

## **Simulation and evaluation of environmental aspects throughout the design process.**

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### **ABSTRACT**

The evaluation of environmental aspects in architectural design has traditionally been performed by means of simple (and often simplistic) rule systems. These generally remain at the normative level of minimal control one encounters in building rules and regulations, thereby failing to provide sufficient information and clarity for design guidance. Despite this, evaluation results normally bound subsequent design decisions as fundamental, inflexible constraints. At much later design stages, when architectural form has been largely crystallized and when environmental subsystems must be specified in detail, both the architect and the contributing engineers often realize the severe limitation of the initial choices.

A frequently voiced argument for such simplification in the guise of abstraction is the lack of detailed information on the form and functional content of a building in the early stages of the design process. This obviously presupposes a *tabula rasa* generative approach. The application of *a priori* knowledge in the form of types, cases, precedents and automated recognition permits direct transaction from the abstract to the specific at and between a number of predefined relevant abstraction levels in the representation.

The combination of *a priori* knowledge at the typological level with multilevel representations permits the use of precise simulation techniques already in the early design stages and throughout the design process. The simulation results employ the dual representation principle of scientific visualization, thereby linking form with measurable performance. Feedback from the simulation provides the analysis and evaluation means for design guidance and for communication between the architect and the contributing engineers. A prerequisite to this is that the abstraction level in the representation constrains the analysis derived from the simulation, e.g., by means of grades of fuzziness applied to different zones in the representation on the basis of information specificity.

### **1. INTRODUCTION: DESIGN AND ANALYSIS**

In contrast to other design professions, architecture is a discipline where design performance must be judged on many different aspects. Some of these aspects, such as aesthetics and structural integrity, are within the capabilities of most architects. Experience, information and technology provide the means and criteria for assessing aspects like form and stability. Other design aspects are more difficult to predict and often require the assistance of contributing engineers. Consulting these experts at an early design stage is cumbersome and expensive and is consequently often postponed to a later stage.

However, the distribution of light, air and humidity have great impact on the occupants' interaction with the building. Design decisions that may determine the resulting indoor climate are taken in early design on the basis of limited information at a high abstraction level (Luscuere 1992). The quantities needed for assessment of indoor environment are either difficult to measure or not present in the current design representation. In order to have the capability of control over the designed artifact, the designer needs constant feedback on aspects relating to the design parameter(s) under investigation. These range from floor areas to describing the complex motion of air, smoke and people in the building and are usually produced by either experts (including the designer) or automated analyses. Our research concentrates on the development of automated analyses which also facilitate communication between the designer and contributing engineers on both isolated aspects as well as on integrated evaluations (Luscuere 1996).

Communication between designers and specialists is based on abstraction, i.e., the exchange of abstract descriptions of a design. The advice given by specialists is an abstraction of the systems and techniques that make up the intellectual equipment of their area. The goal is to transfer the principles of the applied mechanisms without overloading the architect with technical details. This is frequently achieved through visualization. Especially when several alternatives must be considered, the final choice is normally a matter for the designer. Climatic installations are usually designed with few constraints from each particular design. This makes installation types applicable to many situations (also within the methodology of case-based design) but also creates the possibility of deferring installation choice until the design is completed.

The integration of analyses in designing is largely a matter of approach. Design approaches can be classified under three basic categories (Koutamanis 1997c):

1. *proscriptive*: Proscriptive approaches limit design actions and products to certain *a priori* areas. Acceptability of a design is determined by whether it falls within the confines of the approach. Prime examples of proscriptive systems are architectural styles, where specific attributes become the *sine qua non* of the system. A classical building, for instance, must contain elements from the canonical orders. Otherwise it may fail to register as a classical building (Summerson 1980).
2. *prescriptive*: Prescriptive approaches imply that a (good) design can be achieved only when a specific sequence of actions has been followed. Such approaches are usually found in a theoretical or computational context, i.e., respectively as deterministic formal models of designing or as algorithmic design instruments.
3. *descriptive*: The descriptive approach is emerging from the necessity to tackle an ever increasing number of design aspects and amounts of design information involved in architecture and building of today. This approach relies on explicit information that is processed in a way that provides decision support mainly through feedback.

These three categories have their counterparts in design analysis and evaluation:

1. *normative analyses*: These derive from proscriptive design approaches: a design is acceptable with respect to certain criteria if it is within the solution space(s) defined by the criteria. Building rules and regulation operate in a normative fashion, by measuring building performance against thresholds of acceptability.
2. *knowledge-based analyses*: Long before the emergence of artificial intelligence professional knowledge has been formalized in textbooks and reference sources in a prescriptive manner. Instead of generating a design, such knowledge parses and evaluates design through sequences of the same steps that prescriptive design approaches use. It appears that experts rely on such sequences as mnemonic structures. Expert and knowledge systems have built on such analyses, making evident their possibilities and limitations. The ability to provide design guidance is a significant improvement over normative analyses. However, the scope of the analyses is usually limited by the available knowledge. New solutions or intricate problems are often inadequately handled.
3. *descriptive analyses*: Based on the premise that a better informed designer is also a better designer, descriptive analyses project a design's behavior and performance so as to allow the designer to take decisions on related matters. Currently the descriptive approach is reinforced by the popularization of advanced simulation techniques that offer detail, accuracy and precision at a higher level than early, simplistic computerized analyses (Maver 1988). In particular the technologies of scientific visualization offer visual representations linking geometry of a design with measurements of visible and invisible aspects in a transparent manner that facilitates feedback and interactive design manipulation. Within this framework our research is concerned with the basic issues of abstraction and feedback as part of design guidance.

