Ecoefficiency in residential building –
A prototype for optimizing consumption of resources

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This prototype was developed to determine key figures (classification numbers) for the resources (1) material, (2) energy and (3) (capital) expenditures for residential buildings. Distinction between construction and utilization phase should give the opportunity to plan long-term ecologically and economically sound products (i.e. buildings). Based on these key figures this prototype provides a ranking of different modulations of a building. The ranking is done by simultaneous reference to the key figures using Multi Criteria Decision Making (MCDM) methods.

The prototype is an instrument for the decision-maker (planer, builder) to realize the impact on consumption of material, energy and expenditures of different planning decisions (different modulations of a building). The linkage of ecological (material and energy) and economical (costs) rating constitutes an important innovation of the prototype.

Keywords: Eco-efficiency, sustainability, multiple criteria decision making, building constructions

1 Introduction

In the face of many ecological problems the concept of "sustainability" has become a relevant topic in building industries nowadays. One of the largest difficulties during planning a "sustainable" building is the question: What is a sustainable building? Or: Is one building more "sustainable" than another? This prototype shall be an instrument, which makes it easier for the decision-maker to answer these questions. As "sustainability" is a concept, which comprises ecology, sociology and economy, the prototype does not focus only on the attempt to optimize the consumption of ecological resources, but considers the financial resources, as well. Furthermore it gives the decision-maker the possibility to determine which of these aspects shall be emphasized. For these purpose suitable criteria have been chosen (see below) which focus on the main problems in building industries.

The objective of the prototype is the ranking of different modulations of a residential building with regard to optimizing the consumption of resources. In a first step the planer has to define the different modulations (different geometry, different parts, …) of the building. By evaluating the criteria the key figures for each modulation are calculated. In the next step the decision-maker weights the criteria, corresponding to its significance. Together with the key figures they are the input into a multi criteria decision making algorithm, which calculates the ranking. Finally, a sensitivity analysis is applied to estimate the uncertainties of the results.

2 Criteria

In order to choose the criteria with regard to sustainability the main ecological problems of the building industry have to be identified. On the one hand there are enormous material flows, created during the construction, maintenance and removal phase of buildings. On the other hand the large amount of energy, which is necessary especially for their operation. Therefore it seems to be useful to choose "*material flows*" and "*energy consumption*" as criteria in order to evaluate buildings ecologically. Looking at the life cycle of a building the material flows has its maximum during the construction phase, whereas most of the energy is consumed during the utilization phase. Thus a further distinction of the criteria between construction and utilization phase is made. The material flows and energy consumption during the removal phase are neglected in this prototype.

Striving for a nearly complete ecological picture of a building it is important to consider not only the material and energy amounts, which are used directly for its construction and operation, but in addition the material and energy consumption which has been necessary to produce the building materials and to provide the energy sources. For this purpose already existing evaluation methods are used which investigate the whole life-cycle of a product: The *Material-Input (MI)* value (see [1]) in order to evaluate the criterion "material flows" and the concept of the *Cumulative energy demand (KEA)* (see [2]) for the criterion "energy consumption".

Investigating the criterion "material flows" with regard to sustainability it seems to be meaningful to distinguish between renewable (biotic) and non-renewable (non-biotic) substances. Therefore the criterion "material flows" is split up in two criteria, namely "*biotic*" and "*non-biotic material flows*".

In the history of the "sustainability" concept a lot of projects could not realized satisfactorily because in many cases the link to economy was neglected. Up to now ecological and economic evaluation methods, i.e. the prices, seems to be more opponents than partners. In this prototype these two methods shall be linked because both of them have their advantages in different fields. Not only the consumption of material and energy resources shall be optimized, but also the consumption of financial resources. For this purpose the criterion "*expenditures*", separately for the construction and the utilization phase, as well. The calculation for the expenditures during the utilization phase is based on life cycle costing (see [3]).

