Design and Evaluation in the Early Phases of the Design Process Some Problems and a Solution

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This contribution contains the description of a design and evaluation system which is formulated for the early phases in the building design process. These phases include the conceptual and the preliminary design steps. The design system is based on the idea that the evaluation should be performed on the same kind of data throughout the design process. That means that as the decisions about a number of attributes of the design are not yet taken, the system automatically provides the default values for those attributes.

INTRODUCTION

One of the problems in the early phases of designing buildings is making reasonable accurate estimations of costs and performances on basis of a proposed spatial structure. In practice this problem is usually solved by applying rule-of-the- thumb measures or relying on past experience. In this day and age this seems rather unsatisfactory.
A number of researchers have solved this problem by for instance focusing on the design of the building envelope (Fazio Bedard and Gowri 1989) or on dividing the design process in a number of steps and applying for each step the appropriate estimation method for the thermal performance of designs (Shaviv and Kalay 1992).
In the first case the effort was directed at generating a number of design alternatives with respect to a set of different performance attributes. In the second case a mixture of heuristic and procedural methods were applied; the mixture depended on the design phase. For two reasons we prefer using only the procedural methods. The first concerns the interaction between the general and the particular part in the relationships between design and effect variables in building design.
Applying rule-of-thumbs measures supposes that the effects are only ruled by general laws. Most of the outcomes for the values of effect variables are however influenced by some general laws and by the (geometrical or other) attributes of the building designs. It is fairly impossible to predict the quantitative influence of the one or the other in the resulting relationship. Therefore we recommend developing variant solutions for a specific design problem and study the relationships between the design and effect variables using procedural methods. The rule-of-the-thumb measures that can be developed on basis of this process can only be applied in the context of a specific building design.
The second reason lies in the availability of a number of the relevant computer programs for the evaluation of various subjects at our faculty.
In order to combine the application of these programs to evaluate arbitrary building designs, the design system COSMOS (Hacfoort and Veldhuisen 1992) was set up as a means to define the geometrical attributes of buildings and the material compositions. One of the objectives of the system was to enable users producing building designs with relatively little effort. This objective is reached by defining a large number of default values for functions, layouts and materials.
Another objective was to use external computer programs as much as possible. In order to enable the user to synthesize the separate evaluations, the computer program EVALUATE was formulated. With this program an analysis of the relationships between the design and effect variables may be made.

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It is fair to say that we were inspired by the well known programs GOAL, BIBLE and GLOSS of ABACUS.
The remaining part of this contribution consists of a description of
1. The design system COSMOS
2. The transfer from COSMOS to EVALUATE
3. The analysis of the evaluations
4. The evaluation
5. Summary and conclusion

THE DESIGN SYSTEM COSMOS

Introduction
The design system COSMOS is based on default values for a large number parameters. These parameters are mainly attached to the functions of spatial units and to the construction elements. In the case of the functions, the parameters refer to the desired climatic or lighting conditions of the spatial units; in the case of the construction elements the parameters describe the materials and a number of physical attributes. Before the geometry of the design is established, through defining the sections, an automatic selection is made of a number of subsets of these parameters. This selection depends on the choice of the building function, the choice of the building structure and the choice of the materials of the construction elements. The defaults are based on the building practice in the Netherlands. At any time in the design process, the default values, especially those concerning the construction elements may be overruled by specifying other materials.

The Building Function
In the context of COSMOS a design is conceptualized as a hierarchy of spatial units from building blocks to rooms and spaces. For each of the spatial units a number of attributes is being established during the design process. The central attribute with respect to the performance attributes is the user-function of the spatial units. Each function refers to a particular regime for energy and light conditions.

Building Block	Building Function
Section	Section -
Room/Spaces	Room -

For the rooms/spaces the parameters describing the energy and light conditions are relatively easy to establish. The next step up in the hierarchy, the sections, may be regarded as clusters of the rooms or spaces that form them. Consequently the parameters of the sections referring to the energy and light conditions are estimated on basis of the combination of the relevant rooms. In general, a unit of higher order forms a cluster of the next lower order. For each of the building functions, 11 in total, a list of sections and rooms has been predefined (for an example see appendix).

