Contribution to Building Research and Information

Integrated life cycle analysis

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Abstract :

There is a structural distinction between assessment tools for green buildings and integrated, life cycle oriented design tools. The criteria for life cycle integrated design tools are listed. They concern the scope of the methods as well as their scalability. The basic methods and assumptions of the integration of Life Cycle Analysis, in particular energy and massflow analysis, into the normal work environment (CAAD, specification and quantity surveying, energy need and building physics calculation, comfort and health risk appreciation) are presented. The first experiences from the application of an integrated tool are discussed. Conclusions concern the time span for the development and the diffusion of new tools in the planning process.

1. From green assessment to integrated life cycle design

Designers, building owners and developers have been demanding simplified ratings of building performance to identify “green“ buildings on the market. A number of available assessment tools[BRE93] fulfil this function quite well since several years. They are however not adapted for the use of comprehensive planning teams during the different design phases. LCA based design tools have been developed over the past years in Europe and to a certain degree also in Canada and the US. The European REGENER project has established the methodological principles and a first comparison between different methods and tools [REG97]. The GBC development integrates assessment aspects and LCA aspects [GBC98]. Due to the difficulty to establish a common international database on precombustion emissions and embodied energy, GBC has chosen a relative distance to target rating. In the IEA Annex 31 - energy related environmental impact - LCA (design) tools were compared more in detail and the results were available in 1999 [IEA00]. The Maastricht conference on Sustainable building in 2001 has shown a multitude of LCA based tools. In these tools the basic LCA framework of SETAC [SET93] and ISO [ISO97] has generally been adopted. The protection goals of sustainable building are environmental, economic, social and cultural. Taking these goals into consideration requires a considerable conceptual enlargement of design tools [KOH98]. Life cycle assessments (for European situations) show that the use phase of individual buildings and the maintenance of the building stock become more important issues than the design of new buildings [KOH98b]. In the future the crucial issues are therefore the scope of the tools, the number of performance aspects they address simultaneously and their degree of integration in the usual design environment (e.g. through the sharing of data with other design tools). Tools of this type are referred to as integrated building life cycle analysis.

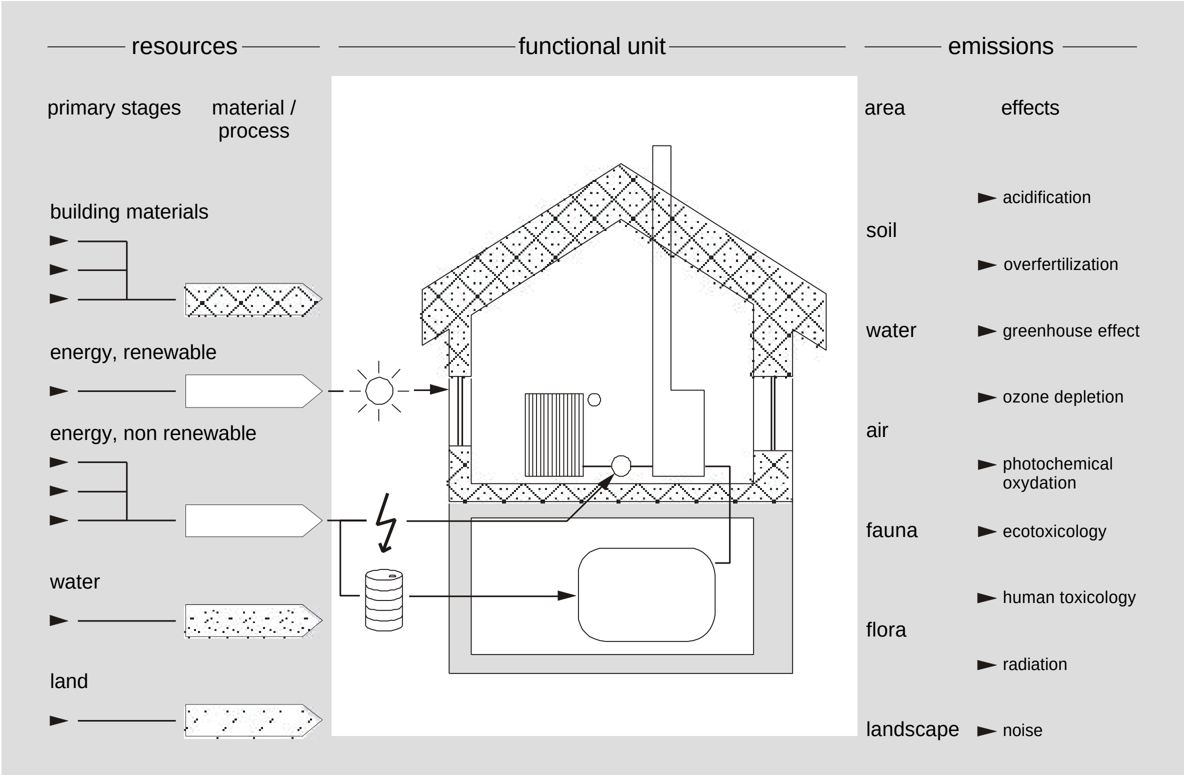

Fig. 1: System limits of building life cycle analysis. The limit has been gradually extended from final energy consumption to materials, land and precombustion on the upstream side and to impacts on various scales on the downstream side.