## 2. ANALYSIS AND EVALUATION OF ENVIRONMENTAL ASPECTS

When dealing with the general well-being of occupants, four areas of comfort apply (Schalkoort et al. 1996):

- Thermal comfort (air velocity, air temperature / humidity, radiation temperature, etc.)
- Olfactory comfort (air refreshment / pollution)
- Aural comfort (noise from outside, from installations, insulation between spaces, resonance)
- Visual comfort (light level, luminance facade, contrast etc.)

In our research we are mainly concerned with thermal behavior and airflow in buildings. Therefore, we limit discussion to thermal and olfactory comfort.

Thermal comfort is influenced, among others, by the following physical factors: air temperature ( $A_t$ ), radiation temperature ( $R_t$ ), air velocity ( $A_v$ ) and air humidity (RV). Human bound factors such as metabolism and clothing have a strong impact on

the way the physical factors are experienced. Maintaining a healthy air quality implies ventilation of the space ( $N_v$ ) in order to reduce the percentage of pollution ( $P_p$ ) in a space. In ventilation, airflow has an impact on factors regarding thermal comfort (draft). The quantities of these units should be carefully governed and are therefore kept between boundary values to avoid discomfort or even an unhealthy indoor climate. Building regulations describe, among others, criteria regarding thermal and olfactory comfort.

Environmental building regulations in The Netherlands consist of two different levels. The basis of policy forming is the building code (*Bouwbesluit*), a set of rules concerning the design of new buildings and the evaluation of existing ones. These rules take the form of quantitative performance specifications and guidelines. Minimum and maximum values are given for, e.g., fire safety, indoor climate and facilities. When applying for a building permit, the design is examined for inconsistencies with the *Bouwbesluit*. When a criterion is not met, the designer has to prove that the design achieves an equivalent performance in order for the design to be accepted.

The second level of regulations consists of the Labor condition code (*ARBO*) which have been proposed by the trade unions. With respect to indoor climate they determine the level of minimum comfort and maximum discomfort an employee may experience in his/her working environment. A major disadvantage of the *ARBO* guidelines is the relativity and abstraction of their criteria. The term 'reasonable' is used in many cases to qualify a required performance. The explanation of what is reasonable may depend on the viewpoint chosen by the decision-maker. An architect serving the interests of both his client and the building's occupants may experience difficulties in determining the level of comfort.

Both the *ARBO* and the *Bouwbesluit* refer to measurement methods by which performance can be estimated. The Dutch NEN norms, for example, are extensions of the *Bouwbesluit*, which describe in detail the constraints, conditions and settings for measuring compliance to the *Bouwbesluit*, as well as provide rules for interpreting the measured values. These measurements require a huge amount of knowledge, funds and time. Furthermore, they have little possibilities for reducing the amount of work by reusing previous results from similar situations.

The *Bouwbesluit* (VROM 1992) includes regulations regarding air quality. In maintaining a healthy air quality, air velocity as part of the thermal comfort is restricted to a maximum value. To describe regulations more specifically, we will list some of criteria found in regulations regarding indoor climate.

For instance, regarding air quality, the *Bouwbesluit* states that for a use or sanitary space a facility must exist for the intake of fresh air and the outtake of air from the space. This facility must lie within two meters from the parcel's perimeter so as not to pollute adjacent parcels. In addition to the previous facility, building elements which separate the exterior from interior must contain a moveable building element which can cause a rapid ventilation of heavily polluted air. The design of the required facilities and the analysis of their capacity must be in accordance with the Dutch norm NEN 1087. Table 1 shows some of the quantities found in sections 30 and 31 of the *Bouwbesluit*.

**Table 1: infiltration capacities**

<i>space:</i>	<i>capacity:</i>	<i>minimum:</i>	<i>remark:</i>
• occupant area	$0.9 \cdot 10^{-3} \text{ m}^3/\text{s} / \text{m}^2$	$7 \cdot 10^{-3} \text{ m}^3/\text{s}$	(50% from exterior)
• common occ. area	$0.9 \cdot 10^{-3} \text{ m}^3/\text{s} / \text{m}^2$	$7 \cdot 10^{-3} \text{ m}^3/\text{s}$	(100% from exterior)
• occupant space	$7 \cdot 10^{-3} \text{ m}^3/\text{s}$		
• toilet room	$7 \cdot 10^{-3} \text{ m}^3/\text{s}$		
• bathroom	$14 \cdot 10^{-3} \text{ m}^3/\text{s}$		
• other spaces	$0.1 - 7 \cdot 10^{-3} \text{ m}^3/\text{s}$		elevator, circulation, etc.

The *ARBO* states in general terms that the indoor climate may not cause any damage to the health of the employees. Also, the indoor climate should be as comfortable and constant as reasonably possible, taking in account the activities conducted by the former (table 2). Annoying drafts should be prevented unless not reasonably avoidable. These general guidelines are quantified by references to the Dutch NEN norms. A comfortable and constant indoor climate has, according to NEN-ISO 7730, a Predicted Mean Vote (PMV) between -0.5 and 0.5 or causes dissatisfaction to less than 20% of the employees. Office spaces should have minimal air refreshment of  $30 \text{ m}^3$  per person. Spaces for teaching have a minimum of  $20 \text{ m}^3$  per person. Other spaces should be refreshed with  $25 \text{ m}^3$  per person. This in accordance with NEN 1089. These figures, together with space's volume and function, are used to calculate a space's rate of ventilation. The facilities for providing for this rate of ventilation must be designed in accordance with NEN 1087.