The building structure, the construction elements and the materials
In a similar way, a set of building structure types is a priori defined. As the type of the building structure and the choice of construction materials are usually related, sets of materials are therefore also defined as defaults.
The properties of the materials, from which the construction elements are composed are used to calculate the parameters for heat, light and sound transmission. Apart from that, the costprices for the materials and for manufacturing the construct- ion elements are used for the cost- calculation.

Building Structuctures	Construction Elements
Load-bearing brickwork	External cross walls
Solid concrete	Load-bearing
Heavy prefab	separation walls
(precast concrete)	Internal Panels
Medium prefab	Floors
(concrete/metal framing)	Roofing
Light prefab	Windows
(metal/timber framing)	Doors

Defining the Section
The functional sections form the central units for the definition of the spatial structure of the building design. The building blocks and layers are a combination of one or more sections. The sections can be divided into rooms or spaces by placing panels. Zoning can be used to direct this division. Apart from the functional sections, i.e. sections with a specific function, roof-sections can be defined. The base of both kinds of sections can take the form of a rectangle, a triangle, a regular polygon or of a combination of these three. The functional sections are completed with rectangular vertical panels with identical height. The roof-sections are defined by using the base together with a roof-tree, resulting in a set of roofpanels. For an illustration of the kind of input the reader is referred to the appendix.

The default sections
To enable the user making an evaluation of the design without specifying the floorplans of the section's, default sections may be applied. The basic idea is to use a set of values for inner panels, doors and windows so that the evaluation of costs, energy costs and loads can be performed. In order to produce these values, a model layout for every section is designed and afterwards, for each of the categories, normalized on m2 floorspace. The values are used in the basic external file that serves as a database for the numerical evaluation by the program EVALUATE.

The two path's through COSMOS

There are two path's to through COSMOS.

Path 1 consists of defining the spatial structure by entering the sections and taking the decisions about the functions and the materials of the section panels. Apart from that, the interior division of the sections can be made through placing the inner panels, windows and doors by specifying their end points.

Path 2 consists of effecting changes in all the attributes (functions, materials, inner panels etc) keeping the spatial structure constant.

Whenever path 1 is completed, COSMOS can be terminated and restarted again to accommodate changing the attributes.

In either of the path's the design can be evaluated.

THE TRANSFER FROM COSMOS TO EVALUATE

The transfer of the data from COSMOS to Evaluate is technically performed by means of a number of different data bases.

The internal and external data bases

The estimated performance attributes of the design concern energy, light, acoustics, utility and building structure. For each of these subjects external data sets are produced and used to perform the desired calculations. Apart from the structural calculations the results are added to a basic external data base to be related to the design variables. The complete overview of the internal and external data bases is being shown in figure 1.

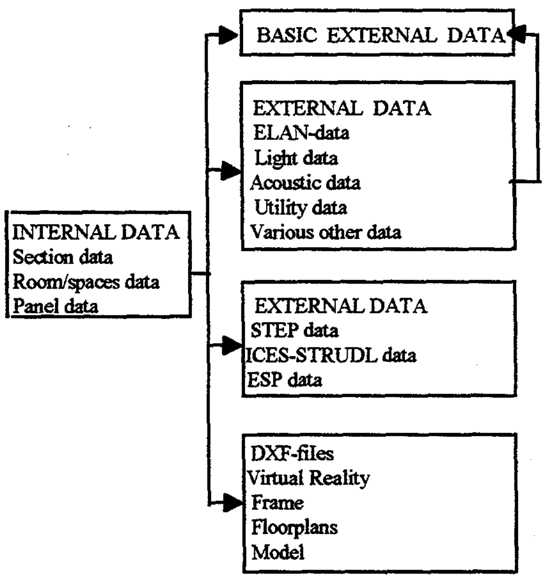


Figure 1. Overview of the internal and external data bases

The internal data bases

The elements of internal product model form the contents of the data bases for the sections, the rooms and the panels respectively. These data bases together contain all the attributes of the various spatial units and the panels as well as the geometrical data.