2. Criteria for Integrated Building Life Cycle Analysis

To cope with long time frames and complex design situations, LCA methods for buildings must be process oriented and differentiated for specific decision and information levels. They should have the following characteristics :

- Be adapted to building life cycle phases, different actors and different decision levels:

Each important decision (design, use, build etc.) depends on the life cycle situation (new building, refurbishment) and the actor (designer, owner, contractor etc.). Methods must therefore be able to give answers for specific actors and situations [PAP93]. Building design decision imply a long time horizon because of the generally long life time of buildings. Simulation of a supposed life cycle is necessary as a basis for most decisions [KOH97].

- Be adapted to different types of impacts and effects :

The resource conservation is predominant in the building program and design brief stages (feasibility, type of solution, performances in design brief) and for existing buildings (demolish or refurbish). The potential impacts for the ecosystem and for humantoxic effects are decisive in the design phase (form and performance of building, use performances, durability). The real impacts on users and workers can only be taken into account in construction and operation relevant decisions e.g. in the form of maximum admissible concentrations of certain substances in indoor climate (peak and average values)[LUE98]

- Refer to absolute and relative target values

There is no sense to look for the most environmentally friendly building, juste like there is no sense to look for the cheapest building. The evaluation of the design and of the effective performance of a building are always very complex issues. There is no simple and transparent performance optimum. Multicriteria methods are of not much help in the real design process. The best evaluation model is probably constraint satisfaction. The target performances of buildings are considered as constraints forming an n-dimensional performance space. The design alternatives must be inside this space and the optimisation depends on aesthetic, cultural, social, psychological qualities. It is possible to determine a priori a LCA solution space for certain types of buildings (in the design brief) and to assist the different actors in the life cycle of the building to verify if the chosen solution is inside the solution space [LEG00]. To ensure a coherent set of performance targets it might be preferable to chose the performance of a real or at least a fully designed building.