**Table 2: activities in the ARBO**

<i>activity:</i>	<i>Human metabolism:</i>
Office work	$60 \text{ W}/\text{m}^2$
Teaching/learning	$60 \text{ W}/\text{m}^2$
Medium labor	$150 \text{ W}/\text{m}^2$
Heavy labor	$220 \text{ W}/\text{m}^2$
Work in cold environment	$200 \text{ W}/\text{m}^2$

In order to determine whether a design performs under or above regulation criteria, experiments are used to test performance on a certain aspect. Such experiments are described extensively in publications by institutes such as The Dutch Normalization Institute (NEN), the ministry of Housing, Planning and Environment (VROM), ISSO, etc. A design's performance must be measured and interpreted according to the constraints and conditions in the Dutch norm NEN 1087 with respect to ventilation capacity, ventilation control, thermal comfort, direction of airflow and dilution factor. Thermal comfort analysis requires a physical real size model of the space. The model must contain several air inlets, outlets and the relevant construction parts. The ventilation capacity is determined using the size and occupation of the space. Ventilation is induced using large fans. Air velocity sensors are used to measure air



quantities stated in the regulations cannot be estimated with accuracy and reliability in early design stages. Secondly, the performance derives from specific notions of comfort, associated with specific prototypical solutions. As many architects have realized, there are several alternatives that do not match the required criteria. As a result, a common complaint among designers is that building regulations restrict innovative and creative design instead of providing design guidance.

Regulations state what to do and what not to do when designing. Compliance to these regulations usually means a design is acceptable but does not imply that the design is a 'good' one. Architects must master their designing skills to the level of being able to make a good design. Building rules should govern and guard a design-process, not lead it. Therefore, architects are interested more in what their design is and how it performs rather than what an acceptable design looks like. We have determined a need for an early-stage, intuitive-based, design feedback which will assess a design's performance, even roughly, on a certain aspect.

In recent years compliance to performance criteria is increasingly measured with computer programs. In the Netherlands a series of computer programs have been developed by the VABI. The VABI (Vereniging voor Automatisering in de Bouw en Installatietechniek) was funded 20 years ago. Through cooperation and use of specialist knowledge, series of reliable and affordable software were released. The VABI distributes circa 25 programs on the area of building, installations and indoor climate to technicians in over 500 companies.

These computerized simulations formed a welcome relief from manually checking a design's performed values on the rule criteria. In the range of VABI programs, the tools for calculating heat loss, cooling load and temperature overheating risk assessments are of interest to us.

**VA101 Heat loss** can conduct a calculation of the loss of heat energy through a space or building. The simulation is done in accordance with NEN 5067 thereby replacing the need for a physical measurement. As input data is required on the configuration of spaces and walls as well as building function and location (figure 2). The result is a summary of the heat losses through each wall indicating if and where more insulation is needed.

**VA102 Cooling load** calculates the estimated energy needed to keep a building under a certain temperature on an extremely hot year. Again geometry and some building characteristics (humidity, shadows, etc.) are requested. The output is the maximal cooling-load needed on the warmest day.

**VA114 Building simulation** performs a temperature prediction of a design. Geometry and building and wall properties are needed. The output is a temperature-simulation for a full year (van Nieuwkerk 1991).

Figure 2: VA101, input for heat loss calculation

The screenshot shows the VABIMENU - VA101 software interface. At the top, there is a menu bar with options: Bestanden, Wijzigen/Invoeren, Printen, Instellingen, and Esc. Below the menu bar, there are several input fields for configuration:

- Lokaal opslagnummer: 1
- overslaan: :NEE
- nummer: :1
- naam: :Woonkamer 1
- temperatuur: : 20. °C
- type ventilatie: :1
- soort verwarming: :1
- infiltratie (m3/s): : 1.
- ventilatie (m3/s met buitenlucht): oppervlak = 6.00

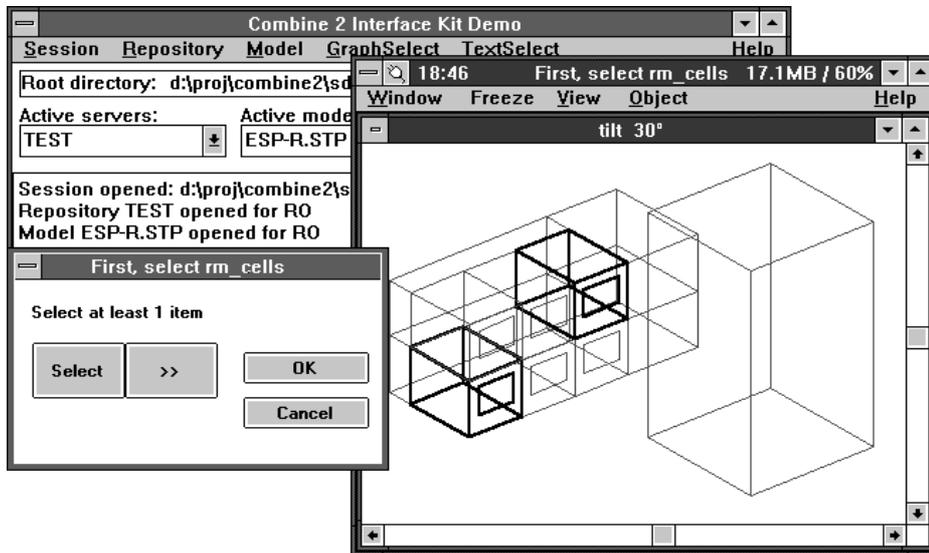
Below the input fields is a table with 14 columns: Nr, Wand naam, C1, Lngte, Brdte /hgte, Aftrek opprvlak, Aan-tal, U wrde, Aangrzd Temp., Ulr Uwm, Zone, C omt, C opp, and R. The table contains 10 rows of data:

Nr	Wand naam	C1	Lngte	Brdte /hgte	Aftrek opprvlak	Aan-tal	U wrde	Aangrzd Temp.	Ulr Uwm	Zone	C omt	C opp	R
1	1.1	1	3.	3.	3.	1	1.2	T		1			1
2	1.2	1	4.	3.	0.	1	1.2	T		1			0
3	1.3	1	4.	3.	2.	1	2.	T		1			1
4	1.4	1	4.	3.	2.	1	2.	T		1			0
5		1	0.	0.	0.	1	0.		0.	1			0
6		1	0.	0.	0.	1	0.		0.	1			0
7		1	0.	0.	0.	1	0.		0.	1			0
8		1	0.	0.	0.	1	0.		0.	1			0
9		1	0.	0.	0.	1	0.		0.	1			0
10		1	0.	0.	0.	1	0.		0.	1			0

These specialized programs require a precise and detailed design information and often use a separate design representation. Manually inputting this information is a tedious and time-consuming task. Furthermore, once a design representation has been input, it takes considerable effort to change the information and go through a number of alternatives. A second drawback of the system is the limited scope of the analysis. Usually a design is tested with respect to only one or two aspects. Evaluation of compliance to the complete *Bouwbesluit* requires a large number of different programs and calculation models.

In order to overcome this, several integrated environments have been developed. These environments employ a single design representation and use its data as input to several specialized analyses. Examples of these environments include the COMBINE environment (figure 3) (Augenbroe 1993b) and the VABI uniform environment (Jordaans 1996). These are promising developments, despite the large amount of data required. One disadvantage of using a single design representation is the fixed character of the information. The interfaces of integral environments have been designed to input large amounts of design data. Dynamic change and interactive manipulation are not supported adequately. This results in limited opportunities for design improvement following the analyses and their findings.

Figure 3: COMBINE environment interface



### 3. COMPUTERIZATION OF DESIGN AND ANALYSIS

A response to the growing number of building regulations has been the development of computer applications which reduce manual labor by evaluating designs with respect to building regulations. As these systems are directly derived from legislation and guidelines, they are useful but limited normative analyses of regulation compliance. One such example is the VABI suite of programs. They require information on building geometry and several design characteristics as input and use straightforward mathematical formulas to estimate total heat load or noise level. Such tools do not draw any conclusions that can be made from facts implicit in the design information. While architects may expect some explanation of why a building element fails, normative systems respond only with figures and give no reasons.

At the moment, an architect may have disposal of a growing number of computer driven tools which assist in predicting performance. There is a need for this kind of prediction of performance since building rules and contractors demand guarantees that the result will habitable and healthy. Architects have therefore accepted the influence of third parties in their design process. Specialists and the tools they use have found a place in negotiating a design's implications on indoor climate, circulation, etc. (Luscuere 1996).

The problems encountered in using the first generation of rule systems led, among other, to the development of more complex structures for design support. These systems became known as the knowledge- and expert-systems. The aim of such systems is to provide design guidance and information feedback. One example of such systems is the *Design Formulation System* (DFS) (Szalabaj et al. 1993) that attempts to support the architectural domain by avoiding dependence on overtly defined

objective knowledge and accepting bottom-up and top-down definition of a design, as well as subtractive procedures. The *engineering data model* (EDM) (Augenbroe et al. 1993) is an information model for building design. It was developed at UCLA and based on a small number of structures to capture the semantics of design and engineering information. The *Building Design Advisor* (BDA) (Papamichael et al. 1997) is an interface meant to stimulate simulation in the design process by allowing sophisticated simulation tools to be accessed through a single program. The *automated building design system* (ABS) by Warszawski & Sacks (Warszawski et al. 1997) generates information and design documents for a design. The advantage of this system is the high quality of the generated information and the saving of human input. The *Information Management Model* (CIMM) (Brown et al. 1996) attempts to manage the growing amount of information used in building. CIMM provides a structured framework for addressing multiple levels of abstraction and functionality, as well as recording and monitoring design intent. The META-4 project and the SEMPER environment (Mahdavi 1995 & 1997) are aimed at the field of installations. The bi-directional nature of these systems provides an active feedback and optimizes certain parameters by means of an inference engine. The above systems provide us with useful knowledge regarding behavior and function of knowledge systems. They are built around an in-depth understanding of the problems, parameters and relations controlling a specific design aspect. However, knowledge-systems failed to provide a breakthrough in architectural design.

Since issues regarding physics are hard to predict using intuition or experience, several models have been developed which describe these phenomena in terms of physical elements and their relations. The extremely complex stress calculations in use with aeronautics formed the basis for the development of the finite element method. Together with other discrete methods such as finite difference and finite volume these methods are used to generalize complex physical phenomena using a grid of partial differential equations. These equations are then solved using a large number of iterations, flattening out the influences between neighboring grid-cells. When applied to models describing the behavior of air in or outside buildings, these methods have proven their usefulness in predicting air flow and air dynamics. Although the methods may have varying accuracy depending on the complexity of the model, the results approach real-life behavior, save sufficient care is taken for problem definition, grid optimization and starting as well as boundary conditions.

