CAAD system with integrated quantity surveying, energy calculation and LCA.

Authors:

Manfred Hermann, Niklaus Kohler, Institut für Industrielle Bauproduktion - Universität Karlsruhe, Germany

Holger König, Ascona GbR, D-82194 Gröbenzell, Germany

Thomas Lützkendorf, Institut für ressourcenschonendes Bauen - Bauhaus-Universität Weimar, Germany

Abstract:

In the framework of the German LEGOE project, an integrated tool is developed for computer aided architectural design (CAAD), quantity surveying (catalogue of building elements), life cycle cost calculation and estimation (construction and refurbishment), direct energy consumption (heating, hot-water, electricity) and environmental impact assessment (mass flows and effect oriented evaluation). During the design process the architect works in his usual CAAD environment with building elements (e.g. one m^2 of outer wall) which in turn are composed of detailed construction specifications, energy and mass flow coefficients and cost data. These elements are part of an independent catalogue of elements with all their relevant data. The different application programs use the same basic data and write the specific results into a project-specific database called a PDB which allows the comparison of these data to reference data from other projects. Evaluation and visualisation programs refer to the PDB only.

Keywords: CAAD, life cycle costs, life cycle assessment, building elements

1.   Introduction

The design world of architects and engineers is changing. Private owners, local planning authorities, industry and trade representatives expect information on energy, ecology and health as well as precise costs estimates. In addition to the still dominant investment orientation, costs arising during the whole life cycle of the building are being taken into account. The legal standpoints are evolving in the same direction. The European „building product directive" formulates ecological and economic as well as technical requests for objects produced from building products. The requests must be fulfilled by the whole object as well as by its parts. Today only few planning offices can provide complete and competent information on all these aspects in the design phase. The costs of such a complex approach are very high and the results are often not reliable. Specialists are necessary to apply design tools and simulation programs, to complete the missing data (often manually) and to interpret the results. The documentation and rating of the environmental and economical quality of a building is in itself a complicated task. For all these reasons, there is a high demand for complex tools to support design decisions. They must guarantee that previous evaluation criteria, like function, form, and economy are met and not negated by environmental and health protection aspects.

The goal of the German LEGOE project is the integration of an ecological evaluation into normal work routines and tools (CAD, specification and quantity surveying) used by architects and engineers. This integration will take the form of complex integrated design and construction tools. In addition to usual building cost rates and performance certifications, the designers will be provided with the following additional information during the design process which will allow a direct feedback:
- economic data (investment and running costs)
- ecological data (resource consumption and environmental impact)
- energetic data (observance of national laws and ordinances)
- health data (comfort).

Unlike in conventional design tools, the whole life cycle of a planned construction ought to be represented. The usual work flow in building design will be maintained to keep the adaptation difficulties to additional problems as low as possible.