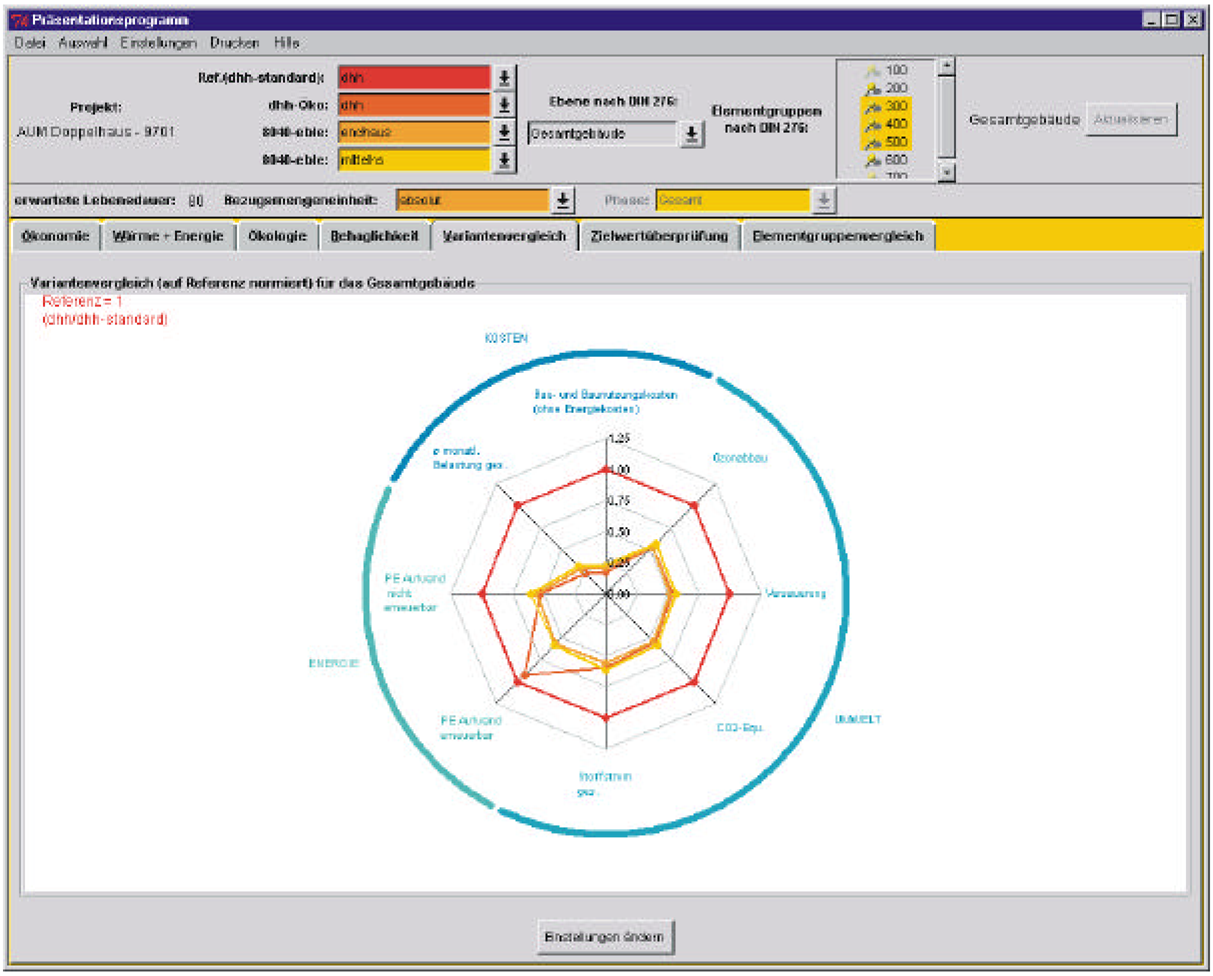

Fig. 2 : Multidimensional (energy, cost, impacts) solution space comparing two alternatives (or one alternative and a target.[LEG00]

- Be embedded in the usual professional working environment

The necessary data for LCA are considerable. They concern geometric, constructive, user relevant, environment (site) relevant and finally execution relevant data. It is impossible to establish these data for the unique purpose of LCA and the results would rapidly be obsolete due to continuous design and construction decisions. One of the crucial problems is that designers work on a functional-geometric level (plans, sections) with implicit assumptions on how the design will be realised. Quantity surveyors in turn bring in their knowledge through detailed specification without questioning the functional and geometrical design solutions. Energy and building physics calculation need several type of information (geometric, constructional as well as environmental and use specific). Building product models which link the different aspects have been developed in research in a top down way and are not based on the huge amount of real design, cost etc. data. Integrated LCA tools cannot rely on research type product models, they have to realise their own integrated framework integrating implicit product models and existing databases (bottom up).

- be scaleable – allowing a zoom

In the design process the same questions are asked several times during the advancement of a project, but the level of accuracy and the granularity changes. Furthermore, other specialists enter the design process later on. One of the problems is that for each stage (and specialist) new conceptual models (and their corresponding software) are used. These methods have different assumptions, different system limits and different mathematical resolution techniques. One way to overcome this dilemma is to use scaleable methods where the same complex model is used from the very beginning of the design process. In the beginning only very few inputs are open, most of them being occupied by default values (average values). When the process advances and new evidence or new specialists appear in the process, the default values are gradually replaced by resulting design or dimensioned values. At the end the measured values can be used allowing improvement of the model for further applications.[KOH00]. The basic idea is that the common model for the life cycle of building can only be the "building as built" which is the starting point of the life time of a building and of its induced mass, energy, work and monetary flows. All planning steps, which precede the "building as built" can be considered as a temporarily uncompleted building or as not yet instantiated structure. This allows to produce a large number of simulations of possible design outcomes, which are of course not exact, but which are plausible and which can be improved.

3. The development of LEGOE

The goal of the German LEGOE ** research project was the integration of Life Cycle Analysis, in particular energy and massflow analysis, into the normal work environment (CAAD, specification and quantity surveying, energy need and building physics calculation, comfort and health risk appreciation) used by architects and engineers. A new integrated tool based on existing tools with their implicit product models was created and allows to appreciate a design solution simultaneously from different points of view and with different life cycle time scenarios [LEG00].

In the LEGOE tool the architect starts out by creating a design in his CAAD system. Instead of drawing simply lines, he will constitute surfaces, cubes or punctual/linear objects. For each the program will ask him to chose a corresponding element from a catalogue of several thousand building-elements. For the rooms the user will have to give similar use and performance indications. The internal model of the CAAD system will realise an element-room oriented project file which links the geometric and topological data of the project to the semantic data. Different modular calculation and simulation programs will proceed to the standard energy, mass flow, cost and comfort evaluations over the life cycle of the building. Visualisation programs will in turn present the results in a user specified way. The user can chose the life cycle range, the scale of decomposition and the reference data (targets). All data will be incorporated in a life cycle building performance document which is produced automatically and will serve a s a basis for building operation and facility management.