To make the different modulations of a building comparable all eight criteria are referred to the useable floor space. An overview of the criteria and how they are determined provides *Table 1.*

Criteria	Key figures	
	Construction phase	Utilization phase
Material flow (*non-biotic)* [kg/m²]	- **Non-biotic MI values**	- **Non-biotic MI values of the material used for maintenance** - **Non-biotic MIPS values of the energy source used for heating**
Material flow (*biotic)* [kg/m²]	- **Biotic MI values**	- **Biotic MI values of the material used for maintenance** - **Biotic MI values of the energy source used for heating**
Energy consumption [kWh/m²]	- **KEA values**	- **KEA values of the material used for maintenance** - **KEA values of the energy source used for heating** - **Heating energy referring to ÖNORM B 8135**
Expenditures [ATS/m²]	- **Prices**	- **Prices of the material used for maintenance** - **Prices of the energy source used for heating** - **Life cycle costing referring to ÖNORM B 8110-4**

Table 1: Calculation of the key figures referring to the useable floor space [m²]

3 Database

The database is implemented in an MS Excel worksheet. The main idea of the structure of the database is based on the fact that most of the parts of a building are consisting of homogenous layers. Therefore three levels structure the database: The lowest level is the table called "*building materials*": Here the basis data (MI and KEA values) of the different building materials are listed. The second level is the table called "*layers*", containing the MI and KEA values and the price of one square meter of a layer with defined thickness. For homogenous materials these specific data are linear functions of the basis data and the thickness of the layer and therefore can be calculated directly. The specific data for inhomogeneous materials have to be calculated extern and to be entered separately. The third level is the table "*building parts*" where the layers defined on the second level are put together to one square meter of a building part. The three-level structure makes it possible to construct easily new parts by putting existing layers together in a new way, or to vary the thickness of some layers using the same basis data. Of course the data of building parts, which do not consist of layers, can be entered "by hand", as well.

Additionally there are tables containing the data of different energy sources and the data, which are needed for the calculation of the expenditures.

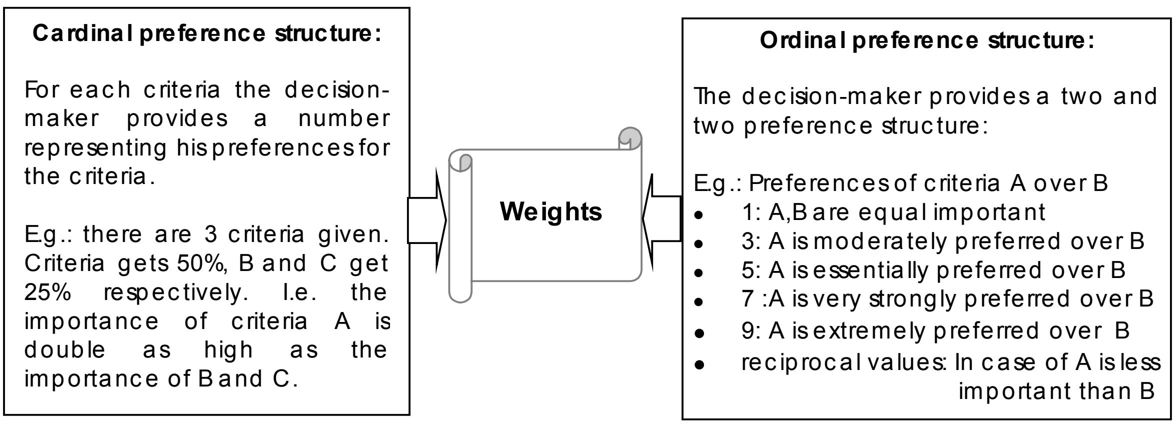
The basis data are taken from existing life cycle assessments where the considerations of the material and energy consumption end when the product leaves the production plant. Those materials and energy amounts, which are used for transportation, for the work at the building site and for the removal of the building or parts of it, are neglected. We assume ± 20 percents inaccuracies in the data.

4 Multi Criteria Decision Making (MCDM)

Multi criteria decision making aims to give the decision-maker some tools in order to enable him to advance in solving a decision problem where several criteria (valued as key figures) must be taken simultaneously into account.