Fig. 1 illustrates the complexity of the LEGOE approach and the relations between the different components, Fig. 2 illustrates the relations and the data flow between the different modules. In the following sections, the partial modules and their interaction within the LEGOE concept are explained more in detail.
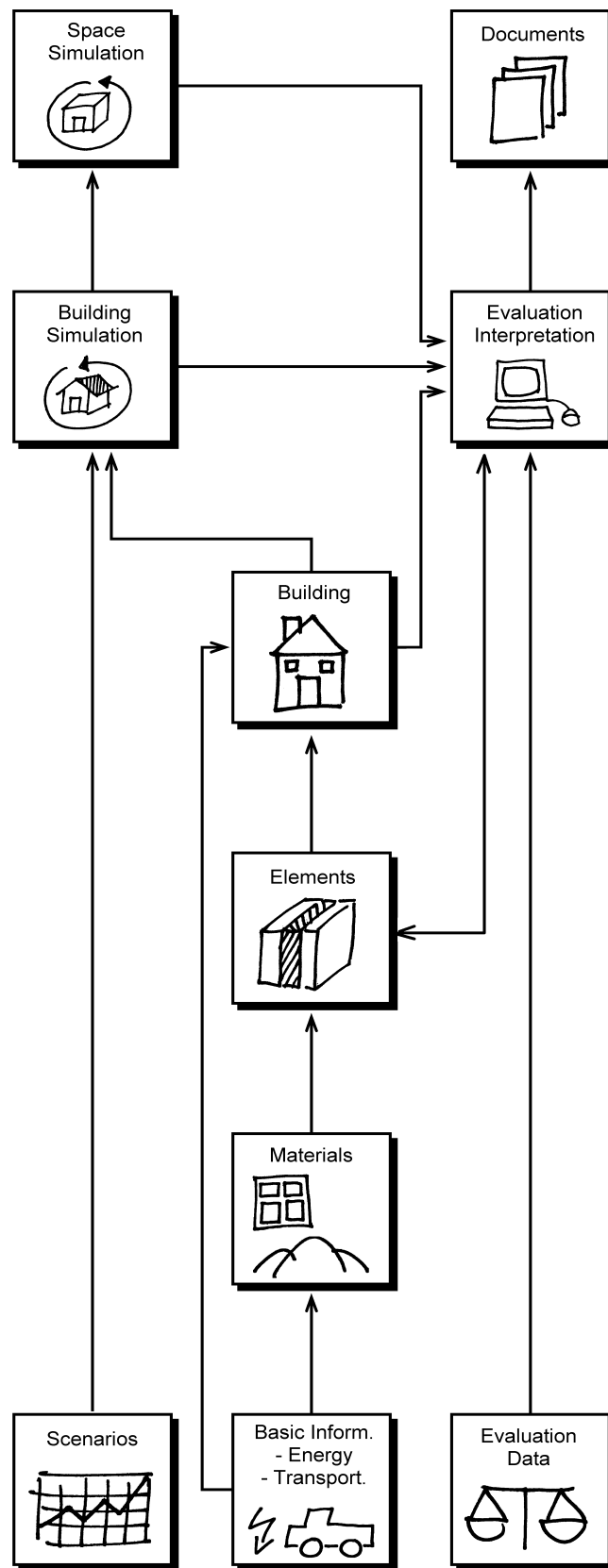
Fig.1 Structure of the LEGOE project and relations between the different components
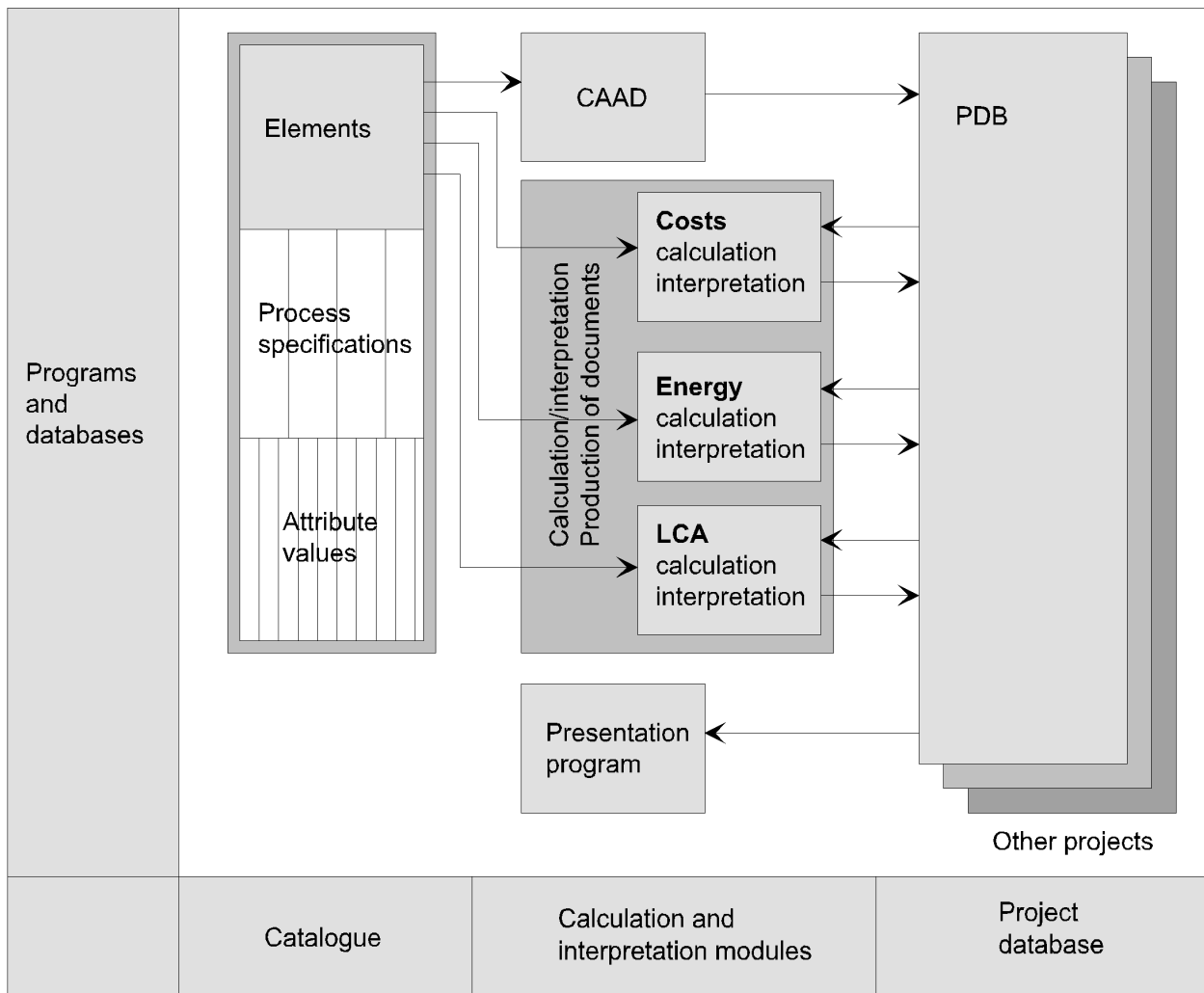
Fig.2 Relations and data flow between the different LEGOE modules