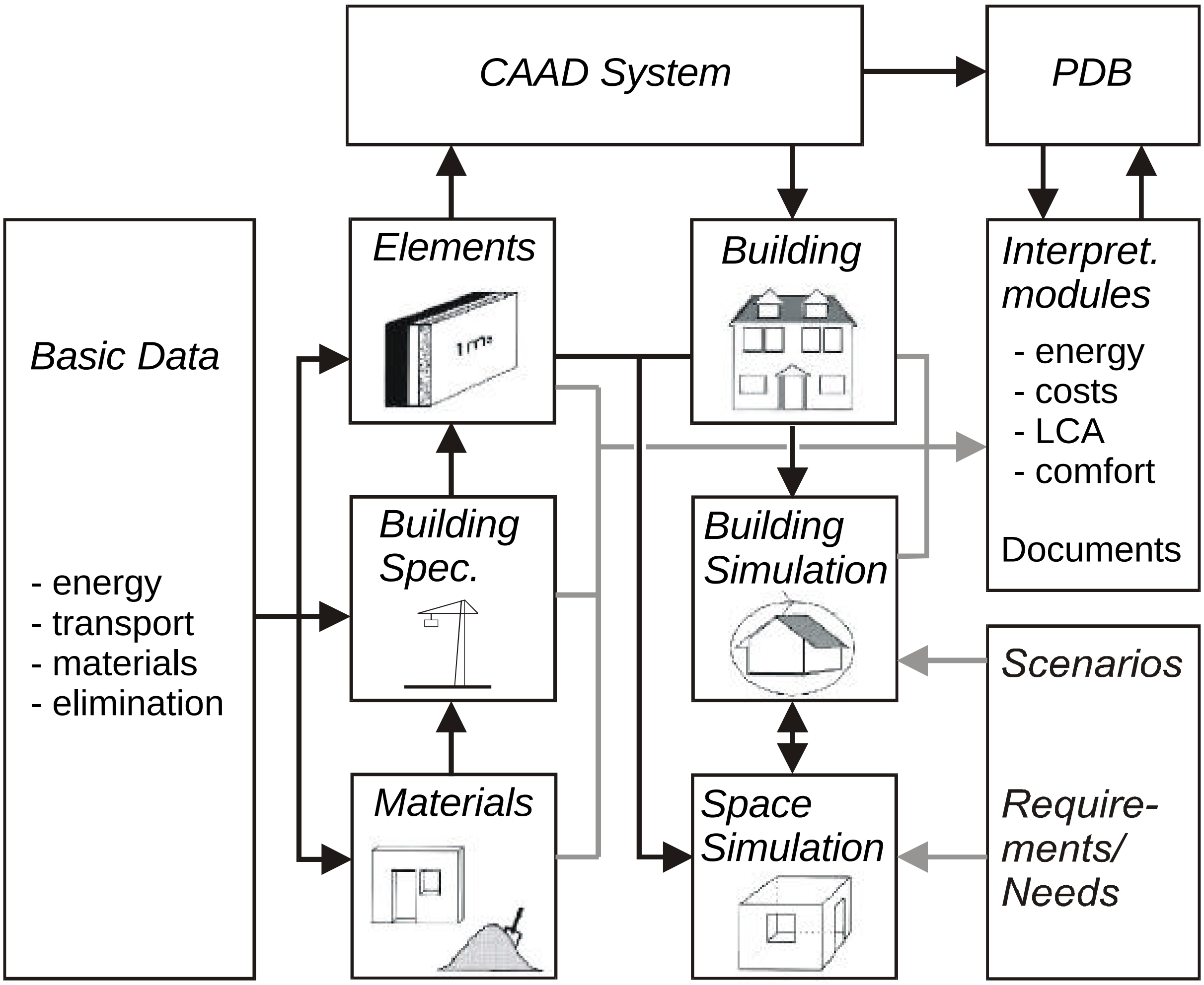

Fig. 3 illustrates the relations between the different modules of LEGOE. In the following sections, the partial modules and their interaction within the LEGOE concept are explained more in detail.

3.1 Basic information

Data on energy, transportation, materials, and waste elimination :
The life cycle analysis of energy and mass flows of building products, building parts and buildings as a whole requires data about resource consumption and environmental impact resulting from the preparation of final energy, the standard transformation of energy, transportation services, production of building materials as well as recycling and waste elimination (downstream process). These data are kept separately within LEGOE which allows an independent and continuous update and improvement of the data. The data for the life cycle inventory and life cycle impact of building products were obtained by specific process chain analysis (inventories)together with industry in Germany, Austria and Switzerland and not simply by taking data from literature. The values are average industry values. For the moment there are inventories for approx. 250 building materials and construction process [OIB95].
This allows for a standardisation of assumptions and constitutes a consistent framework which can be improved. The inventories of building materials and building process were combined with precombustion, transport, energy transformation and downstream data of ECOINVENT [FRI95]. In a recent study the basic data of ECOINVENT have been replaced by the German GEMIS precombustion data[GEM95]. Even if there are differences between the basic data due to different assumptions and system limits, results on the building life cycle level were comparable, i.e. the ranking of identical elements and buildings turned out very similar.