Simulation of physical phenomena is usually costly in time. The general rules of thumb and simplified mathematical formulas avoid time-consuming calculations but suffer from limited accuracy, which at later design stages may cause rejection of alternatives when more precise simulations are conducted. Another problem when simulating design performance is the calculation overload when performing a series of analyses. However, certain design criteria need not be determined in five digits. A global result may be sufficient, especially when one is only interested in the direction the performance of a design takes when varying a given parameter.

One general problem often encountered in computer systems is the manipulation and transformation of information. Data exchange is needed whenever a user switches from one system to another. In the absence of one overall system containing procedures for every aspect in the design process, different tasks are still performed by different systems. Since all these systems need information on the same design, information must be transferred back and forth. An additional problem is that each system uses a different data structure and has different data requirements in both design-parameters and level of detail. An integral data storage must contain all design information and have the possibility to convert that information to every form needed by internal or external procedures. This integral data storage must be capable of integrating new information. When the simulation tools finish their calculations, the results have to be stored and explored by the user. Since feedback is at its most visible against the background of the original design, data storage must provide an overlay of design geometry and simulation results.

The interface of a design supporting system consists of support on two mayor tasks, inputting design information and reviewing results of design simulation. The design geometry and properties must be input manually but this labor can be greatly reduced by automated recognition and the appliance of precedent information. Moreover, CAD systems provide an interactive visual interface for inputting geometric information. Systems for inputting design characteristics such as users, climate equipment and building products are scarcer. The OBOM protocol demonstrates an attempt to provide a protocol for the appliance of available building products in a framework of simple geometry and building properties (den Hartog 1997). The manipulation of design properties is supported by the layout and information management facilities of the user interface. Users must be able to switch between design representations, information on precedents, visualizations of simulations, spreadsheet with the results of analysis, etc. Feedback on the current state and performance of the design may be requested at any moment. The techniques used in scientific visualization provide *computational steering*. This enables manipulation of the way information is visualized. Varying parameters such as viewpoint, color schemes and point of focus influences the amount of information used in the decision making process (Post et al. 1993).

#### 4. DESIGN REPRESENTATION: SPATIAL FORM AND ANALYSIS

Our definition of a representation derives from the framework for computer vision defined by David Marr (Marr 1982). According to this, a representation is a formal system for producing descriptions of a certain class of entities in a transparent manner, i.e., together with an explanation of how the system returns the particular description. Transparency is achieved by establishing a set of symbols used in the representation and a system of decomposition / correspondence by which the symbols are related to the described entity.

Examples of such representations are abundant in daily life. For instance, quantities can be described using a set of Arabic numerals.

$$S_A = \{0,1,2,3,4,5,6,7,8,9\}$$

and the following decomposition rule:

$$n_0 10^0 + n_1 10^1 + \dots + n_{i-1} 10^{i-1} + n_i 10^i \Rightarrow n_i n_{i-1} \dots n_1 n_0$$

with  $n_n, n_{n-1}, \dots, n_1, n_0$  being members of the symbol set. A quantity such as 123 is produced as follows:

$$1 10^2 + 2 10^1 + 3 10^0 \Rightarrow 123$$

The description changes if we alter the symbol set. Binary numerals, for example, use the following set:

$$S_B = \{0,1\}$$

The reduction of the symbol set is reflected by a corresponding change in the decomposition rule (2 replaces 10 as the base):

$$n_0 2^0 + n_1 2^1 + \dots + n_{i-1} 2^{i-1} + n_i 2^i$$

Accordingly 123 is described as:

$$1 2^6 + 1 2^5 + 1 2^4 + 1 2^3 + 0 2^2 + 1 2^1 + 1 2^0 \Rightarrow 1111011$$

As the above example shows, there are many alternative representations for each class of entities. Each representation is better suited to different tasks and uses. Arabic decimal numerals appear to be more appropriate for general use by humans, presumably due to the correspondence between the base 10 with the number of fingers in both hands. Binary numerals are preferred for machines as the symbol set maps the two states of a basic device (“on” and “off”). For specialized tasks, representations are altered to suit the processing information. For example, when registering incoming or outgoing quantities, humans frequently revert to ancient symbol sets which are handier for the procedural, additive character of the task. “123” could be initially described by:

while the task is in progress. After completion it can be easily converted to the much more compact Arabic decimal numeral. (Koutamanis 1997)

Representation should not be confused with the mechanisms used for its implementation, such as a relay or diode for binary numerals. The reason for that is a particular representation can exist in various implementations with no change in content, structure or result. Binary numerals, for example, remain unchanged whether on paper, in a computer or in a calculator, despite the superficial differences in the implementation mechanisms.

Nevertheless, as many representations are associated with dominant or canonical implementations, the symbols of a representation are frequently confused or equated with implementation mechanisms. In conventional architectural representations, such as floor plans and sections we read spaces, building elements and components (the actual

symbols). However, the lines we draw and the surfaces these lines bound (the implementation mechanisms) are only too often discussed as the primitives of architectural composition. This testifies the significance of geometry as a foundation of architecture and its representations and parallels the shift from the geometric object in Euclidean geometry to its images in descriptive geometry (Evans 1995).

