Modelisation of a building during its life cycle.

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Abstract

The appreciation of the performance and the costs of a building should be carried out over the whole life time. The usual life cycle cost approach has to be extended to the external costs. Different models of the building-energy-environment system are proposed. The building description is based on a basic physical process model which is linked to the construction operations and cost elements used by quantity surveyors. The necessities for new data structures allowing different views of the data are discussed.

1. Introduction

During the next 10 years the development of the construction sector will meet new challenges. Two of these challenges seem of primary importance :

1. Information technologies will be used more and more in all stages of conception, production, utilization, and recycling of a building, but integrated tools will be lacking. Data management will be the central issue.
2. The impact of construction on the environment will become an important criterion of choice. The usual decision criteria affecting investment costs will be enlarged during the lifetime by new costs (exploitation, energy, maintenance, refurbishment, recycling.) Additionally, the consumption of energy in all its forms (direct, embodied) as well as the impact on the environment will become a new decision criterion.

These two challenges are strongly linked. It is not possible to know the life cycle costs , without having integrated data management tools which link the different phases of conception, realisation, utilisation, and recycling.

1.1 Building Industry

The environmental and energy issues are important for the building sector. Building as a whole is one of the most energy intensive activities. Energy consumption for space heating, cooling and warm water accounts for 30-50 percent of the overall energy consumption in industrialized countries. The building industry probably absorbs the largest part of energy of all industries, the energy consumption per value being relatively high. The building industry consumes the largest quantities of raw materials of all economic and industrial activity. Its waste production is equal if not superior to the domestic waste production. The impact of building activities on the environment is very large, on one hand through the amount of energy consumed, on the other hand through the destruction of vegetation and animal habitat.

2. Life-cycle Costs

The basic definition of life cycle costs is: "The sum of all costs incurred during the lifetime of an item, i.e. the total of procurement and ownership costs. " [DHIL]. The primary uses of life cycle costs are in comparing different projects and controlling going projects. These objectives cannot be reached through usual financial cost accounting when energy, resources and environmental impact issues become predominant.

All existing life cycle cost models reflect the objectives of the owner of the equipment. They take into account only "real costs" which have to be payed. It is, however, clear that the real overall cost of any type of item is much larger if we take into account the social costs associated with the production, use and disposal like :reducing natural resources, using public facilities, pollution of all kind, noise, sickness and accident, destroying natural and urban scenery

These costs are considered "external" costs in economic theory [HOHM], because they are not charged to the user of a piece of equipment but are accounted for by society (this is why they are also called "social" costs). In the building sector, traditional life cycle cost calculation has been practiced for a rather long time. [BEKK].

The objective, to establish a systematic and broad approach to life cycle costs of buildings, raises immediately two difficulties:

- the description of a very complex system touching human activities (as well as the environment (chemical cycles, organisms, water, soil, air, energy, information and material flow).
- there is no way to "measure" the life cycle costs in the way an accountant can calculate the financial costs of any item and then compare the calculated money flow and the real money flow.

Whatever will be done will rest on the level of a model: a very simplified representation of reality. Of course some of the inputs of the model can be quantified and measured, some of the outputs also. However, the non measurable part of inputs and outputs will be predominant. [KOH91b]. Furthermore it will not be possible to construct one overall model which will give the answers to all questions. There will be a spectrum of different models (model of a building, model of the environment, economic model etc.) which will be of different types and different levels of precision. These models will, at least for the moment, be only loosely connected.

The basic objective of all models will be:

- to describe different processes in a similar way
- to identify and quantify flows (of material, energy etc.)
- to choose strategies as well for particular situations (construction of a building at a certain place) as for general purposes
- to allow to imagine possible futures, either by prospective techniques or by backcasting [ROB].

There is one idea which will have to be abandoned immediately: there are no "true" or "right" values of total energy needs, social costs, pollution impacts. All answers will depend on the limits of system and on the way the models work. This situation is rather new, and the main methodological consequence is that it is as important to say what models are used and where the system limits are, as to present results.

