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A CAAD Model for Use in Early Design Phases

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In this paper we present a model for handling design information in the early design phases. This model can be used for representing both vague and exact defined information. The first part describes the difficulties involved in using CAD in the architectural design process and the characteristics of that process. Then we give a description of the design information and its representation during the design process. Next an overview of the architectural design process describes how design information is added and manipulated during the design process in order to achieve an effective result. Finally, we include a brief description of a simple prototype program to illustrate how this theory acts in practice.

Introduction

Computer-aided design technology has been adopted widely as a useful tool for speeding up and improving the design process. It is already normal practice for parts of machines or complete chemical plants to be designed mainly on a CAD system. A notable exception is the field of architectural design. Today CAD systems are being used more often as a drafting package, but most attempts to use this technology to improve architectural design have failed. There are two major reasons for this failure.

In the first place a designer uses vague concepts, especially in the early phase of the design process. Computer programs are not yet capable of handling this kind of data and require that the information be exact. Unfortunately this kind of precise information is not available until relatively late in the design process. At that point the information that can be generated by using CAAD tools can no longer be used effectively to improve the design, as it is already almost completed. Major modifications at this stage will lead to unacceptable financial, technical, or aesthetical costs.

We find that most CAAD tools currently available concentrate on the late design phases. The designer can provide the necessary information for calculation of cost, strength, heat balance, and so on. For the early phase of the design process no such programs are available, although here they can be used more effectively to improve the design.

The second problem with using CAAD is its constant interruption of the design process. To use a CAAD tool the user must normally supply a geometric description of the design and a list of characteristics (material) for each part of the design. This means that the designer must temporarily stop the design process to translate his mental representation of the design into a form more suitable for the tool he is intending to use. This new representation must then be entered into the computer. After the program finishes, the designer must try to link the results to his own mental representation of the design in order to decide how the design must be improved. This process has a number of drawbacks. First, it. takes much too long. In early design stages new alternative solutions can be generated within a few seconds. Application of a CAAD tool may interrupt this for ten minutes or more, which is not acceptable. The designer must also concentrate on a different representation of the design. This makes it very difficult to relate the result of the tool to the design. Therefore the CAAD tool is not very useful, as the designer has great difficulties in using the information it generates.

Finally, the CAAD tool interrupts the association link." During the design process every step is evaluated and may lead to new steps and new alternatives. Every attempt brings up ideas for improvements. Interruption of these steps for a long period makes it very difficult for the designer to find creative solutions to the problems he/she encounters. It is difficult to regain a line of thought and concentrating on one solution tends to block creative search for alternative solutions.

Using available CAAD tools in the early design phase thus raises severe difficulties for a designer. Basically these difficulties are caused by the specific nature of the architectural design process. A brief summary of these characteristics may help to explain the model of architectural design and design process presented in this paper.

The Architectural Design Process

There are three characteristics of the architectural design process which together make it different from all other kinds of design processes.

First, the architectural design process is ill structured. It is not possible to describe a series of steps that will finally lead to a successful solution for a design problem. The best that a designer can do in such a process is to create a solution and verify that it satisfies the constraints.

It is also very difficult to predict which modification will lead to an improvement of the design and which modification will not. This is possible for only a very small part of the design at a time. Such part must have a limited number of constraints.

Experienced designers know about a large number of solutions and their weak and strong points. They can use this knowledge to choose a primary solution that best suits the problem.

Second, the architectural design process is open-ended. A design is never completed and can always be further improved. During the design process the designer continues to work on the design until a deadline or budget limit is reached. It is very rare for a designer to stop the design process because he feels he cannot further improve the design. This is because each design is an optimization of a large number of partially conflicting constraints and requirements. Each improvement of one of these will also affect most of the others, either positively or negatively.

The designer decides which constraints he/she considers most important and optimizes the design accordingly. More important constraints are improved, even if this means that other less important ‘requirements are not met. Choosing which constraints will be considered depends not only on the design problem, but also on the preferences of the designer and the principal.