The transition from descriptive and projective geometry on paper to their computational equivalents has reinforced attention to implementation mechanisms such as lines and surfaces. (Gasson 1983). In an attempt to integrate the new computer media in architectural design, CAAD research and teaching has focused on modeling and visualization with computer media at the level of practical skills (Mitchell 1995). These skills are guided by development in the study of spatial descriptive formalisms such as rectangular arrangements and shape grammars, which interpret the geometric or other models of a design in terms of surfaces which bound a space or component of a building subsystem.

The abstraction and relevance afforded by such representations links visualization to our understanding and processing of a design. Rather than merely manipulating loosely and arbitrarily grouped geometric primitives in a CAD system, we can organize spatial information in multiple, closely correlated structures, usually of an associative nature, as in the dual graph representation (Steadman 1983). The advantage of these structures is that they link design thinking with the appropriate implementation mechanisms. Probably the most striking example of such linkage is between design form and requirements on or analysis of function and performance, e.g., of fire safety, pedestrian circulation or lighting (Koutamanis 1993, 1995 & 1996).

An underlying assumption in most spatial architectural representations concerns the choice of basic primitives for the description of a design. The 'solids' and 'voids' of a building, i.e., the building elements or components and the spaces bounded by them, are the obvious choice. They are linked together by the fundamental relationships of adjacency into a single holistic or multiple complementary networks which describe one or more aspects of the design in a coherent and comprehensive manner. These networks are generally sufficient for the design and analysis of building at the macroscopic, normative level that characterizes apparent design thinking, including matching to requirements in a brief, in legislated measures of performance or in standard textbooks.

Other types of analysis require further analysis of the network representations. For example, typologic studies are usually performed at a higher abstraction level that omits much of the basic information on a common design representation. Such schemata can be derived by means of the logical grouping and visual abstraction that characterizes local and global coordinating devices. These transform the 'flat' network into multilevel modular structures which address simultaneously problems and issues of a global or local nature (Koutamanis 1997b).

Our research also aims at an exploration of coordinating devices in multilevel architectural representations, especially (1) within the spatial primitives and (2) for identifying and parsing relevant design precedents. When linking simulation to the abstract descriptions of an early design, we are confronted with a serious mismatch in

specificity that often prohibits use of advanced evaluation tool in the early design stages.

Multilevel representations are instrumental in this respect, as they permit comparison to design precedents which can provide additional information with a higher probability and specificity than averaged default values. Precedents are also significant as images of possible further developments for a design and hence design guidance. Coordinating devices and multilevel abstraction also challenge the assumed integrity of basic spatial primitives. On the one hand, correlating physical phenomena with human activities and built form frequently requires a finer grain than allowed by spaces and building elements. Adaptive zoning schemes and identification of activity planes provide the required higher specificity. On the other hand, they allow for a sharper distinction in the analysis result between general patterns common to a wider class and the more case-relevant patterns that arise from particular local characteristics of a design, as well as from information derived tentatively from precedents (in the absence of the same information in the design).

## 5. OUTLINE OF THE PROPOSED SYSTEM

Analysis throughout the design process presupposes an information system that accommodates and processes design information. Processing takes place in several steps. Design information must be stored and retrieved with little effort, time loss and data manipulation. This could be achieved through transformable design representations that meet the requirements of both the architects and contributing specialist disciplines. These representations should be amenable to change following performance simulation with external programs (feedback). Feedback and transformability could also facilitate comparison of results from different analyses.

For the analyses existing advanced computational methods and techniques provide sufficient reliability and effectiveness. In addition to transforming representations so as to provide input for these, the integral database will have polymorphic access to different storage possibilities based on data structures used by external systems. In order to keep the representation compact and non-redundant automated recognition and intelligent interpretation of design information can be employed to produce the data implicitly. For example, topological relations can be deduced from the geometry of spaces in the CAD data.

Despite advances in three-dimensional visualization and modeling, two-dimensional geometric representations (in particular floor plans) remain the basic design representation, even in the computerized design office. For our research we accept the practicality and cognitive significance of the floor plan (Koutamanis 1994).

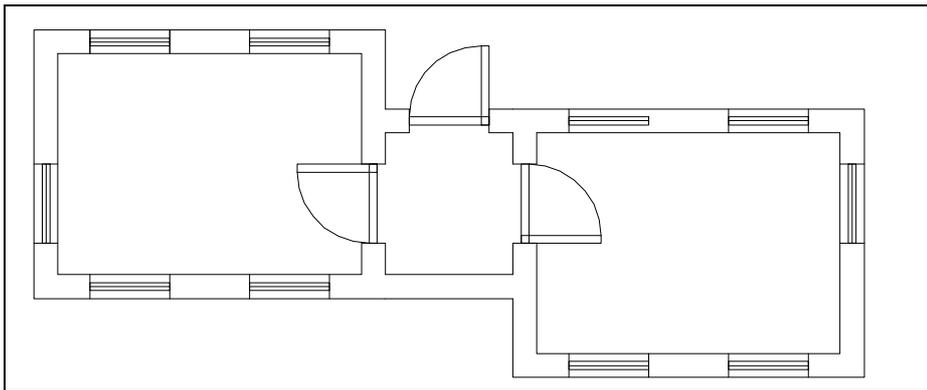
Unfortunately, architectural CAD Drawings are only too often an unstructured collection of loose lines. This diminishes the usability of the drawings as both input and geometric interface of analytical processes. One possibility is the use of automated recognition (Koutamanis et al. 1993b), so as to restructure the drawing as a network of

meaningful primitives —spaces and building elements— that derives from the dual graph representation (Koutamanis et al. 1995b).