3. Mass and Energy Flows

3.1 The Basic Model

A building is represented during its life time as the superposition of different flows and activities.
The physical flows are :
- Material flow (Building material, water)
- Energy flow (embodied and operation energy)
- Waste flow (building materials and waste from use)
- Pollution flow (part of waste which is considered pollution)

The basic activities are:
- Production of the building materials
- Construction of the building
- Use of the building
- Maintenance and refurbishment of the building
- Demolition and disposal of the building

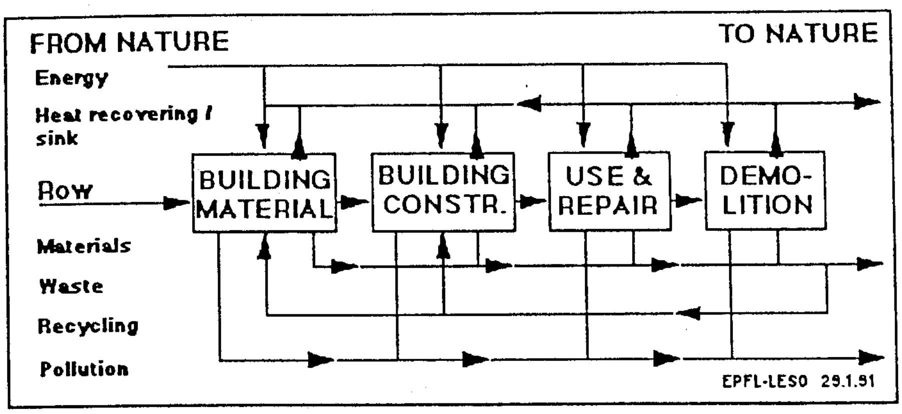

Fig. 1: General Model.

Money is an exchange medium that flows as a countercurrent to materials, energy and information flows . Financial flows can therefore be associated with all of the physical flows and activities. This allows us to identify the internal as well as the external costs.

4. System Limits and Evaluation

The question of how to find the value of limited resources has not found an answer in economic theory at all. The first attempt goes back to Hotelling [HOT].A number of economists have tried to find a link between energy, resources and economic theory.Traditional economic theories limit themselves to the price mechanisms in a market economy. The neoclassical economic theory limits itself to economic goods which are by definition rare [WALR]. It is quite evident that certain environmental goods (like clean air) become rare, but while they are not exchangeable, they do belong to somebody. Environmental qualities therefore do not have a price in the sense of the neoclassical theory.

4.1 Necessity to Separate Data from Evaluation

In order to be able to establish the Life cycle costs, the flows of materials and the construction operations of a building must be known for the entire life cycle of the building. The knowledge of these flows and operations exists to a large extent today, but it is dispersed and in very different formats. All the flows and operations can be evaluated according to mass flow, energy flow, information flow, use of resources, financial flows and environmental impact criteria. These quantitative data can be determined with the necessary precision and put in relation with other data (how much aluminium goes into a window during the window's lifetime etc.). The evaluation of these flows (how much they cost, what their impact is on the environment) passes generally through the attribution of unitary prices or coefficients of emission, for example.

It is very important to separate the quantitative data from the evaluation. The evaluation of the flows and their appreciation in a larger context must be possible from different points of view and in different ways. The goal of the evaluation is to allow the decision maker (designer ,owner, politician, producer) to make conceptual, political, constructive, and economic choices.

4.2 Different Evaluation Methods

There are different attempts at overcoming the shortcomings of actual economic theory and finding a link between the economic theory and environment. We will briefly look at three models:

a) Monetarisation of External Effects:

This is in fact the extension of the neoclassical theory towards external costs. The basic definition of external costs are costs which are not supported by the producer of a good but by other persons or the collectivity (that is why they are also called social costs). External costs are generally costs of negative external effects. The classical example are the cost of reparing buildings or of the health system (increase in lung sickness) resulting from the dissipation of SO_2 produced by the combustion of coal or oil. [HOHM],[WICK]. These external costs can be described in a simple conceptual model.

from / to	Economy	Environment
Economy	MARKET	WASTE(external)
Environment	"FREE" RESSOURCES	NATURAL CYCLE

Fig.2: Input-output economy - environment

b) The Ecological Bookkeeping Methods:

b1: Equivalence Coefficients:
These methods try to find indicators for the use of rare resources or for the impact on the environment. There are several theoretical possibilities [BRAU].

