LIFE CYCLE ASSESSMENT OF BUILDING MATERIALS AND STRUCTURES IN GERMANY

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1 Abstract

Life-Cycle-Assessment (LCA) becomes more and more an important tool for industry to choose the adequate material or technique leading to an expected product quality from environmental point of view. As the environmental aspects are just one part of the decision making process, economical aspects have to be implemented as well.

Sustainable construction is a major driving force of building and construction technology. The building sector uses extensive quantities of natural resources, raw materials and energy. The reason is to change parts of the natural environment in order to create (necessary) human surroundings. If the environmental effects of buildings will be described in it's entirety design, construction, use, demolition of buildings, respectively the whole live cycle must be taken into consideration. As the system is complex, the architect/planer needs supporting tools leading to acceptable decisions, concerning environmental effects of the choice, yet during the planing process. Authorities need brief and reliable background information, if decisions of environmental consequences are to be made.

Considering this facts in 1994 IKP started a research project with more than 50 producers of building materials, components and manufactures of buildings. The projects follow two main goals. A database of the most important materials and components is in development with the producing industry, to create LCA´s under comparable system boundaries with actual data, and developing a methodology to integrate environmental aspects in the planing process. The approach is linking methods like computer aided design, simulation of energy consumption during utilisation of buildings and possibilities of waste treatment. The database management and the assessment is supported by the IKP-Software "GaBi".

2 Introduction, Motivation and Task

The necessity of environmental related management in industry cannot be ignored anymore and is even expected of society. It is important to choose suitable tools and consistent data which is applicable and objective.

Meanwhile LCA is a widely accepted and applied tool for many branches of industry to manage their product related environmental assessment.

The anthropogen material flows caused by the total life-cycle of buildings contribute in many ecological categories to the impact potentials /1/ /2/.

To describe a building during the whole life-cycle inter alia information are required concerning the depletion of mineral resources (mining and produc-

tion of building materials), depletion of energetic resources and release of pollutants (construction material production and transport, energy supply of production and during utilization of the building, etc.), land use (e.g. of a quarry and surface sealing by the building) and waste treatment (construction, use, renovation, demolition).
To structure these data sets the life cycle is systematically divided in several unit-processes forming a chain respectively a network representing the mass- and energy flows caused by a building cradle to grave.