The results of automated recognition provide us with the required information in an appropriate representation. In our case, however, we believe that the user should be responsible for the structure of spatial information. Automated recognition can simplify transition from one state to another, but the user should remain actively in control of primitives and relations. This is critical to the feedback stage, in particular for the interactive manipulation of analysis results, so as to produce alternative versions and variations of a design.

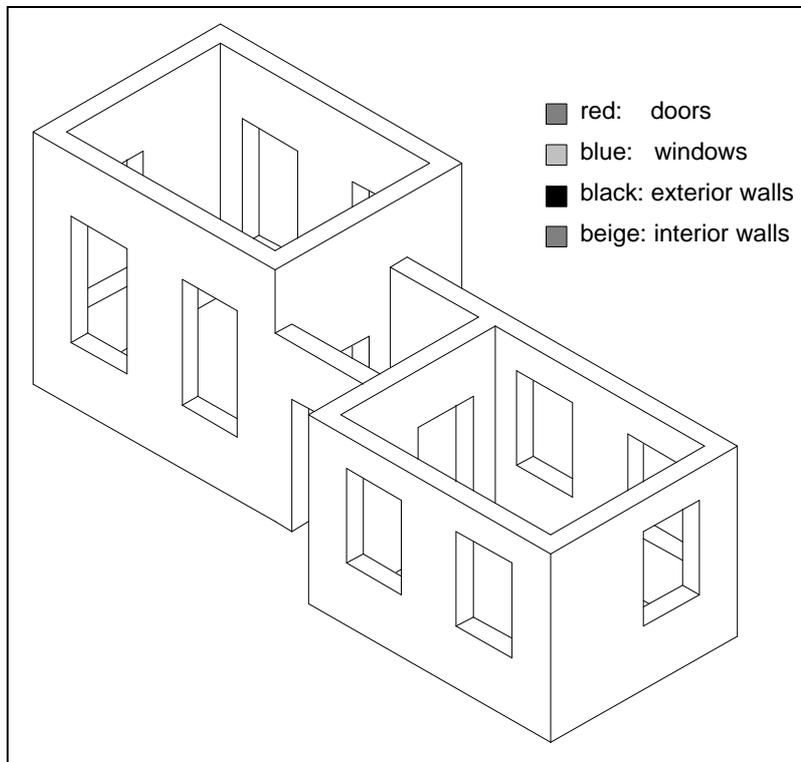
For these reasons we have adopted the view that the designer should input spatial information using familiar tools. The same tools are also used for integrating the analysis output with the spatial representation. Conventional CAD programs like AutoCAD can act as our primary design environment. The user should input a design in AutoCAD as a collection of spatial primitives (spaces and building elements) in a manner similar to mainstream drafting (figure 4).

Figure 4: **spatial primitives**



The essential difference lies in the primitives of the representation. Instead of using loose lines as in drawings primarily meant for printing (reproduction), each relevant entity is drawn as a single, integral entity. Initially we are using polylines which indicate the perimeter of each entity. As the third dimension is of importance to most environmental analyses, each polyline is given its appropriate height ('thickness'). The use of layers allows us to distinguish between different information sorts, primarily between the spatial network and the construction network:

Figure 5: **primitives, layout and distinction**



The resulting representation exhibits the following properties:

1. It conveys the essential information for the analysis of the aspects we are concerned with. This agrees with other types of formal and functional analysis (Mitossi & Koutamanis 1998; van Leusden & Mitossi 1998).
2. Consequently to (1) it permits coupling with the output of analyses (feedback). Feedback can assume a spatial form, either as properties of a space or element or even as subdivisions of a space or element. As such they match elaborations and augmentations of the basic spatial information in the representation, which are also added as attributes or by subdividing the basic elements in a modular, hierarchical fashion (Koutamanis 1997b).
3. The representation includes abstraction levels that correspond with the design information that is available during the early design stages.
4. The user is required to input only the minimal information normally available in abstract architectural representations, that is, the form, the size and position of spaces and building elements. Spatial relations between these and aspects relating to these can be recognized (inferred) automatically with little if any intervention by the user. This reduces the intellectual burden of information processing and facilitates concentration on the relations between analysis and design.

The primary purpose of this representation is to support communication between design and analysis, which is performed by external simulation systems. In this project

we concentrate on the simulation of indoor climate. More specifically we will try to stimulate in-depth understanding of issues regarding air in office buildings. Therefore, the analytical tools we will use may take the form of Computational Fluid Dynamics (CFD) or Finite Element Methods for heat conduction.