There is a second form in which the design process is open-ended. Especially in the early design phase, there is no real goal the designer can work toward. As a starting point there is only a common idea about the building that is going to be designed (its type). This common idea must be extended by the designer to satisfy the particular needs of the principal. This occurs during the design process, so in the early phase the designer has to make a design without knowing exactly what he/she is supposed to design.

Third, the designer has no fixed starting point. This characteristic relates to the preceding one. Usually the designer must start with a design brief and a given site. These two are not fixed. The design brief is usually global and incomplete, and the site can be adjusted if needed. Before the design process starts, the designer must make a number of assumptions about the design objectives. These assumptions include the shape and appearance of the design and how it is going to be used. When the design is completed to such a level that it can be appraised by the principal, these assumptions can be evaluated properly.

Most theories of the design process concentrate on the design process for mechanical engineering. This differs in two ways from the architectural design process. It is less open-ended and it is better structured.
Criteria used with design for mechanical engineering can commonly be quantified. It is therefore possible to a large extent to describe the design goal early during the design process. This also simplifies the design process, since it is easier to check if a design is satisfactory and to know which modifications will improve it. In the architectural design process, the later phases are similar to the stages of the design process in mechanical engineering. CAAD tools developed for that kind of design process can be used very well in the later phases of the architectural design process.
Architectural designers use some special techniques to overcome the problems of vagueness and complexity that inhere in the architectural design process. Two techniques most frequently used to control the design process are decreasing the number of requirements to an acceptable level and superimposing some ordering principle on the design.
The number of requirements cannot really be decreased, but, conveniently, most requirements influence only a part of the entire design. In the early phase of the design process only those requirements that influence major parts of the design need to be considered. They can be combined into groups of requirements that have essentially the same effect on the design. In effect this means that in the early design stages the designer does not need to consider all requirements in depth but can look at a very small subset. Later in the design process the designer can and must consider more requirements in more detail. When he/she does so, those requirements will not affect the entire design.
The following schematic example may clarify this concept. When deciding the building shape, the designer may follow one of two tendencies: to minimize the building envelope or to maximize it. Both tendencies stem from a number of requirements. External walls are relatively expensive and cause heat loss; therefor, the smaller the elevation the better. On the other hand, it is better to have as many rooms as possible situated on the exterior wall because such rooms require less artificial lighting and air conditioning and are more pleasant places.
In the early design phase it is sufficient to choose a shape that allows enough rooms to be situated near the external wall of the building without creating an envelope that is too large. The designer does not need to consider all the individual requirements for these two tendencies. Later in the design process the designer will optimize cost for the exterior walls and the internal climate but does not reconsider the building shape.
The second technique, superimposing an ordering principle, is used to provide a starting point for the design process. Furthermore, it gives a set of

criteria that can be used to evaluate the earliest designs. This aspect is especially important because in the early phases there is no information that can be used for a more conventional numerical evaluation of the design.

The ordering principle is in a sense a minimal design. It consists of an abstraction of the essential parts of a design, considering only one or two requirements. Because it is so limited it can be designed fairly easily. The only important rule is that it is both simple and consistent with a basic idea for the building. The structure can be used to generate design alternatives and variations and extensions of the structure. It can also be used to evaluate the design alternatives. Each alternative must obey the rules that are laid out in the principle, otherwise a design derived from that alternative will not be acceptable because it will be inconsistent.

An ordering principle can take many different forms; for instance, a routing scheme, a construction in which the building must be fitted, a cell of which the building will be composed, or a geometric form.

Each CAAD tool intended for use in the early design phase must allow the user to apply these techniques. Otherwise the use of these tools will obstruct the design process. These tools must also allow the use of vague information to avoid requiring specificity too early in the design process.

Design Information

During the design process the designer builds a mental model of the design. Simultaneaously, he/she makes sketches of the design. Observations of designers lead to the following conclusions:

1. The sketches act as memory aids and contain only the most important parts of the mental model.

2. The mental model is based on decisions about units of the design and not on objects. This is true particularly in the early stages of the architectural design process. Later the difference between decision and object is not as clear.