2.   Structure and procedure

2.1.   *Basic 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 the environmental impact resulting from the preparation of final energy, transportation services, the extraction and production of materials and waste elimination. These data are kept separately within LEGOE which allows for an independent and continuous update and improvement of the data. The database for building products, building processes and energy services can also be improved independently. The data for the life cycle inventory and life cycle impact of building products are obtained by recording the process chains and not simply by taking data from literature. This allows for a standardisation of assumptions and a regular update of the data. By preparing basic data on a national and/or European level (average values), the life cycle inventory analysis and life cycle impact analysis of building products can be generalised. The same data sets can also be used for the energy transformation due to the use of buildings which raises the consistency of the life cycle approach. In the framework of LEGOE, basic data of the Öko-Institut Darmstadt (GEMIS) [GEM95] as well as that of the ETH Zurich (ECOINVENT) [FRI95] are used.

2.2. Database for ecological 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. Ecological data are provided for the level of life cycle inventory analysis and life cycle impact analysis. These are calculated by using uniform basic data stored in a DBMS. Since the linking of the process steps are maintained within the DBMS, an update of the data stock (due to changes in the process chains) is possible at any time. The system limit of the data acquisition by the Bauhaus-Universität Weimar (including additional sources) is the finished building product at the production site corresponding to the approach „from cradle to gate". On the level of building products, there is no continuous evaluation of the life (from cradle to grave). 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 possible kinds 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. In conclusion, a uniform set of data is available within the system limit of production (production site); for the future use (forecast), different paths are possible.

The inventories of building materials and building products used in LEGOE represent an average level of technology. These values are used in the early design stages in LEGOE. For the construction stages, additional values can be used for particular building products with known inventories. There will a distinction of „average technology" used in the beginning and „best technology" used in the latter phases if possible. Along with ecological data, technical information (e.g. for building physics) about building products are stored in the DBMS. Both ecological and technical data are handed over to elements using an interface.

2.3. Evaluation procedures of environmental impact

LEGOE is not limited to one particular evaluation method. It allows the possibility to choose between several methods. This results from the conviction that no consensus can be reached in the medium-term with respect to one particular method. Simultaneously, it is assumed that the different actors have different information needs which one single method cannot satisfy. A wider use in practice will allow the judgement of which methods in the spectrum of evaluation methods will be most useful. 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
- effect-oriented impact categories
- full aggregations (eco-indicator, ecological impact points).

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 software module.