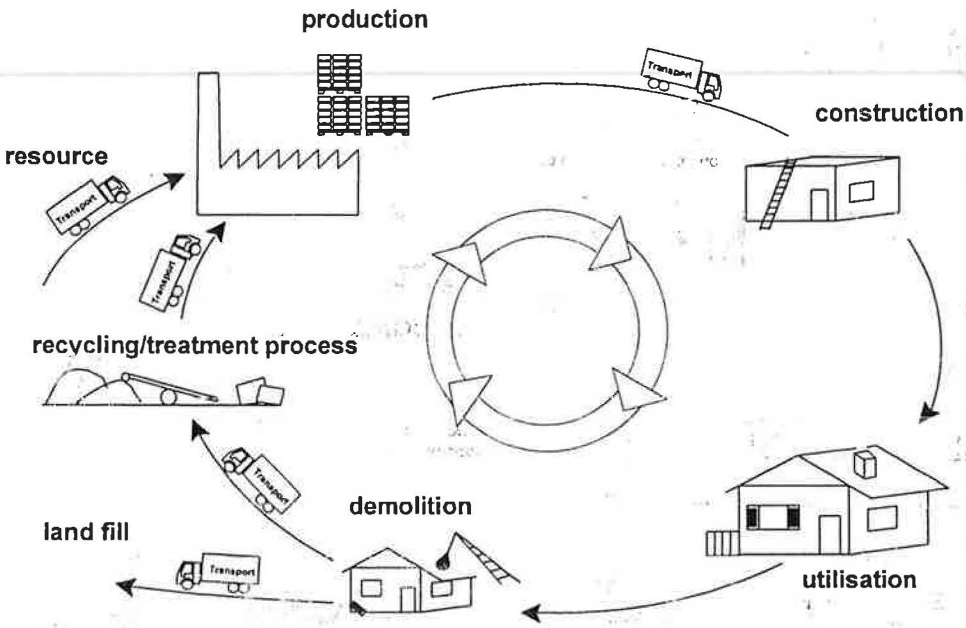

Figure 1: Schematic life cycle of a building

Neither the isolated reflection of building materials concerning environmental impacts nor comparisons are useful and may inadmissible, since it is not related to a functional unit, which may be a physical requirement or a desired performance of a component or building. The used general data (e.g. transport, energy supply) has to be comparable as well as system boundaries and methodological key points (like cut-of-criteria and allocation rules), as it may influence the result considerable.
LCA's of building related materials and components are carried out by several institutions. Data of this studies often cannot be used to characterize a building, as the different data sets are often not set up under the same boundary conditions or often based on data of aged literature. This does not mean that the studies are wrong or useless, but comparisons of it are not possible and data cannot be merged.
This situation in mind the IKP in cooperation with the IWB and the PE Product Engineering GmbH initiate a research project with several companies of the building industry. A structure of 5 divisions consider branch specific topics, but still do not loose the link to the task of characterizing a heterogen system under comparable conditions.
Divisions: • mineral building materials • windows and technical facade
• insulation materials • heating systems • construction companies