Basing the model on decisions instead of objects allows a much more flexible approach to the design process. Intentions and relations, for instance, can be expressed only in this form since there is no physical translation for them that can be used in an object-based model. Decisions are also a better basis for roughly describing a design. Later in the design process the design can be made more specific by adding more accurate decisions about the same units or their composite parts. This is possible for the entire design as well as for a part of it.

The units about which the decisions are made are not simply the objects of which a building is composed. In the early design phase a more global unit is used. Decisions are made about compositions of properties and requirements

Figure 1 Form follows structure as an ordering principle: Church, Barcelona, by A. Gaudi

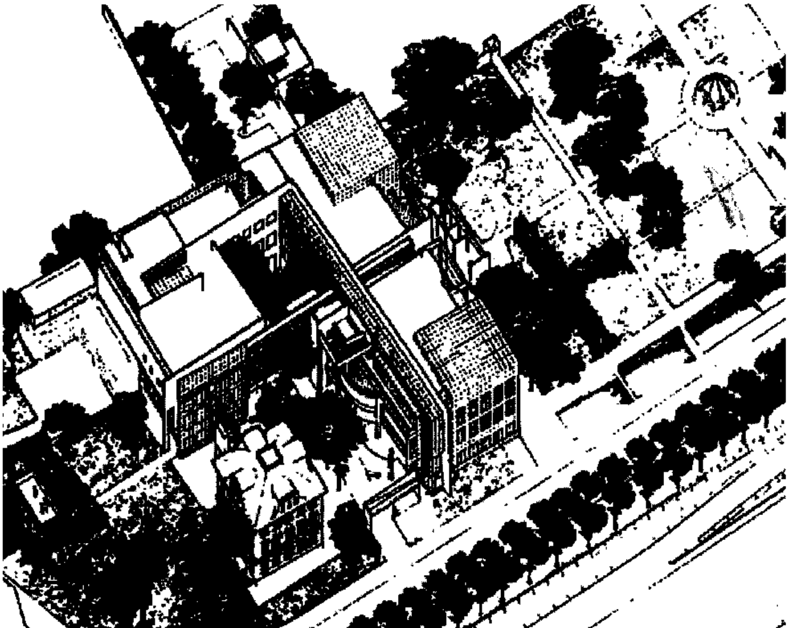

Figure 2 Geometric ordering principles: Museum, Frankfurt am Main, by R, Meier

that have specific architectural meaning. This can either be a 'function" or a "building property." Both lead eventually in the final design to an arrangement of spaces and materials that suits the specific requirements of the unit. A "living room" and a "stair" are typical examples of functional units, whereas an "axis of symmetry" and a "vista" are common units about properties.

A building houses several kinds of activity specific to the building type, such as "sleeping" and "going upstairs' in a house. These kinds of activity need special provisions, such as a separate space of certain size with regulated internal climate and connections to external spaces via doors, windows, telephone, or television. All these requirements for functions and many more are combined in a single architectural unit.

A different kind of unit is used for decisions about the entire building-the way it is shaped, how its should look, and so on. These decisions are usually made early in the design process because they affect all other requirements and properties in the design.

Levels of Accuracy

The decisions that are made by the designer during the design process vary greatly in accuracy. In the early design phase they are very rough and concern large parts of the design at a global scale without any detail. The decisions in the latest phase of the design process are very precise, at a scale of millimeters, and concern very detailed parts of the design.

In the earliest stages decisions are often made about units without the designer knowing exactly how these units are composed. Decisions in this stage are normally expressed in terms of earlier decisions. For instance, a decision about size could be that a certain division occupies about "half the building." After having made the major decisions, the designer can make new decisions about smaller parts of the building. These decisions can be more accurate, which indirectly makes the major decisions more accurate. Use of a design grid is typical for this stage. The grid size can range from very small (30 centimeters) to over 10 meters for very big buildings. The size of a step (about I meter) is most commonly used. In this stage a size will already be expressed in measurable quantities like "6 meters," although this still is not very accurate.
Final decisions are made at the same level of accuracy as the building materials, normally in multiples of 10 millimeters.