Environmental and technical qualities of building products :

The term “building products“ means building materials as well as building parts, composite building parts and manufactured components as large as prefabricated houses. Environmental data are provided for the level of life cycle inventory analysis and life cycle impact assessment. Since the linking of the process steps are maintained within the DBMS, an update of the data (due to changes in the process chains) is possible at any time. The system limit of the data is the finished building product at the production site. For the phases of life after the completion of the building, the user can choose between various scenarios in the form of life cycle modules. The scenarios include information about the expected life time, the maintenance strategy, as well as different types of recycling or waste elimination. Building products carry information, which can only be realistically evaluated in the final context of the building on its site, taking into account local constraints and combinations of elements.

Building elements and building specifications :
LEGOE uses an existing commercial catalogue of specifications, elements and their corresponding prices. The catalogue, which is the German market leader, contains today approx. .... specifications and .... elements. The prices are updated each year and given in the form of intervals and average prices. The attributes of the building elements contain all necessary life cycle specific information. This is the basis for the analysis of the economic and environmental consequences of design decisions over the entire life cycle of the building.. Usual data like technical information and cost rates are maintained. Automated links to specialised contractors databases with humantoxic and other environmental related information will be implemented by the end of 2001.
The building elements of this catalogue are composed of building process specifications. A building element describes a part of a building resulting from a sum of building process which are proportionally necessary. On the level of the building process specifications, it is possible to identify the single material processes needed and to describe them by the necessary quantities of materials used (including all auxiliary materials and waste) and of tools and machines used (including their energy consumption and their maintenance). Since the building process specifications are assigned to building elements, the basic quantities can be calculated for the building elements and then linked to the evaluation data (mass flow, primary energy consumption, effect-oriented impact categories, aggregate indicators). In order to reflect the life cycle of a building element, additional information is needed about the life expectancy, maintenance and cleaning cycles, energy consumption during use, recycling behaviour and appropriate elimination paths. Through this method, the traditional construction elements for building parts and technical equipment are complemented by cleaning, maintenance, refurbishment and demolition elements with their specific set of evaluation data. Element information refers not only to the building process specifications, but the element catalogue contains information on succession and the nature of the different layers. In turn, this information allows the calculation of energy flow, vapour diffusion, acoustic protection, fire resistance, construction time and the like. At the end of the design a complete list of elements and specifications exists. Specifications can later on be grouped by trades or contractors without loosing their initial information.

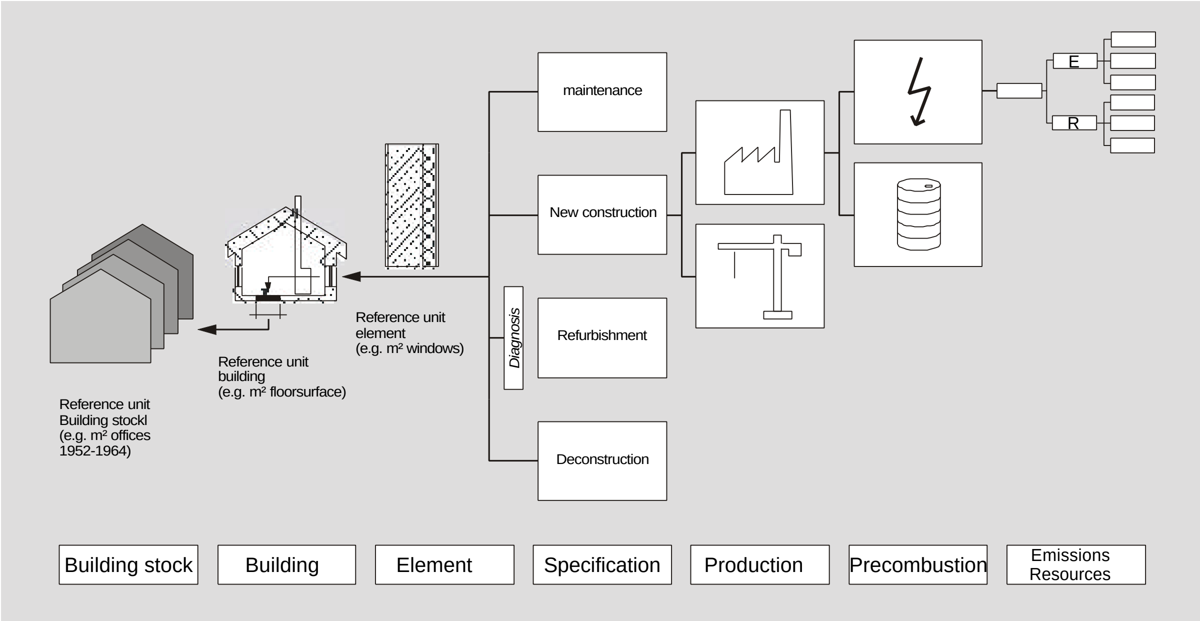

Fig.4 Hiererarchical system description linking the building stock to resources and impacts through elements and specifications.[KLI96].