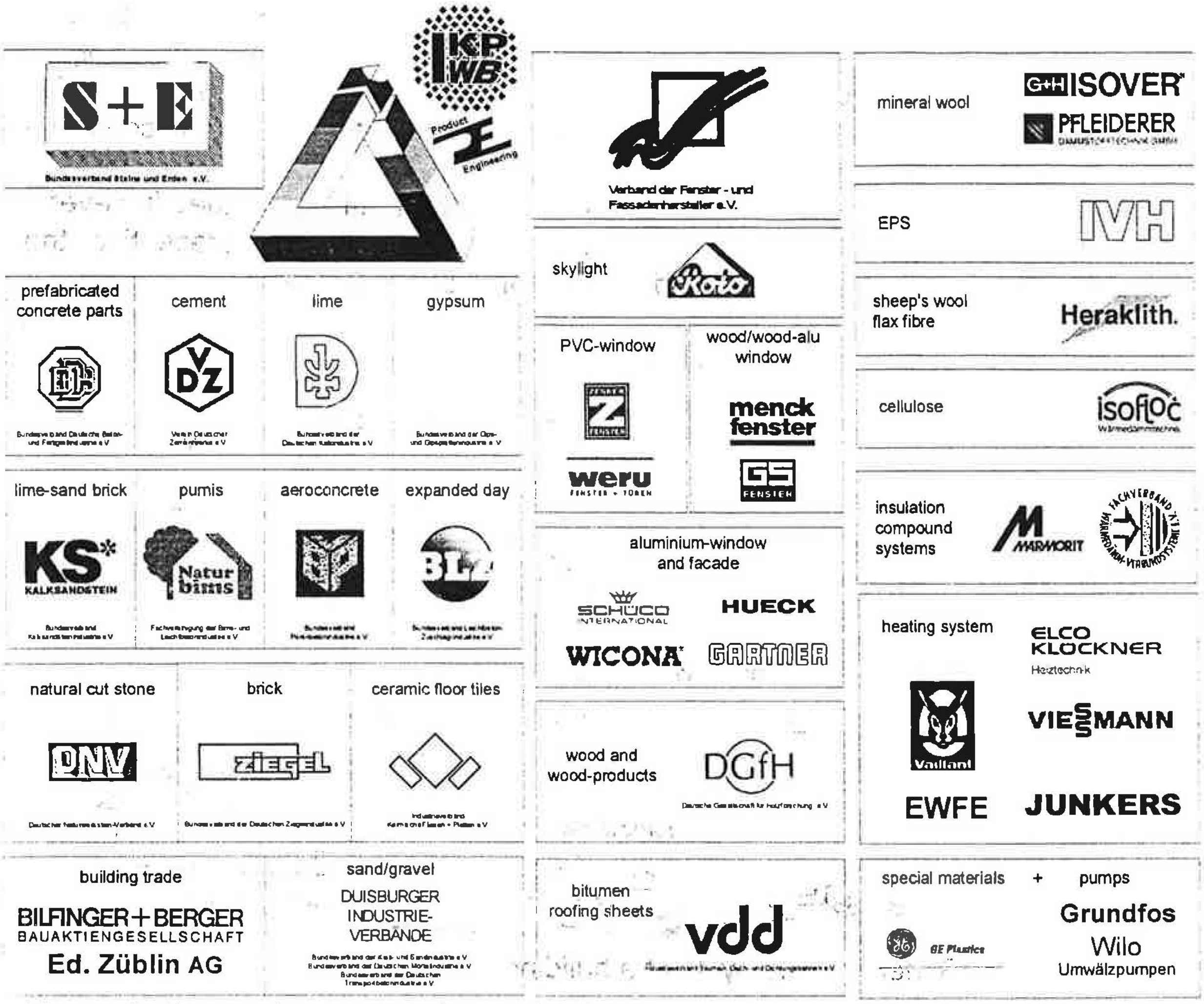

Figure 2: Supporting companies and unions

Based on actual data sets constructions and components are set up (e.g. wall and ceiling, insulation systems, windows, facades) in a data base, which can be extended by the user in combining different material-data-sets to new construction at will. The choice of constructions and components is performance-orientated (e.g. on static requirement or utilization-orientated performance). The components and constructions can be combined to buildings and together with the heating-systems and the process of construction the life cycle is characterized including interactions of the components. This topic will be discussed later on repeatedly.

As economic aspects of material- or procedure-alternatives can be also restricting a choice, it is necessary and helpful to characterize the life cycle by monetary values as well. This happens in describing the different costs (resources, energy, auxiliary materials, wages, machinery) of a product or procedure as input flows of the unit-process and the value of the product(s) as output.

The Life-Cycle-Assessment under technical requirements extended by additional economical aspects is reflecting the philosophy of IKP's "Ganzheitliche Bilanzierung (GaBi)", which means Life-Cycle-Engineering and is a tool for optimization, weak-point-analysis and sustainable product development.

3 Methodology and the example of windows

As in a sustainable context single steps or partial system assessment become increasingly doubtful, if the total system and it's inherent interactions are not known, the total system is to take into consideration. The complexity of the cause-result relation is enormous and at least main influencing parameters has to be identified, if positive effects the total system shall apply.

The total system "building" is divided into components. The components are in interaction with other parts of the system (e.g. windows with heating system, as the transmission losses are influencing the needed heating energy). As an example of different analyzed components, which can be installed and used in a building, windows with PVC-, Timber- and aluminum-frame materials will be considered in this context.