Symbols

The design sketches are not the main representation of the design. Still they play an essential role in the design process. Observations showed that a designer sketches a symbol for each decision he/she makes. This symbol contains a graphical description of the essential parts of the decision. Figure 3a shows a typical symbol for a functional unit sketched very early in the design process. Figure 3b shows the parts of the decision and the way they are represented in the symbol.

If the designer reviews this symbol later in the design process, he/she remembers the decision it represents and, more importantly, the reason for that decision. Different symbols represent different kinds of decisions, each dependent on the properties of the architectural units.

For most decisions more than one type of symbol can be drawn. The different symbols for the same decisions are necessary to represent the accuracy of the decision. A more precise decision is represented using a more detailed symbol. Figure 4 shows a more accurate symbol of the same architectural unit as in figure 3. The main difference between the symbols is that in the accurate decision the composite parts are also considered and therefore can be found in the symbol.

Context

This way of using symbols representing decisions raises one problem. There are far more possible decisions than there are different symbols to represent them. Designers seem to use the following way around this problem. Associated with each decision is a set of other decisions that must be present before the decision can be made. We have called this the context' of a decision. No two decisions represented with the same symbol can have the same context. Within a certain context all symbols therefore must unambiguously represent a decision. Consider the following example. Figure 5a shows a very simple design consisting of one rectangular and three round shapes. Now assume that the rectangular shape represents a decision about the building shape and that a round shape can represent a decision about either a room or a tree. The sketch can have only one meaning because a room can never occur outside the building and a tree can never occur inside it. This mechanism removes most ambiguities from the design sketches.

The Architectural Design Process

Most theories of the design process are based on a variation of the Analysis-Synthesis-Evaluation cycle. The theories differ in the number of steps used in each cycle and in the number of phases in the process. The basic idea is that the cycle is repeated until the design is completed. These theories cannot adequately describe the early phase of the architectural design process. They describe design processess with objective and fixed requirements that are fairly well structured. None of this applies to the architectural design process.

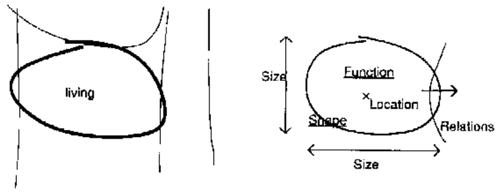

Figure 3 Symbol in early design:
the Symbol and the decision it represents

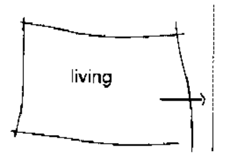

Figure 4
More accurate symbol

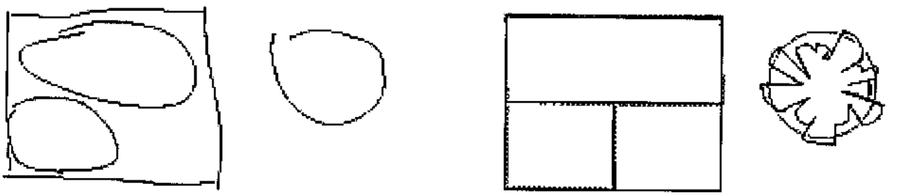

Figure 5 Context sketch: Interpretation

A theory to describe the architectural design process in the early stages must be less rigid and include mechanisms to state goals and criteria during the design process.

Observations of design processess reveals that the architectural designer uses synthesis-evaluation cycles in a rather unstructured way. At first sight there appears to be no relationship between the successive steps in the process. Each step stands on its own, and correction of unsatisfactory designs does not seem to occur very often. The design process takes place very rapidly but at irregular intervals and may be interrupted for a longer period of time. Furthermore, it appears that the designer is working on several parts of the design simultaneously, thereby constantly moving between the different drawings.

Underlying this seemingly chaotic process is a complicated though logical structure. The design process cannot be thought of as a single cycle that is repeated. Instead, it must be considered as three nested synthesis-evaluation cycles.

The fastest and innermost cycle is the "decision" cycle. Most design decisions are made in this cycle. The outermost cycle is the "development" cycle, in which the development of the design is controlled. Between those two is the "structuring" cycle.