Building description :
The attributes of the building element catalogue can be used to describe buildings composed of building elements. However, this description is not sufficient for certain life cycle calculations. They need topological information and neighbourhood relationships which cannot be derived from the element catalogue attributes. LEGOE is based on a CAAD system using a building model which serves as an input module which is able to store, to manage and to interpret geometrical and semantic building information. The user can associate elements of the catalogue to the elements of the design in the CAAD system. By this procedure, all building element-specific data of the catalogue are available and can be used in combination with data at building level. In the case of topologically independent criteria, the quantities of different building elements and classes of elements of the design are immediately available and can be transferred into the project-specific database (PDB). The building specific topological data are used as input for calculation methods which require attribute values of the building elements as well as data derivable only from the spatial and space enclosing structures of the building. The interpretation programs use a combination of building-specific and element-specific data.

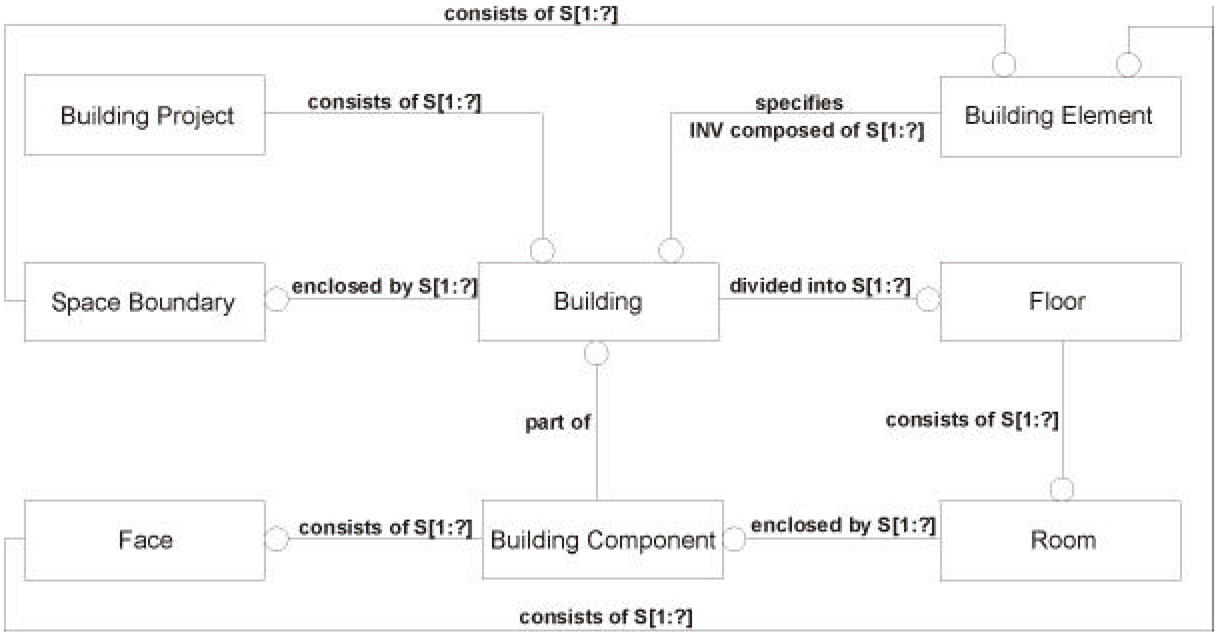

Fig.5 : Internal model of the CAAD program Speedikon which is used in LEGOE. The model associates rooms, surfaces and elements. [LEG00]

3.2 Simulation

Scenarios :
The resource consumption and resulting environmental pollution due to the production of materials and the construction process can be considered as an accomplished process which is "reviewed". The appreciation of the life cycle can only take the form of a simulation of use, maintenance, refurbishment and waste elimination cycles. It is a "forecast" using scenarios and assumptions concerning the future. Within LEGOE, a set of scenarios is available for the user. In addition, specific assumptions can be formulated. In modelling the assumed life cycle, the following criteria must be established: utilisation including a standard-use-scenario, considered time period, trends in cost development and conditions of financing (price increases/interest), levels of equipment and procurement (scenarios of future technical developments), cycles of cleaning and maintenance, cycles of refurbishment and type of deconstruction, waste elimination and strategies of recycling.

In order to determine the energy and mass flow due to utilisation, life cycle inventory analysis and life cycle impact analysis is necessary, corresponding to the evaluation of the construction phases. It is necessary to provide rules of calculation for the determination of the present consumption of heating, lighting, air conditioning as well as service and maintenance. Whereas the determination of the running energy consumption of room heating and hot water can be performed according to national standards or internationally acknowledged methods of calculation, new procedures had to be found for service, maintenance, and the use of auxiliary energy.