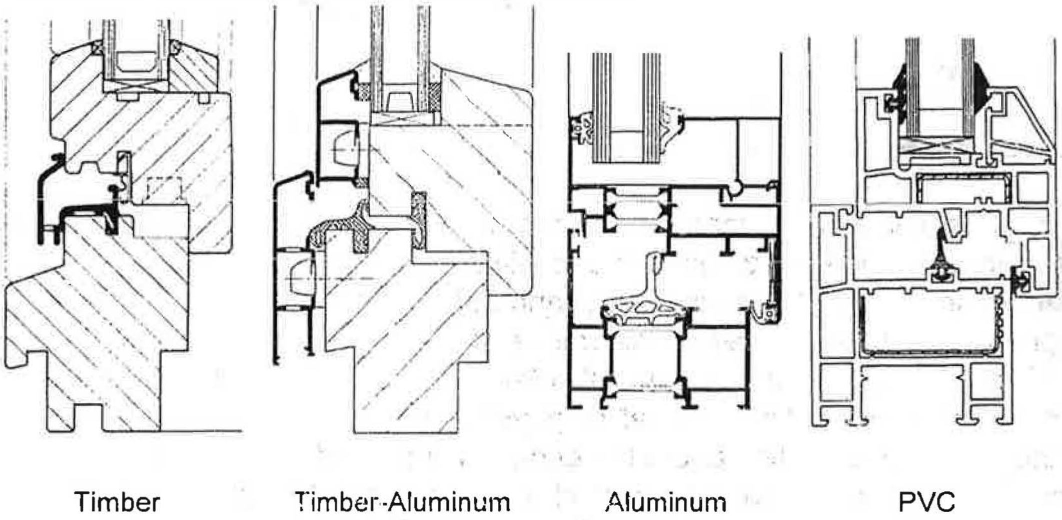

Figure 3: Timber-, Timber-Aluminum-, Aluminum(Al)- and PVC-Windows as example for component alternatives.

To be task-consistent, the life-cycle respectively the investigated system has to be modeled under comparable boundaries. As the approach is bottom-up the research is starting from the product and it's materials. All used materials were followed back to the resources, as extracted from the environment. This means all steps of the synthesis of the raw materials are taken into consideration to identify if it contributes to the result of the study and whether it has to be integrated into the system boundaries.
As mentioned above often not only the main materials have to be taken into account, also relevant auxiliary materials and auxiliary resources, energy supply and transports have to be considered, if they contribute to an environmental effect. The basic data is supplied by the IKP database GaBi 2.0 /3/. As a goal of the method is the application in industry, this approach leads to further research in the possibility of the assessment of land use and realizing methods to check the cut-off-criteria "ecological relevance" claimed by the ISO 14040 standards. Approaches are in development at IKP /4/.

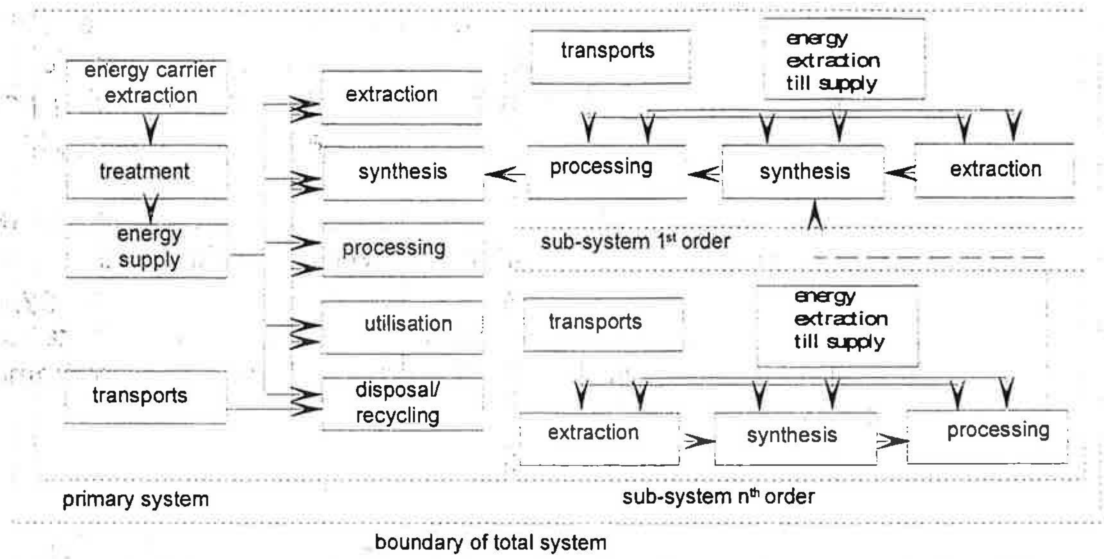

Figure 4: Primary- and sub-systems forming the system boundaries /5/.