The Decision Cycle

This is a simple synthesis-evaluation cycle. It can normally be completed within a few seconds. The cycle consists of only two steps. No analysis step is included

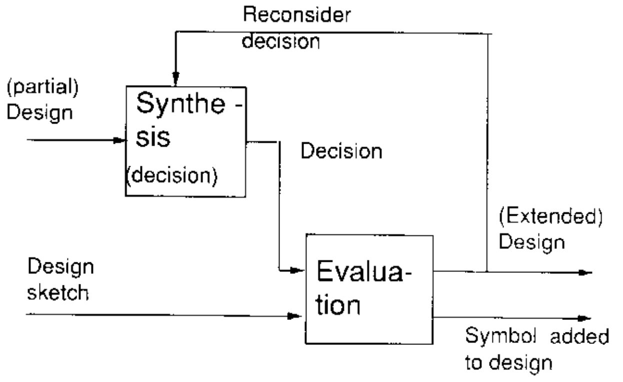

Figure 6 The decision cycle

because the vague and unstructured nature of the process at this stage makes analysis of a problem difficult.

In the synthesis step the designer makes a decision about an architectural unit. He/she then immediately enters the evaluation step to check if his decision meets the requirements. During this evaluation the designer sketches the symbol for the decision. The evaluation focuses on the properties of the decision itself and less on the relationship to other decisions. If a decision is not satisfactory, the designer will reconsider it.

The **Structuring** *Cycle*

This cycle is slightly more complicated than the previous one. In the synthesis step of this cycle the designer performs a number of decision cycles for different architectural units. This creates an appearance of chaos. Another side effect is that the complexity of each decision grows rapidly because each decision is influenced by most earlier decisions. At a certain point the complexity becomes too great for the designer to continue. When this point is reached depends on the complexity of the relations between the various decisions, but it is normally reached after four to eight decisions. The designer then enters the evaluation step of the development cycle. The first thing he/she will do is evaluate all decisions again, this time focusing on their relations. This process is more complicated than evaluation of a simple decision and may take some time.

When the decisions are all correct, the designer finally groups all newly added decisions together into one new decision. This allows for new decisions to be made because the designer has to consider only the relation to the group decision.

This process can be repeated only a limited number of times because these grouped decisions have very complex relationships. A typical design can contain about thirty decisions and four groups.