4.1 Weights

One crucial point is to fix the decision-maker's preferences for the criteria, e.g. does he/she want to base his decision more on economic or more on ecological preferences. On the one hand the decision-maker can assign cardinal quantities (weights) to the different criteria based on his preferences (e.g. 50% money expenditures, 25% material, 25% energy). On the other hand he/she can provide ordinal quantities for the criteria, like "low money expenditures are very strong important in comparison with energy"). Verbal judgments "equal importance", "moderate



importance of one over another", "essential importance", " very strong importance" up to "extreme importance" are transformed to numerical judgments 1, 3, 5, 7, 9. Numbers 2, 4, 6, 8 represent intermediate values between the two adjacent judgments. Using the methodology of AHP (see, e.g.,

[4],[5]) we compute weights for the different criteria based on the decision-maker's two and two preferences.

4.2 Ranking

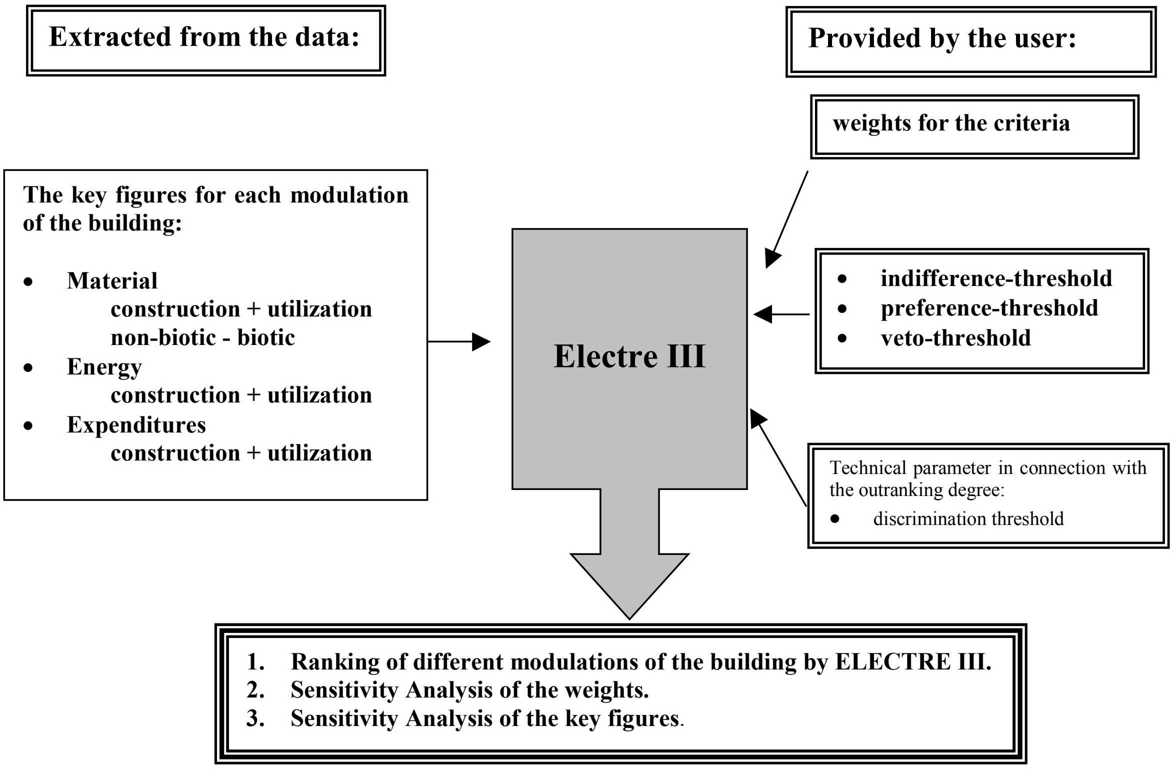
We use the methods *Analytic Hierarchy Process (AHP)* and *ELimination Et Choix Traduisant la Realité (ELECTRE)* that provide a ranking of different modulations of a residential building based on the computed key figures and the decisions-maker's preference for the criteria.

4.2.1 AHP

AHP is a straightforward methodology to rank the different modulations of a residential building by aggregating the normalized and weighted key figures. Then the single-valued sums for all modulations are compared, which provides immediately a ranking. However, there is a problem when the key figures contain statistical outliers. An extremely low material consumption, for instance, can compensate bad performances in all the other criteria (i.e. in comparison higher energy and money expenditures).