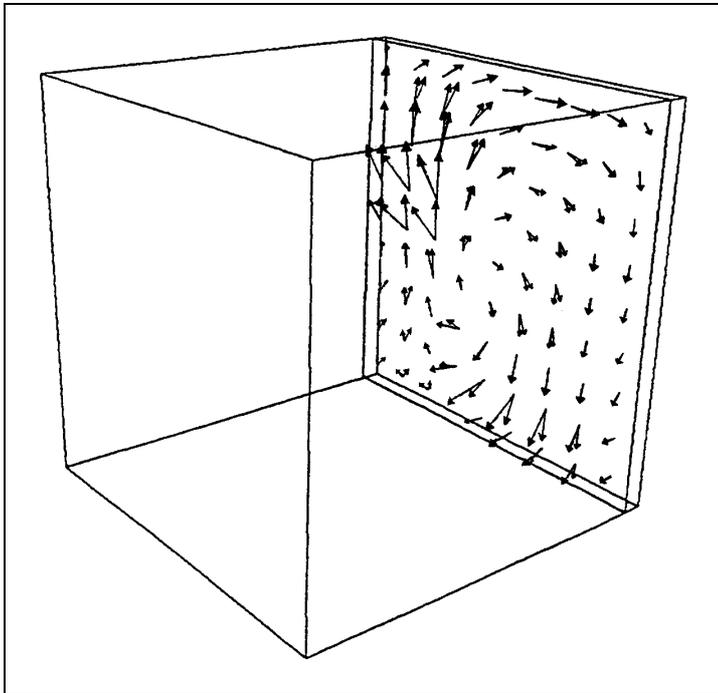
CFD simulation systems as *FLOVENT* will depict air circulation in a space, i.e., air velocities to be expected, linking air flow to thermal comfort. These simulations result in large amount data, which can be combined with other factors such as air temperature and acceptable pollution levels. This permits accurate description of indoor climate in the combination of analytical / numerical and visual representations used in scientific visualization

Facilities used for air inlet or heat radiation have a strong influence on comfort. Architects are interested in the capacity and positioning of these facilities in relation to the occupants' experience. Interaction between facilities reflects on their capacity and range and may restrict choice of positioning. This interaction can be simulated with CFD systems that allow the architect to explore the problem and its solutions by varying the relevant design-parameters.

Another interesting development is the production of heating and cooling load prediction tools such as the *VABI* tool *VA114* described in chapter 2. These tools combine geometric and functional information to calculate the energy needed for heating and cooling. When linked to information on installations and capacities, they produce temperature overheating risk assessments. Several systems are capable of making these temperature simulations given a building representation, but few offer dynamic feedback for manipulating design parameters with respect to thermal behavior. Our research aims at adding dynamic aspects to the existing static simulations.

The technologies of scientific visualization offer a wide range of methods and techniques for visualizing geometry and simulation results. Using color, three-dimensional display and animation, architects obtain insight in air movement and flow phenomena. Our system adds human experience of indoor climate to simulation results by means of 'virtual occupants' who interpret simulation results and display a measure of comfort. This approach will allow correlation of a number of different aspects and analyses. Also visualization of results takes place on top of the design representation (figure 6). This provides a direct link of analysis results with design decisions and supports identification of problem areas.

Figure 6: **CFD visualization; arrows connected to plane, with projections**



Graduation report, J. van Beukering (1991)

One of our working hypotheses is that simulation may result in patterns which uncover zoning schemes in the spaces under investigation. Zoning can be seen as a distinction between areas that require particular attention and others that remain gray under the given circumstances. With 'circumstances' we refer predominantly to stages of the design process and associated abstraction levels, as well as to the conclusiveness of analyses. Zoning can simplify the interaction between analysis and synthesis by means of qualified, manageable abstraction. For example, design parameters which influence only gray areas can be ignored in certain design stages. Application of zoning schemes to simulation can also improve efficiency and communication by concentrating on areas of interest for a particular stage or aspect.

The use of precedents and cases in design is currently a favored research subject. In our system, existing knowledge in integral cases and precedents is essential to early analysis. Our precedents are typically buildings which have been realized and perform in a known, documented and adequate fashion that corresponds to the initial design goals. When referring to solutions used in a precedent or case, we select one or more characteristic parts or aspects from the documentation on the particular project. The selection of values can then be applied to a new design. We assume that, given sufficient compatibility between the existing and the new design, the performance of the former will be transposed to the latter. Furthermore, design entities used in

previous projects can be re-used in new ones, thereby reducing the workload of preparing a design for simulation. This attitude is familiar in many design disciplines, including indoor climate and installations. In architecture, however, adopting and adapting a precedent is often mistrusted as a limitation of design innovation and individuality. To overcome such prejudice, we employ similarity matches, which present existing solutions in part and as examples of further design elaboration.

The interface will provide one handle for the use of default values, values based on profiles and values derived from cases and precedents. Input design characteristics will be supplemented by previous figures regarding, for instance, the number of employees in a space, the rate of pollution, etc. The user interface focuses on the requirements and modalities of architects. Easy manipulation of geometric properties and rapid visualization of architectural form are qualities which must be present in the interface. In addition, the design representation and information processing should be capable of identifying design properties which have a large impact on indoor climate. These properties play a key role in communicating with the contributing specialists and in subsequent improvements of the design. Our interface will focus on receiving input on these key role properties. Another requirement of the interface will be the intuitive handling of primitives. Of importance when developing an intuitive interface is the presence of a one-to-one mapping from primitives recognized in the user interface to primitives used in the representation's data structure.

The system is implemented in a Rapid Application Development (RAD) language because speed and robustness are of lesser importance than interactivity and user-friendliness. Furthermore, RAD languages support embedding of external modules which is prerequisite when using existing applications and tools. Using existing applications and tools for simulation and geometric input reduces development time and material needs. Integral to the project is extensive testing of the implementation. We intend to use a preliminary version in educational activities of the Faculty of Architecture at the Delft University of Technology. Students will test and evaluate the operation and handling of the interface in the framework of design and graduation projects. Accuracy and relevance of simulation results will be tested by several indoor climate specialists, also in the framework of these projects.

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