Simulation of the building life cycle :

Specific calculation programs are developed or extended to simulate the life cycle of a building with regard to costs, energy, health/comfort and environmental impact. The life cycle calculations require the mentioned specific description of a building related to rules of calculation and pre-configured scenarios. The calculation programs require this description of the building, extracted from the building model of the CAAD system, as well as the data from the building element catalogue as input data. For each calculation program, the required data are prepared from the building model data and stored in the central data repository.. The element-specific data are available for each calculation program through the specific labelling of the building elements.

In detail, the following calculations depending on the chosen scenarios for the life cycle phases of new construction, utilisation, refurbishment and demolition are executed:

- costs according to DIN 276 (investment costs) and DIN 18960 (use costs)
- environmental indicators (mass flow, primary energy consumption, effect-oriented impact categories, etc.)
- heating energy according to different, partially standardised methods of calculation
- energy consumption's for room heating and hot-water
- electric energy consumption
- water consumption

The data generated by the different calculation programs are stored in the PDB and are available to the other modules.

Simulation of indoor environment :
The environmental construction approach (estimation and evaluation of energy and mass flow during the lifetime) is completed by an assessment of the health and comfort conditions of the users. The estimation of the energy and mass flow can be done for the building as a whole. The assessment of the thermal comfort, the interior air quality or, for example, the room acoustics can only be realised for specific rooms. In future development of LEGOE the rooms results will be aggregated into estimations on the comfort quality classes (thermal, acoustic, etc.) of the building. In the present version of LEGOE, the thermal comfort in winter is evaluated on the basis of the average climate assessment = predicted mean vote (PMV) and the predicted percentage of unsatisfied (PPD). The evaluation of the summer comfort condition is realised by calculating the probable number of days of utilisation with undesirable high internal temperatures.
The examination and the assessment of the interior air quality on the room level within LEGOE can only be done by including the interactions between material characteristics of coatings and the utilisation of rooms (persons, user induced air change. Using the current room-schedule data of existing CAAD tools, health relevant information will be assigned to coatings and other enclosing elements. Combined with room-specific use scenarios, simulations of probable concentrations can be performed and compared to target values. The evaluation of the acoustical qualities of rooms is based on the reverberation-time T60.

In future developments of LEGOE, these assessments will be completed by identifying weak points (calculating of all spaces and marking of problematic areas), assessment of air quality based on a medium internal quality (based on TVOC). These assessment will be include in a performance record, the so called “building passport“.

3.3 Evaluation of environmental impact

LEGOE is not limited to one particular evaluation method. It allows the possibility to choose between several methods. Simultaneously, it is assumed that the different actors have different information needs which one single method cannot satisfy. A wider use in practice will show which evaluation methods will be most used. It is a particular concern of LEGOE to initiate and to promote a goal-finding-discussion between clients, designers and consultants and planners through the selection of evaluation procedures and impact categories.
The module “evaluation procedures and evaluation data“ consists of a selection of known evaluation procedures including the required basic data. “ Basic evaluation data“ are method-specific evaluation factors for single elements of life cycle inventories as well as weighting factors of aggregation

methods. It is possible to take into account additional evaluation methods as well as to update known procedures regarding their specific evaluation and weighting factors. At present, the following evaluation possibilities are available:

- mass flow
- primary energy consumption (renewable and non renewable)
- effect-oriented impact categories [HEI92]
- full aggregations (Eco-indicator, environmental impact points) [ECO99]

Additional evaluation methods are under preparation [LUE98]
Energy prices are managed separately to allow different present and future economic evaluation methods. All evaluation procedures and evaluation data are grouped in a specific module.
For evaluation, interpretation and, if necessary, modification, a comparison of calculated data and target values is performed. The different modules offer the possibility to define target in the form of legally fixed values as well as values taken on reference by literature, and to compare them visually to the calculated results. By decomposing the building along the cost breakdown structure DIN 276 (i.e. by elements), it is possible to define and verify target values on parts of the building. In order to create an overview of the calculated data, another module serves exclusively to produce the graphical representation of a subset of these data. This subset includes all aspects (costs, heat requirements, energy requirements, water consumption and environmental indicators) during the entire life cycle of the building.

3.4 Production of documents

One task in the design process is the preparation of documents for communication or authorisation (forms, certificates, etc.). Such documents are still frequently prepared manually or in some automatic way not connected to a building model (stand alone solutions).
The present discussion in Germany about building certificates (similar to the discussion around the GBC'98 assessment framework) considers the establishment of the certificates at the end of the construction process, but not as an integrated part of the design process.
The approach of LEGOE incorporates the coupling of the production of documents into the evaluation and interpretation. Based on a central object and data administration, information can be generated, evaluated and assigned to the necessary documents afterwards. In this respect, the documents can be generated by the planner during the design process "just in time".
For example, the following documents can be generated:

- object descriptions and room planning schedules
- room schedules (room books)
- reports of building costs and of the building use costs (life cycle costing)
- standard forms on fulfilling insulation requirements
- energy certificate
- building certificate related or not to the GBC'98 assessment framework
- evaluation of resource consumption and the resulting environmental pollution
- record of the degree of achievement of targets

The achievement of pre-determined target values can not only be checked with LEGOE, but also be fully documented for the relevant phase of decision making.

