kg CO_2/m^2/year)	6.8	18.4
Acidification (kg SO_2/m^2/year)	0.03	0.1
Smog (kg C_2H_4/m^2/year)	0.006	0.06

Adobe was compared to concrete in the internal walls of the sunspace. The conductivity of this material is a little lower than for concrete. The heat losses in the sunspace are thus lower and globally, the heating load of the building is reduced by 500 kWh. The fabrication impacts of adobe, being produced locally, are lower than for concrete. Nevertheless, the difference on the global life cycle indicators is small (a few percents). Reduced heating load (by 2%), renewability of the material and lower emissions during the fabrication and demolition are arguments in favour of adobe in this case.

Concerning insulation materials, rock wool has been compared with recycled cellulose flocks. We assume that the conductivity of both materials is equivalent (according to data from the manufacturers) and remains constant during the service life. If cellulose flocks need to be inserted in wooden frames, these frames induce thermal bridges and the heating load could be increased by 7%. On the other hand, wooden frames store CO_2 at the production step (photosynthesis). The release of CO_2 at the end of life is smaller, depending on the process (incineration, landfill, etc.). Using this approach, the use of wood could reduce the global GWP by 8%. But other authors consider a neutral CO_2 balance for the whole life cycle of wood. End of life processes, e.g. energy recovery from wood incineration, are difficult to foresee. We could assume a certain probability of landfill and incineration, and calculate probabilistic CO_2 emissions. Such a probabilistic assessment could be generalised to other uncertain parameters.

The inventories for the fabrication of paper flocks and rock wool are similar because the density of paper flocks is around 4 times higher, according to the information in the database we used. Another alternative tested is to insulate the internal wall of the sunspace. This reduced the heating load by 10% and the GWP by 5%. Consequences on thermal comfort in the sunspace should be examined, according to the use of this space.

The results concerning the comparison of materials (adobe versus concrete, rock wool versus paper flocks) should be validated by checking the corresponding inventories (production and end of life) with the concerned manufacturers. An approach using probabilistic scenarios could be used e.g. for the management of demolition waste at end of life, particularly concerning wood.

Conclusions

The main limits of the present knowledge concern the environmental data on material fabrication, the environmental indicators, the durability of the materials and possible variation of their performances, the processes which will occur in a far future (renovation, demolition in e.g. 100 years). Despite of these questions, some trends can be identified and sensitivity studies provide information on the most important parameters. The overall conclusion is a confirmation of the relevance of energy efficiency and use of solar gains in buildings, while paying attention to summer comfort and reduction of cooling loads. Renewable materials (wood, renewable or recycled insulation) may also contribute to reduce some impacts like global warming and solid waste generation. Thermal mass may be optimised in order to provide comfort with a minimal use of materials.