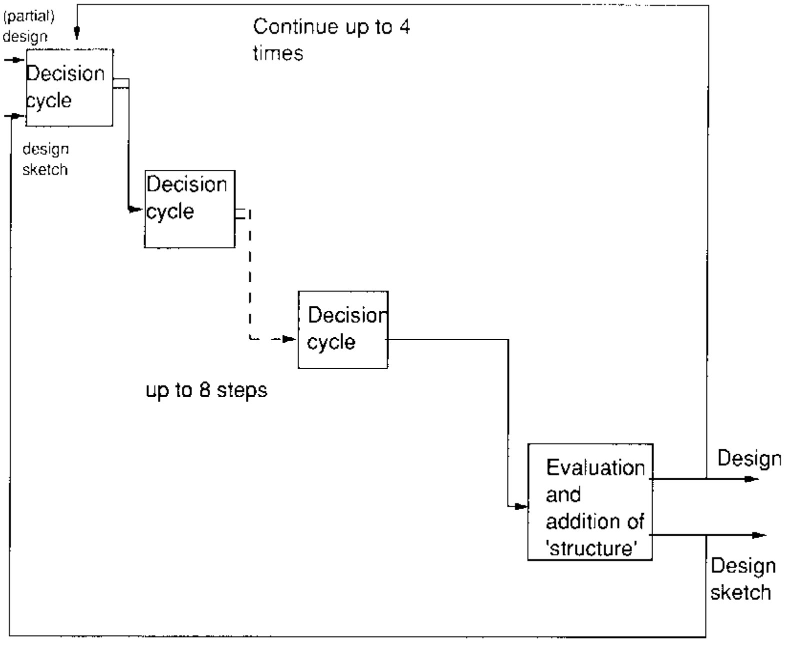

Figure 7 The structuring cycle

The Development Cycle

This is not a real synthesis-evaluation cycle since it contains no separate evaluation step. Each step in this cycle is in fact a completed structuring" cycle. The first step is an analysis of the design brief and site. The analysis of the brief will define which functional units are needed in the design, and the analysis of the site will lead to a number of units about properties. In the next step the designer makes a conceptual design based on the units that were defined in the first step. The third step is the most important partial design: the main floor plan. In the beginning this plan is a translation of the conceptual design in architectural units. Later in the design process this will gradually be improved. All other partial designs will be derived directly from this plan, and all major modifications will be made only in this plan. The fourth step is for the plans of other floors. Though presented here as a single step, there can in fact be any number of plans in this step. The final step is for partial designs fulfilling other requirements. In the early design there are usually two partial designs: a section for height and construction and an elevation for appearance and volumes. Later in the design process more requirements are considered and so there are more partial designs in this step When all steps are successfully completed, the designer returns to the main floor plan. He/she will redesign it, this time considering more

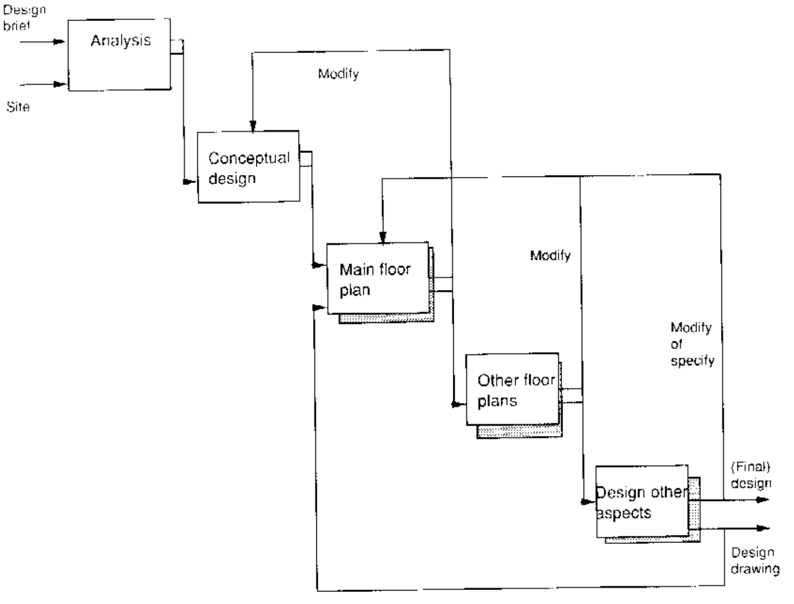

Figure 8 The development cycle

requirements and making decisions with a higher level of accuracy. This process can continue until some external force like a time limit forces the designer to stop. If, on the other hand, during one of the evaluations a problem occurs that cannot be solved by reconsidering the last decisions, the designer must stop. He/she will return to the main floor plan and make a modification that will prevent the problem. After this the designer must check all decisions to see if they are still correct. Sometimes it is not possible to make a modification to the main floor plan that will prevent a problem. In that case the designer must return to the conceptual design and alter it. This brings the design process back to the start. The accumulated knowledge from the aborted design process may help the designer move more quickly through the first steps of the new attempt.

Prototype

We wrote a prototype program to demonstrate the use of this theory for architectural design. Our main objective prototype was to make a computer program capable of handling vague design information. A secondary goal was to create a user interface that could interpret sketched information and would not need commands or dialogue to guide the process.