The use of resources can be modelised by an "environmental price" which would give the equivalent of the ecological rarity of a good. It is a kind of "environmental currency". These equivalence coefficients are expressed by physical units of used resources or emissions.

b2: Equivalent Volumes of Air, Water, Soil:
Another attempt to introduce a type of ecological bookkeeping is based on volume coefficients.[BfK]. They establish a relation between the effective pollution of any type and the admissible quantity of this pollution per unit of air, water or soil. The admissible value is the MAK or the MIK value, i.e. a legally tolerated concentration.

b3: The Ecological Pay-back Time:
The idea is the same as the financial pay back time [HOF] For any type of investment we can compare the invested amount with the achieved return. This method allows us to compare the replacement of warm water production by oil with production by a solar collector during the life time of the two systems. One can also compare if a new technology, during its lifetime, will cause a larger or smaller pollution output than it needed to produce.

c) System Ecology:

The most complete energy-economy- environment models have been established by Odum [ODUM].
For Odum "the environment has organisms, chemical cycles, water, air, humans, machines, soil, cities, forests, lakes, streams, estuaries, and oceans; and connecting them all are flows of energy, including that associated with matter and information "The environment can be described in a system language which is basically an energy circuit language. The energy language is chosen because it is a way of representing systems in which all phenomena are accompanied by energy transformations. In practice energy is defined and measured by the heat that is formed when energy in other forms is transformed into heat. The energy language keeps track of flows of potential energy from sources going into storages or into work transformation and finally into degraded form as used energy leaving the system. Pathways of the energy language are pathways of energy flow.

5. Life Cycle Costs and Building Description

5.1 Flow- and Process-oriented Description

The basic concept in our approach is the definition of a basic process entity. In proceeding to detailed analyses of the production of materials and components we use one single model.[KOH91a] This basic process model characterizes each process by its system limits and its input and output.