The section data consist of the attributes of the building block, the attributes of the separate sections and the coordinates of the section-bases.

The rooms data consist per section of the attributes of the different rooms and the pointers to the records of the panel file.

The panel data consist of the attributes of the panels including those concerning the relations between the panels and the adjacent sections. Apart from that the records contain the geometrical data.

The three data bases keep the same form through-out the design process; the only possible changes concern the various attributes. If the sections are not yet partitioned, the room data refer to one room only. This room is then identical to the section it belongs to.

The basic external data base

COSMOS produces a data matrix in essentially the following form. The analysis units consist of the sections. The variables consist of a number of the attributes of the sections and a number of effects.

	Design and Effect Variables		
	Design	Internal	External
	1........k	1..........l	1........m
Section 1			
.			
.			0
.			
n			
	--------	---------	--------
Design #			

The number of internal effect variables produced by COSMOS is limited for a number of reasons. The first reason lies in the fact that the range and complexity of specialized computer programs for a number of aspects is growing. At the same time the designer needs receiving a rapid feed-back in a fairly simplified form for his solutions to give purposeful direction to his design. In order to apply a set of easy to use extensions of the "rule of the thumb" measures by the designer and, at the same time, to open the possibility of applying specialized calculations a difference is made between internal calculations which are part of COSMOS and external programs. The subjects of the internal effects concern the costs of the panels, a daylight factor and the thermal insulation of the outer panels. The four external programs presently in use for energy, light, acoustics and utility produce data that may be used in the third part of the data matrix. As far as COSMOS is concerned the values are 0.

The external effect programs

The energy costs and climatic conditions are calculated with the program ELAN (De Wit and Driessen, 1988).

The lighting conditions are calculated with the program SKYAP (Vijgen 1993 personal communication). Using this program the luminance for different sky conditions may be calculated for specific rooms or for a set of rooms for a section.

The calculation of the sound transmission is carried out with a program, based on a empiric model. This model is formulated and tested by TPD- TNO (Gerretsen 1979) to calculate the frequency-dependent sound transmission between two rooms by partitions and by flanking structures.

The basis for the application of utility has been developed in the context of designing floorplans for or by potential users (Veldhuisen 1988). This has resulted in a computer program that can be applied to arbitrary utility values for the building designs at hand. As in the case of the former performance attributes, the results of the calculations may be added to the external effects.

Apart from the output from the four programs, any other set of values may be added to the basic external file.

The external data bases

One of the properties of the internal data is their redundancy. This means, for instance, that if two sections are adjacent, they will have a number of planes, edges or points in common. In order to make adding or deleting sections fairly easy, or at least to minimize the calculations on the geometry during the design process, this redundancy is necessary.

Nevertheless, some application programs suppose a non-redundant database as a product model. For two of these programs, ICES-STRUDL (GTSTRUDL 1988) and ESP (see e.g. Clarke and Maver 1991) the topology or geometry data are similar or partly similar to the data of the STEP-file (Altemueller 1988). Although STEP is still in the process of being accepted as a standard, the basic form is sufficiently clear to base a STEP-file (according to the draft of ISO 10303-42) on it. This STEP file can be produced by COSMOS and serve as a means to produce ICES-STRUDL and GENeral-body files for use in ESP.

The DXF-files

One of the exciting developments in the recent years is that of virtual reality. One of the efforts of our group Calibre is the translation of designated dxf-files into virtual reality files. Consequently a design made in COSMOS can be inspected in virtual reality (Smeltzer Roelen and Maver 1992).

For the presentation of the design the frame may be shown in isometric projection.