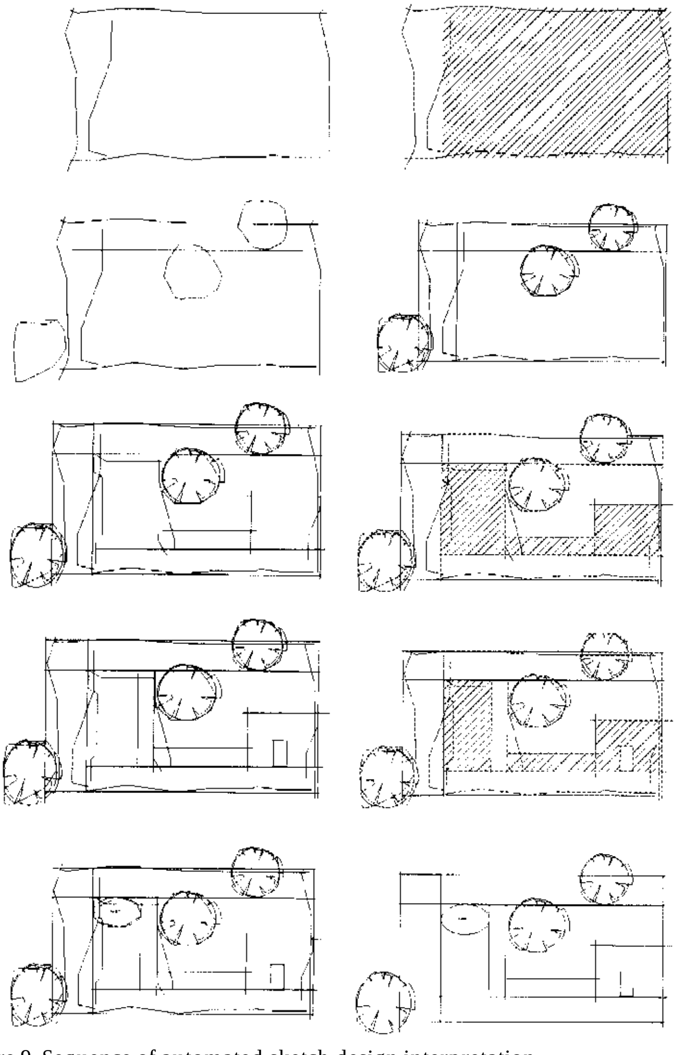

Figure 9 Sequence of automated sketch design interpretation

The prototype is written in a dialect of the Lisp language. It uses keyword association lists to store the design information. This also means that a number of data formats are acceptable for most entries in the lists The program is limited to the first three steps of the development cycle and can therefore not interpret different levels of accuracy. Furthermore, it can recognize only three different shapes: rectangular, round, and linear. In different contexts these shapes can represent decisions about the following architectural units: lot, alignment, tree, building, corridor, elevators, and rooms for four different functions. Additionally, the program can recognize and maintain the following relation: coincidence, partial overlap of two symbols, and complete overlap, which is interpreted as replacement of the older decision. Two properties, size" and "function" are used by the program to check some simple design rules. For instance, rooms should not be too small, and a washroom should not normally be placed in a corridor. The program warns if a decision fails on these rules but does not attempt to correct them.

If the designer sketches a symbol that violates the context rules, the program will warn the designer. He/she must state which symbol was intended. The program will modify the sketch so that it is located entirely in the correct context.

Future Plans

We are preparing a new study to investigate three subjects closely related to this study.

First is a more extensive study of the architectural units. Knowledge about these units is essential for understanding what decisions a designer makes during the design process. This study must also reveal more details about the properties of the different decisions and about the context in which they are made.

Second, the model has to be enhanced. It is not now capable of explaining the hierarchical structure of the design decisions. During the design process each decision is gradually replaced by a number of more detailed decisions. The new decisions are more detailed not only because they are more accurate, but also because they cover a wider range of properties and requirements. This process of specification and the relations between the decisions involved must be explained by the theory.

Third is a new study of the best way to represent in a computer database the vague and nonprecise information that is created by the designer. This requires among other things a study of the levels of accuracy and of ostensible default values for unspecified values. The same problem occurs when generating output. This must refer to architectural units and their properties and may not be too specific in the early stages of the design process.

The objective of the new study is to improve the theory of the architectural design process and to create an new prototype program for a CAAD user interface. This must support the entire design process and should not require any input other than the design sketches. During the design process a data base must be filled that at any moment can be used as input for CAAD tools for appraisal of a design.