The figure shows the inherent problem, that the number of sub-systems n may increase until the whole world is within the system, if no cut-off-criteria is implemented. The ecological relevance of the total system often follows a approximate limits for reasonable values of n. For application in industry this is of importance. If any ecological relevant mass- and energy-flow of the constructions (with it's technical or physical requirements) are known and documented, information about the economic parameters like material-costs, machinery-costs and working-cost characterize the different products from another important view (cost-benefit analysis). The cost-parameters are defined for the same (unit-) processes.

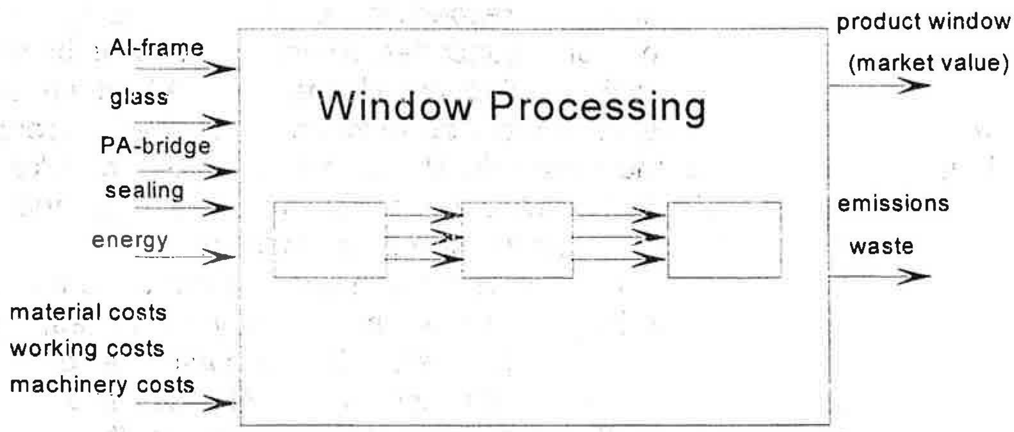

Figure 5: Mass-, energy, and economic-flows are defined for the same levels

So optimizations from an ecological, sustainable and economical view are possible. The technical aspects are considered over the physical- or user-requirements.

In case of the considered window constructions the technical requirements were:

- Area of 1,82 m^2
- heat transmission coefficient of the total component of 1,8 $W/(m^2K)$
- no special sound-absorbency required
- just technical required maintenance in intervals (not subjective optical)

Some other boundary conditions besides the above mentioned:

- components are reflected with contribute essential to German market
- utilization time of 40 years
- recycling-quotes, disposal processes, collecting losses, maintenance intervals are defined for all different constructions

Modeling the system for the different windows leads inter alia to following knowledge:

- the long-time utilization has essential influence on the ecological relevance. The main interactions with the heating system which supplies the energy demand are:
  - the static heat transmission coefficient of the component,
  - the dynamical user influence because of the air exchange by opening the windows frequently and
  - the quasi static room temperature, chosen by the user
- the glass contributes to the ecological impacts of all environmental impact categories, as it represents a high percentage of the components mass.
- the timber-window uses recoverable construction material, but needs protecting varnish and certain maintenance intervals, which contributes to toxicological impacts, as solvents are releasing. Water-based varnish is an opportunity.
- the PVC-window has tendentious the lowest production costs. The Ozone creation potential is low, and low heat transmission coefficients are quite easy to reach. To the toxicity potential it contributes reasonable, although mercury emissions could be lowered within the last years.
- the Al-window has a high energy demand (electrolysis) and therefore a high contribution to the greenhouse warming. The share of hydropower for the production of Al is app. 14% for the German import-mix. A scenario for best available technology comes to 56%. Al is easy to recycle and shows a low toxicity potential as powder-varnish is applied.

Thus information of each component (window, roof, wall,...), including the ecological inventory of the complete life-cycle, is saved in the data base.

To simulate a whole building, other components and it's materials (including it's individual representative inventory) fill up the data base.

New individual construction can be created, as the needed inventories of the materials can be combined at will. So every individual building can be build up, because the information is linked to the materials, which form the construction and not to the construction itself.