In order to present the preliminary design a floorplan file can be made in further detail using a library of utilities and furniture.

The last file to be produced enables the designer to make a paper model of the design.

THE ANALYSIS OF THE RELATIONSHIPS

Suppose that for a particular design problem a number of variant design solutions are formulated. Suppose also, that the databases of these solutions can be used forming a single data matrix of the form (already discussed in the previous section):

	Design and Effect Variables		
	Design	Internal	External
	1........k	1.........l	1..........m
Design 1			
.			
.			
n			

The design variables are in this context the parameters which describe the design-geometry like volume, floorspace etc. The effect variables could for instance contain the costs of the outer panels and the energy consumption for heating. The different designs can be considered as the units of analysis.

The data matrix enables us establishing the relationships between the design variables or attributes on the one hand and the effect variables or performances on the other.

A number of statistical methods could be applied, in order to draw any conclusions from the differences between the designs.

These methods can be roughly classified into uni-,bi- and multivariate methods.

The uni-variate analysis does not, as a rule, yield any insight into the particular relations. This means that possible cause-effect relations can not be inferred from the data. At best, it can produce a frequency distribution for each column of the data-matrix.

Using bi-variate analysis the relation between any two variables can be shown. Allowing for the different levels of measurement of the possible variables (ratio, interval, ordinal or nominal), in principal two forms of expressing these relationships are possible. The first form requires a linear least-squares equation describing the relation, the second form a contingency table (see e.g. Blalock 1960; Siegel 1956). Although literature about it is very scarce, the ABACUS computer program GLOSS, documented by Dinjens and Eegerdingk (1987), also uses some kind of

bi-variate analysis.
Multi-variate analysis can take various forms. Multiple regression, for one, offers interesting possibilities and can be regarded as an extension of the linear regression method already mentioned. Other multi-variate methods which can not directly be applied for the prediction of a single independent variable are not very useful in this context.
The last form that can be considered is Multi-Criteria-Analysis. MCA makes it possible summarizing an entire design into one single parameter so that the designs can be easily compared. Usually it is necessary using weights to calculate the combination of the design parameters. The main disadvantages of the method are that different designs can yield the same value for the summarizing parameter and that it is impossible trace any possible trade-offs after the analysis.
In view of the advantages and the disadvantages of the levels of analysis presented here, bi-variate analysis is preferred. In future the application of multiple regression may be included.
Only the scattergram variety of the bi-variate analysis is applied while the variables are only established on either ratio or interval level.

THE EVALUATION

Introduction
A distinction may be made between two kinds of evaluation. The first kind consists of making judgments of the morphology of the designs in question. The second kind consists of estimating the costs and performance attributes of the design (to be realised). The last kind is characterised here as the numerical evaluation and can be performed with EVALUATE.

The evaluation of the form
In order to perform an evaluation of the form, COSMOS produces (on request) a described set of AutoCAD drawings (see for the example the appendix).

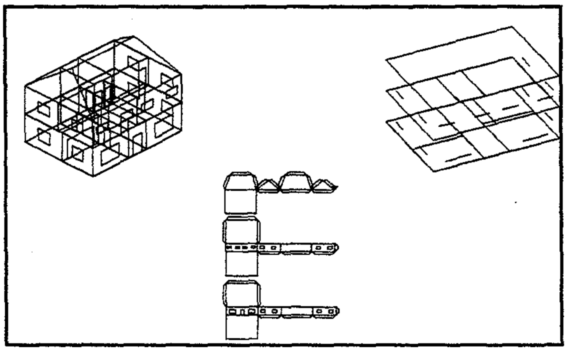


Figure 2. Frame, floorplans and model

The numerical evaluation with EVALUATE
The numerical evaluation is based on the supposed covariance between values of design and effect variables for the different spatial units or designs.
The design and effect variables are two by two combined into scattergrams in which every point depicts a section or design.
Two modes of assessment are possible. The first is based on nine relationships between a fixed set of variables. These relations are on request shown while executing COSMOS. The second mode of operation is only possible while executing the program EVALUATE. This program allows the user combining any pair of variables.
For the time being, the following list applies for the design and effect variables:

Design variables:
1 = volume in m3
2 = floorspace in m2
3 = outer panels in m2
4 = all panels in m2
5 = glass in m2
6 = orientation in degrees
Effect variables:
7 = costs panels inc. floors in Dfl
8 = costs outer panels in Dfl
9 = costs glass/windows in Dfl
10 = thermic insulation index outerpanels
11 = day-light factor

The fixed set of relations
For the fixed set of scattergrams, shown in COSMOS and EVALUATE, three kinds of relations are distinguished:
- between design variables
- between design and effect variables
- between effect variables

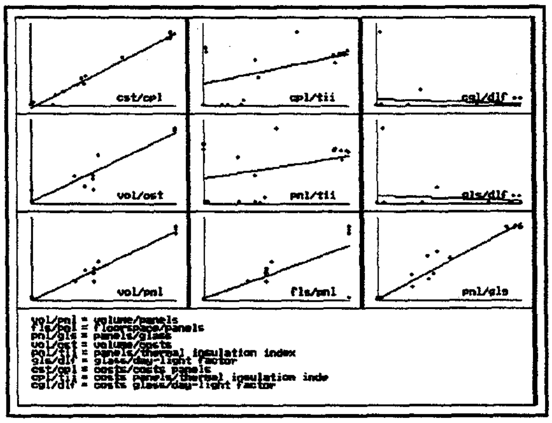


Figure 3. The fixed set of scattergrams

In figure 3 the results for a office building with a volume of approximately 8600 m3, consisting of 20 sections are shown.
On the bottom row: the relations between the volume/panels, floorspace/panels and panels/glass;

on the middle row: the relations between the volumes/costs of the panels, the panels/ the thermic insulation and the amount of glass/day light factor; on the upper row the relations between the total costs/ the costs for the outer panels, the panel costs /the thermic insulation and the costs of glass/the day light factor.
The first variable is always supposed to be the independent one (and shown along the Xaxis) while, consequently, the second variable is the dependent one (along the Y-axis) even when the relationship can not be considered causal. The relationships are shown in the form of least-squares lines.

The single bi-variate analyses
For the purpose of the illustration we add the next list to the core of the 11 variables of the data base:
12 = energy consumption heating in KWh
13 = energy consumption cooling in KWh
14 = % hours under minimum control temperature
15 = % hours above maximum control temperature
16 = mean thermic insulation index design

In the following figure the relation between one of the design variables and the energy consumption for the example design is shown.

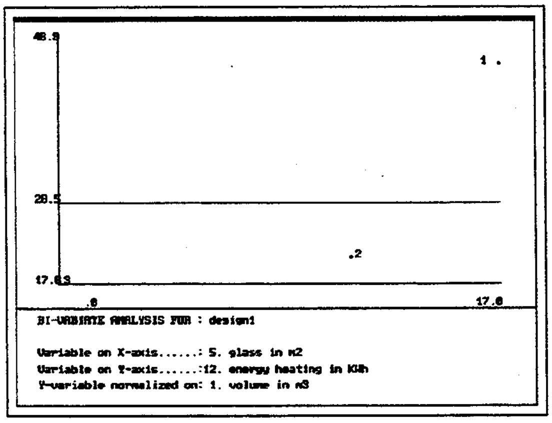


Figure 4. The relation between the amount of glass and the energy consumption per section

The energy consumption is calculated per m3 volume; the difference between the sections is mainly due to differences in the amounts of glass, the differences in the control temperatures (for the different functions) and the heat transmission losses through the different materials.
To investigate the contributions of two of these design attributes to the total energy consumption, two changes are made, following the path 2 through COSMOS.
Firstly the function of the sleeping section is changed into that of a living section; secondly the amounts of glass for the different sides of the sleeping section are made equal to those of the living section. For each of the two changes a separate design is made. The results of the analysis are shown in figure 5.