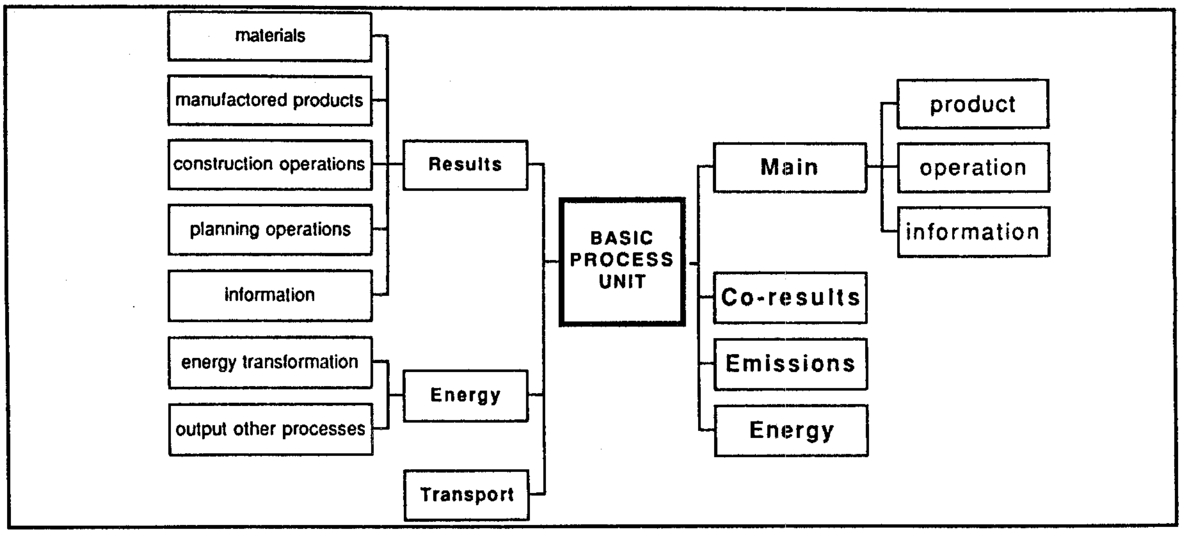

Fig. 3: Basic Process Model

The model is based on a complete mass (and energy) balance. It can be used to describe as well the transformation of energy (extraction of coal, combustion of wood etc.), the production of a material, the production of a component.[IDEA]. It can also be used to describe a service like the drawing of a plan. The drawing of a plan is an activity which has not only an information flow but also a mass flow and an energy flow . The definition of the materials considered as pollutants, i.e., indicators for pollution, is given in [KOH91a]. As we are dealing with units of results (e.g. 1 kg, 1m2) the pollutants take the form of emission coefficients and of specific energy intensity.

All materials and operations are identified in a general conversion table. It is possible in this way to associate a number of characteristics to this model (situation in the building process, association with actors, contracts, documents). The model contains no specific data like physical constants of materials nor general emission coefficients. The advantage of this way to proceed is that there is a clear separation between a description of the physical reality and the evaluation of this reality. Furthermore, the model does not contain specific data on materials and processes which are situated in other data structures allowing specific updates.

It is possible to describe the whole life cycle of a building as a succession of processes. The conceptual data structure is open allowing the application of different evaluation methods (views) during different phases of the life time (which themselves can be changed.) For the moment we will consider the following phases:
- preparation of final energy (kwh of electricity used in an office building)
- preparation of construction materials (kg of aluminium in the al-factory)
- preparation of components (m2 of wood windows with in the window factory)
- preparation of building part (m2 of window in the building)
- maintenance and refurbishment of the building part (m2 of window)
- demolition of the building part (m2 of window)
- disposal of the building part (m2 of window in the corresponding place)

Each material comes from nature and ends up in nature even if the form changes during its life cycle. Energy comes either from nature as a material or directly from sun (warm air, radiation). We do not consider human work time in this model because the energy necessary for the reproduction of human labour force is negligible as an energy flow in an industrial society (but not in non-industrialized societies [KOH86]).

5.2 Links with building description

We adopted for the moment the codification used by quantity surveyors for the description building operations and process stages. in Switzerland [CRB-NPK] operations are described as standard building construction operations like "pouring 1 m3 of concrete for wall construction not higher than 3 m" . All the standard operation description give the quantity of materials and the type of work. It is furthermore possible to know the amount of labour, the average percentage of lost materials and the average transport distance. Each of these operations (or materials) can through the establishment of preceding basic processes be quantified in terms of embodied energy, pollution emission etc.

The building itself is described in the form of cost-elements. [CRB-EKG]. These elements are considered "as built" elements (in situ). They comprise four characteristics :a function, a composition ,a reference surface, associated building operations. There is no need for a more refined geometrical description of a building at the level of precision at which we work. The principal advantage of the method is that we can determine enlarged life cycle cost immediately from primary construction costs at an early design stage.

There are however specific problems in the building description and the data organisation. Bookkeeping establishes either a balance (which gives the situation at a specific moment looking back) or a profit/loss calculation which gives the flow during a certain period. Both representations are needed, but there is an additional way of presenting data: during the design process data are needed which anticipate the future life cycle of the building. Such data have a speculative character, and they include assumptions on lifetime, refurbishment intervals, recycling techniques, all of which will take place in the future.We separate these levels very clearly by introducing three life cycles:
- as built (no particular hypotheses)
- as used and refurbished (hypotheses on life time and replacement cycles)
- as disposed (hypotheses on type of demolition, recycling rates etc.)

6. Relation to Building Product Models

The discussion about computer building representation [BJOE86] [IWCBP89] ,[IWCBP91], [MOR90] shows clearly that the actual CAD systems based on solid modelers can not handle large amounts of non-geometric data. There is a common agreement that the building product model approach is the only possible way towards integrated CAD tools [BJOE91].

In the framework of the development of the STEP/PDES standard a general AEC (Architecture-Civil-Plant-Shipbuilding) reference model has been developed [GIEL]. GARM is based on the idea that information is clustered around the so-called Product Definition Units. (PDU's). A product has characteristics which are related to aspects (strength, cost etc). Refinements can be realised by the four following mechanisms: specialisation, decomposition, life cycle identification and classification.