4 Integration of environmental information into the planing

There are most degrees of freedom at the time of planing, therefore the influence on the whole system is most considerable, as the mass- and energy-flows are fixed in that time. The cost development follows contrary tendencies. The costs rise the later a change is necessary during the construction process. Most effective planing requires an assessment of the impact of the measures planed. Within every planing process the economical assessment is obligatory and covered by the classical costing.

The goal of sustainable development requires an ecological assessment at the time of planing as well.

The goal of providing a all-embracing assessment-tool, reflecting all interactions and cause-result-relations, needs much more further research, but a supporting tool which leads the planer to an acceptable decision (technical, ecological and economical) can be provided by the described tool.

The application of this planing tool is an iterative process.

- The system characteristics and the inventory of the building are described starting from a first conception
- As a next step the assessment for the construction is made based on average construction material and process data and the simulation of the utilization phase
- Main factors and the corresponding interaction can be identified by an analysis of the evaluated results.
- At this point the iteration starts, i.e. the loop starts with the improved construction again.

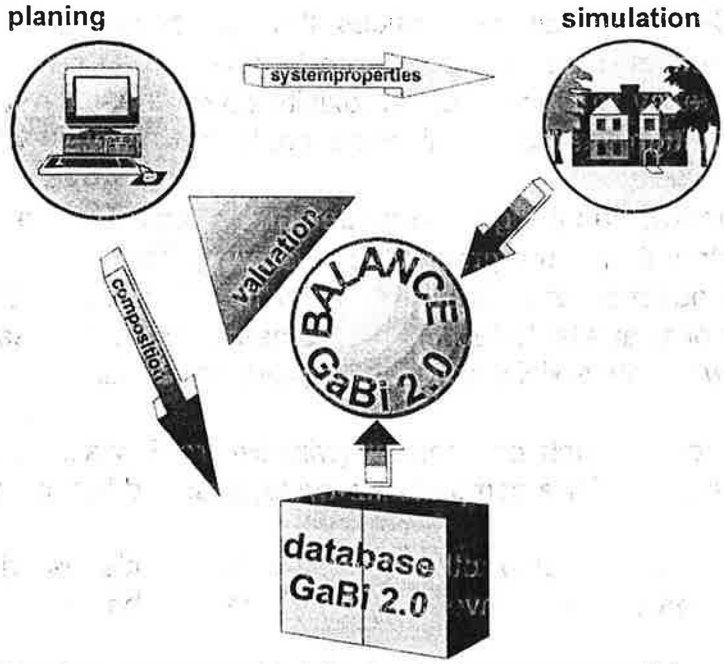

Figure 6: Planing support with Life Cycle Assessment /6/.

5 Conclusions

The ecological impact, even of complex systems like buildings, can be assessed prior to construction measures. Therefore software-tools like "GaBi", including an adequate data base have to be an integrated part within the planing process.
Experiences of the detailed analysis of building components, which follows the data-base formation, show that material bans often are political, subjective and sometimes driven by society. This may happen without knowledge of the total system and the overall impacts of the material and it's prospective substitution. Substitutions will be introduced and the moral dilemma seems to be solved, as the environmental problems change to others or shifted to other phases of the life-cycle.
In most cases not a ban of certain materials solve the problem or optimizes a building in a sustainable way. Much more effective and often more useful is the use the material in a proper way or within the right construction. So the focus shall be more on the constructions, than on materials, even if this way may be the harder one, as material bans are quite easy to release.
Planers may agree in considering environmental effect in their work, but do not have any possibility to do so. Because of this one task of the project is to develop and provide a tool (software tool and database), which can be used even in planing.
For an ecological embracing valuation global criteria as green house effect, stability of ecosystems and influence on human health must be considered besides an energy balance, even if not all cause-result-relations are known or can not be modeled yet.
Today's situation does not allow to wait, until the environmental effects of economics and human activity can be calculated that precise mathematics are able to. If trustful trends are worked out of a systems analysis, considering the whole life-cycle, ways must be found to implement this knowledge to the welfare of the planets future.

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