4.2.2 ELECTRE III

The ranking by ELECTE is more sophisticated than the ranking by AHP, in return results are not so sensitive to statistical outliers. For a detailed discussion of this method (see, e.g., [6], especially caption 4 "Outranking Methods" written by A. Ostanello). Here we want to add only the key features of the method.



First, based on the key figures and on the weights, an outranking relation (a binary relation) is defined on the set of the different modulations of the building in discussion. Due to the fact that the data are noisy (we assume up to 20% inaccuracy), we decided to implement a fuzzy outranking relation (Electre **III**). Whereas a deterministic outranking relation fully characterizes preference, indifference and incomparableness of two actions A and B by "A (does not) outrank(s) B" and "B (does not) outrank(s) A", a fuzzy outranking relation defines additionally an outranking degree associated with each pair (A, B). This outranking degree fixes the credibility of the outranking of A and B. The decisions-maker governs the outranking degree (the fuzzy outranking relation) by three thresholds: indifference-, preference- and veto-threshold. Fixing these thresholds to zero would reduce the fuzzy outranking relation to a deterministic outranking relation.

Secondly, the outranking procedure exploits the outranking relations to create a (partial) ranking of the actions. The basic idea of the method is to look for actions that dominate (are dominated by) other actions; domination is determined by the outranking relation together with the outranking degree. After sorting out these actions, extracting of dominating (dominated) actions continues.

4.3 Sensitivity analysis

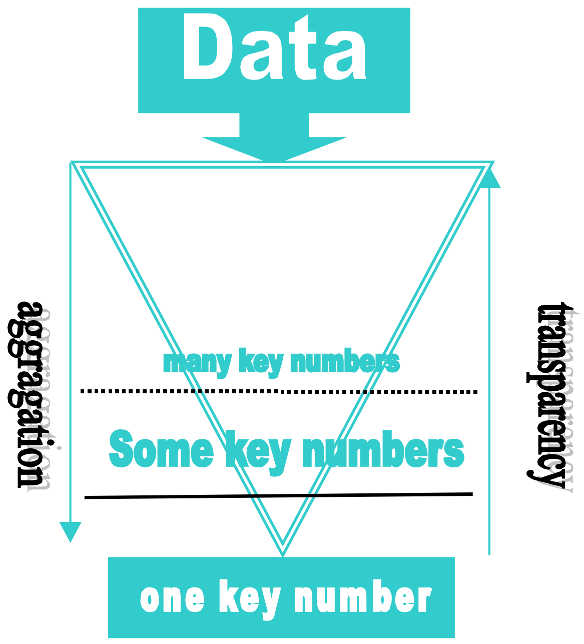
Sensitivity Analysis provides insight, how sensitive results respond to perturbations in the weights and to perturbations in the key figures. Due to the inaccuracies in the raw data it is essential to check the consistency of the ranking referring to perturbations in the key figures.

4.4 Implementation

The user provides the information about the modulations of the building and the preference structure in a MS Excel Worksheet template form. The kernel of the prototype is a C/C++ standalone program, which reads the data from the MS Excel database and calculates the key figures for the given modulations of the. If an ordinal preference structure is given, the weights are computed in the kernel. Finally, the rankings based on AHP and on ELECTRE III are determined. The results are presented in tabular and graphical form in MS Excel.

5 Conclusions

Without a doubt the possibility of weighting the criteria explicitly is a major virtue of the prototype, particularly as different sets of weights may potentially cause different first ranked modulations of the building. Attention is visited to the fact that this is not a defect of the prototype, but it is in the nature of the matter. Such as determining an economically concentrated preference structure may rank first a lower-cost modulation of the building, whereas an ecologically concentrated preference structure may rank first an energy- and material-saving modulation of the building. The crucial point is that the preference structure persists transparent. In contrast, this transparency dwindles away, when the raw data of a modulation are aggregated to a single key number. Of course, in this case someone else has determined the weights of the criteria in advance and the weights are incorporated implicitly (and invisible for the user).



The important innovation of the prototype is the simultaneous consideration of ecological and economical aspects. Furthermore the prototype is designed in a way, which allows incorporating additional (other) criteria without large efforts (e.g. human toxicity and ecotoxicity).

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