The establishment of life cycle costs implies therefore the combination of decomposition (relation to the basic material and energy flows) and life cycle identification. GARM identifies the following life cycle stages
(as required,as designed,as planned,as built,as used,as altered,as demolished)

These life cycle stages relate principally to the planning process and not to the physical evolution (or composition) of the building (seen as a flow of materials, energy, information during its life time). There are however clear convergencies in the phases : as built, as used, as altered and as demolished.

Building product models based on the STEP GARM principles and modelised by NIAM or IDEF1X like [DEWA] can easily be composed by the basic process models. Each construction element on site is the result of a great number of processes. The distinction of an element in site corresponds to the level used by quantity surveyors in the element methods. In the on-going discussion on modelisation of the construction processes the same level is chosen to be the point of departure as well for looking backwards (to recompose the design process) as forwards (to estimate the life cycle costs). [BJOE91].

7. Implementations

The described approach is of course mainly bottom up. Its first applications are in the field of counseling material and component manufactures on the ecological improvment of their products. The next step will be the establishment of a complete catalogue of building elements linked to the building elements used in quantity surveying. It will be possible to analyse rapidly buildings concerning their environmental impact. The model also allows itself to be linked to traditional scheduling because all processes can be linked to the use of resources (machines, man hours etc) and they can be linked to constraint generators [GLAR]. There are also possible links to other fields like energy simulation [MOR90], [KOH90]. The object oriented description of a building has proved to be an appropriate tool [MOR89].

If the proposed approach is very much a bottom up approach from the logic of the materials and energy flow, it is however possible to abstract from the level of the element on site backwards to more general indications. In energy design most planners use today the estimated specific annual consumption per unit of surface . The same data exist for indirect energy, though they are rather old and based on very simplified models. [KOH86] .

8. Data Structure Problems

The described model is the result of discussions between reseachers in different fields. The impact of the new programming paradigms and of the tools developed in Artificial Intelligence have led to an object-oriented approach in a large sense. [IWCBR89].

There is a general use of the support offered by data base management systems (DBMS) today. Present in a large number of software on the market, most of these DBMS use a relational approach (other use even less recent techniques), where the data are organized in flat structures called tables or relations. If, thanks to its apparent simplicity, this approach has permitted the rapid expansion of DBMS, it has just as rapidly shown its limits. They lie in the discrepancy between the concept offered (the relation) and the complex structures of the objects manipulated in the real applications. A growing number of DBMS users in the application field experienced the intolerable gap between the offered concept and the complex structures they were dealing with. The appearance of new approaches which permit the direct modelisation of complex objects will help to solve some of the mentioned problems [SPAC89].

The influence of a convergence of programming language research with data base research will contribute to the solution of these new user needs. Object-oriented DBMS (the first of which are already on the market) have been born from this convergence: they marry the support of complex objects to a certain understanding of the dynamic aspects of these objects.

Several research projects are articulated around a data modelisation made in terms of complex objects and the relations between these objects. This modelisation equally respects the difference between identifiable objects (and relations) and the values expressing only the information available on these objects. These projects are aimed at the specification and the realisation of a coherent set of user interfaces, where the paradigm of modelisation can be easily implemented by the user himself. This concerns the description and the manipulation of data.

In the research of the method of data base design the problems of the integration of views is central. Methods are currently being specified which aim to permit each user to express with total freedom his view of the data; the software (in this case the integrator) will take in charge the margin of the views thus far defined, and will eliminate redundancies. These techniques must also allow the integration or the merging of existing or new data bases into a distributed database.[SPAC90].

9. Conclusions

We believe that the research in the field of life cycle costs must be coordinated with the work on building product modeling. Furthermore, the two domains raise problems in data structures which are still in research in the computer science field. The cooperation of these three research efforts could lead to interesting results in relatively short time. The urgency of environmental problems (greenhouse effect) makes a better understanding of the impact on the environment of construction and building use a short time necessity.

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