The analysis of different designs

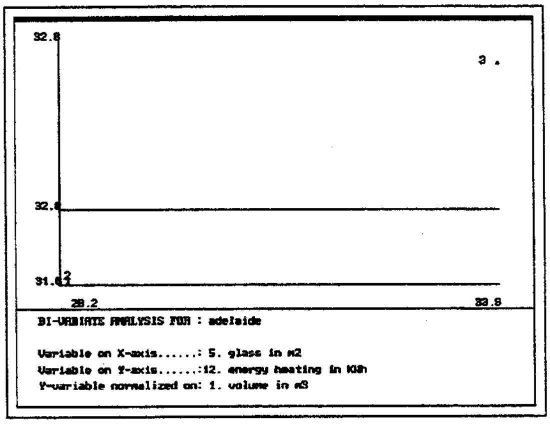


Figure 5. The comparison between the energy consumption of the three designs

The effect of the change of the function is neglectable. An additional analysis of design-2 has shown that the energy consumption for the two sections differs very significantly from that of design-1 but the totals are practically equal.
The effect of the difference in glass surface is approximately 3 %. Other effects of the design attributes on one of the other performance attributes can be analysed in a similar way.

SUMMARY AND CONCLUSION

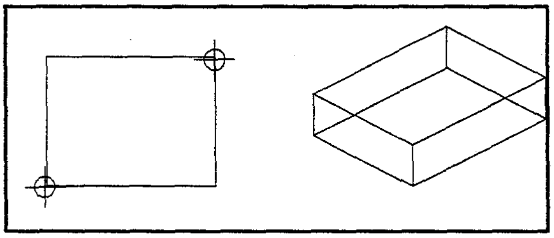
COSMOS is developed for defining and evaluating architectural designs using a set of default values at the beginning of the design process.
For the morphological evaluation COSMOS produces the necessary files to be used by AutoCAD for virtual reality, isometric projection, detailing floorplans and for making a 3- dimensional model.
For the numerical evaluation a distinction is made between the evaluation during the operation of COSMOS and an external evaluation. The internal evaluation is based on differences between spatial elements of the building design, the sections. The external evaluation is based on differences between a number of various design solutions. The program EVALUATE is developed to assess the particular and general relationships between a number of design and effect variables. The numerical evaluation is based on bi-variate analysis.

APPENDIX

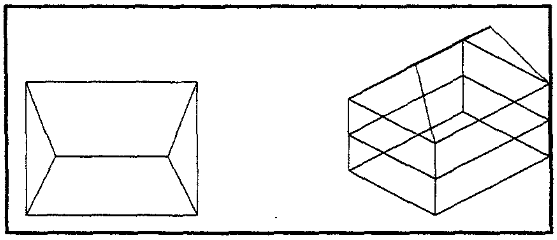
1. The List of Section and Rooms Functions for the Building Function: House

1. house	8. storage
----------------	9. bathroom
2. living section	10. toilet
3. sleeping section	11. service
----------------	12. horizontal circulation
4. entrance	13. vertical circulation
5. living	14. unheated
6. bedroom	15. roofsection
7. kitchen	----------------

2. Illustration of the Input for a house
The input is illustrated with the following example:
1. specifying the building function: house
specifying the structure type: brickwork;
2. specifying the function of the section of the ground floor: living section;
3. entering the groundfloor by specifying two points, the materials of the outerpanels (if different from the default) and the percentage of glass (by default 0 %);



4. repeating the input for the second floor, the sleeping section;
5. entering the roofsection by
- defining the (rectangular) roofbase,
- specifying the two end points of the roof-tree;



(at this point in time the first external evaluation may be carried out.)
6. entering the inner panels, windows and doors by specifying the endpoints.
For the final result see figure 2.

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