2.4. Building elements and building specifications

LEGOE uses a catalogue of building elements whose attributes contain all necessary life cycle specific information. This

is the basis for the analysis of the economic and ecological consequences of certain design decisions building over the entire life cycle of the building. In current practice building elements describe material and constructive solutions. They allow the estimation of the building costs and the plausibility of a solution already in early design stages. The life cycle evaluation is made possible by the introduction of energy and mass flow data, impact categories, health aspects and life cycle scenarios. Usual data like technical information and cost rates are maintained.

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). [BAR95]

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.

2.5. 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. In a further development of LEGOE, the design tools which are at present developed for new construction will be applied to partial or total refurbishment and transformation of existing buildings. This will allow the appreciation of the ecological and economic advantages of reuse, refurbishment and new construction and combinations of the three.

2.6. Scenarios and rules of calculation

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.

2.7. Building simulation

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 PDB. 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)
- ecological indicators (mass flow, primary energy consumption, effect-oriented impact categories, etc.)
- heating energy according to different, partially standardised methods of calculation
- energy consumptions 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.

2.8. Room simulation

The ecological 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.) Co-author Dr. Lützkendorf at the Bauhaus-Universität Weimar developed the concept of an „ecological room schedule". 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".

2.9.   Evaluation and interpretation

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 ecological indicators) during the entire life cycle of the building.

2.10.   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.

3.   Conclusions

In the R&D project LEGOE, the calculation of costs, energy requirements and ecological evaluation is integrated into the design process. The entire life cycle of a planned building is taken into consideration. The first practice test in architectural

firms will take place in the beginning of 1999. The first market solution will be available from mid 1999.

The extension and development of design tools is based on their integration in the current cost breakdown of the DIN 276 standard and on related current design practice. This is the reason why it was possible to develop relatively rapidly these new tools and to have a good chance in their professional acceptance. The LEGOE project, which is mainly driven by software developers, has allowed the transition of the conceptual phase of the research projects OGIP/DATO and KOBEK [KLI96] to a pre-market phase of development within 2 years. The first complete applications of the LEGOE concept could take place within the next two years.

The LEGOE project is sponsored by Deutsche Bundesstiftung Umwelt. The partners of the project are :
Edition AUM, Ascona GbR, Software Sidoun GmbH, IEZ AG, Universität Karlsruhe, Bauhaus-Universität Weimar, IBS Jena, Architekturbüro Eble, Architekturbüro Arndt.

## 4.	References

[ECO95]	Goedkoop,M.: The Eco-indicator 95; Weighting method for environmental effects that damage ecosystems or human health on a European scale, NOH Programme, Amersfoort 1995

[FRI95]	Frischknecht,R. et al.: Ökoinventare für Energiesysteme. ETHZ- ESU. Bern 1995. (ENET-Bern)

[GEM95]	Öko-Institut: Gesamt-Emissions-Modell Integrierter Systeme (GEMIS) Version 2. i.A. Darmstadt/Berlin/Kassel (1995)

[HEI92]	Heijungs,R. et al. (1992): „Environmental life cycle assessment of products; Guide and Backgrounds (Vol. I+II),,; National Reuse of Waste Research Programme (NOH), CML, Leiden,

[BAR95]	Barth,B.; Eiermann, O; Haida,A.; Heitz,S.; Hermann,M.; Kukul,E.: Life cycle modeling of buildings. In EuropIA'95. 5th. International Conference on the Application of Artificial Intelligence to Architecture and Civil Engineering. Hermes, Paris 1995.

[KOH97]	Kohler,N.; Barth,B.; Heitz,S.; Hermann,M.: Life Cycle Models Of Buildings - A New Approach. CAAD Futures '97 - München. 1997

[KLI97]	Klingele,M.; Kohler,N; Heitz,S.; Hermann,M.: Simulation of energy and massflows of buildings during their life cycle. CIB Second international conference Buildings and the Environment Paris June, 9-12, 1997

[KLI96]	Klingele,M. et al.:Optimierung von Gesamtenergieverbrauch, Umweltbelastung und Baukosten in frühen Planungsphasen. Abschlußbericht des Projektes KOBEK. Gefördert durch die Bundesstiftung Umwelt. Karlsruhe 1996

[SET93]	SETAC: A conceptual framework for Life-Cycle Impact Assessment, Novem, 1993.