4 . First experiences in application

The design with a usual CAAD system and the extension of elements obliges the designer to indicate in a very early stage the type of element before he has taken a decision. One of the possibilities to avoid this is to use default elements whenever no decision has been taken to avoid that elements are forgotten. The use of macro-elements with default values is still rather unusual for designers. For many types of application (refurbishment, facility management) it is not necessary to use the full range of possibilities (and the full range of necessary input) of a CAAD system. A more direct way of entering buildings by elements and above all macro-elements with more or less detailed quantities has been developed (stand alone version). This corresponds more to the way quantity surveyors and specification specialists work. The use of macros is appropriated for facility management problems where the detailed geometric description is not necessary. The room book could be another way to describe buildings. It will however be necessary to develop new interfaces and new macros for specific applications.

The main difficulties of the application arise in the interpretation of the results. Designers are confronted with a large amount of synthetic results of the multidimensional design space. This information is both absolute and relative and concerns investment costs as well as global costs and impacts over the presumed life time. For absolute values there are few common references (exempt investment cost/m2, final energy consumption per m2 and year). Many of the values have no significance for designers (e.g. g of SO2/m2, ecopoints per apartment etc.). Relative values refer to existing buildings or to targets (providing from standards). They are more easy to understand. Life cycle related information is difficult to interpret, for many designers it is the first time that they are confronted with such information.

The graphic interfaces and the choice of scale (functioning like a zoom) allow to understand how final values arise and what they depend on (typically the type of element and the quantity of a specific element). To appreciate this information there have to be supplementary reference values like the ranking of one element in relation to other similar elements and ratios on element quantity and use-surface. This is the traditional domain of quantity surveying expertise and designers are often lost. To take advantage of their possibilities comprehensive tools like LEGOE should be used in common by designers, quantity surveyors and engineers.

Research on design tools in the last 20 years has shown that all innovative design tools question the way of designing buildings and the way design teams work together. There is a complex equilibrium to be found between the adaptation of the tools to every day work and the possibility to allow new questions and new ways of work. The basic assumption of LEGOE, that energy calculation and environmental impact calculation are structurally extensions of cost calculation (which use the same basic data) has proven to be correct in the construction of the tool, it will certainly take much time until this idea will enter the conscience and behaviour of design teams.

The extensions of LEGOE on room simulation which are in the beginning of implementation will raise once more the level of basic information for the interpretation of the results. The probabilistic comfort estimations can be used in thermal, air quality and light comfort performance. The interpretation must be made by the whole design team. Introducing risks for indoor pollution by estimating the diffusion of pollutants from elements to rooms will in turn introduce the questions of threshold levels based on TVOC. These issues are barely known by designers and HVAC engineers.

5. Conclusions and perspectives

During the development of LEGOE one of the problems was that additional and new developments appeared constantly. A trade off between realistic and possible goals had to be realised. The current building and specification catalogue is mainly based on housing and relatively simple buildings. For complex office or industrial buildings as well as for laboratories and hospitals there are not enough elements. At the same time new construction techniques, above all based on recycled materials and biomass based materials have not been described yet in classical specifications with reliable costs. LEGOE allows to create new specifications with market costs, it is however not possible for the user to establish himself complete life cycle specifications. The only possibility is to approximately compose new elements with existing similar specifications. The integration of additional evaluation criteria is planned but will take time. It would be interesting to introduce external costs. However the basic data on external costs take only into account the energy and transport related external costs.
A second limitation is the difficulty to use LEGOE for refurbishment. The refurbishment elements which exist are full replacement elements useable for a forecast but not for differentiated diagnosis. There is a considerable professional interest for an additional diagnosis module and an extension of the life cycle evaluated refurbishment specifications and elements. Another interesting extension is the use of LEGOE as a part of building stock management or Facility management tools. The database of cleaning and maintenance elements is already now used by FM specialists.
An extension of the LEGOE method to other countries is possible if specification data and cost element data exist and can be mapped to the existing German specifications. The link of specifications to life cycle data needs specific tools, professional competence and is very time consuming – attempts to automate the process through semantic analysis etc. have not been successful.
The ideas of a modular set of precombustion data [KOH87],[KOH91], of linking life cycle analysis to cost planning [LUE92] and the necessity of using product models as an integration platform [BJÖ92],[IWC89] are all more than 10 years old. The authors estimate that tools like LEGOE (and other coming tools) will be commonly used by advanced professionals in 5 years and by average users in 10 years. The time constants for innovations in the building field still seem to be closer to generations than to years. Looking at the small speed of transformation of the building stock this is dramatic – as long as it realised of course.

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