32. The First CAAD Package (sketch based cad)

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In this paper a theory will be presented that can be used to develop a new type of CAD programs. It supports architectural design and can be applied to the earliest stages of the design process. The theory is based on architectural knowledge and describes how sketched input can be used for CAAD programs. The theoretical backgrounds will be explained briefly.

Introduction

For the last 30 years much research has been made into computer aided design. The optimism of the early years disappeared when the tremendous complexity of the subject became clear. The idea of computer support for architectural design is still tempting. When research started about CAD at Calibre it was decided to work from the designers point of view. Clearly we are a very long way from the 'design assistant' [Negroponte 70] but less ambitious goals can be stated.

When a designer starts to work on a new design he must develop a basic idea of how to meet the requirements of the brief and his own ideas of design. At this stage he could use computer assistance to help find out if his ideas are likely to be successful. The decisions at that early stage are very difficult to change in a later phase of the design process. Not only because the entire design depends on them and they therefore gained too much momentum, but also because it is simply too expensive to start all over again. If we want to work on a theory for CAAD it has to be one that is usable at the early stages of the design process.
A second consideration made formulating the research goals was that a majority of the architects is probably not going to accept a computer in their design process unless it does not force them to change their design techniques. This implied a serious restriction to the research. To a designer the most natural way of interaction with a CAAD program is through sketches. He makes these anyway and they provide a description of the design that may be usable to a computer program. Furthermore this eliminates the need to make a separate cad drawing of a design.

At Calibre research is carried out related to the theoretical background that is needed for this kind of CAAD programs. Up to now the design process has been studied and especially the design information that is generated during this process. At this moment only preliminary results can be presented.

The Design Process

Over the last three decades a great number of descriptions of the design process have been made. A significant number of them does not actually explain the process but gives an overview of the various stages of the (building) process. When one takes a closer look at these theories that seek to explain the design process it is clear that almost every theory regard design basically as a 'generate and test' activity. There is no doubt that this is true, but when applied to the earliest stages of the design process these theories somehow fail to explain all that is going on.

One of the flaws is that they are unable to explain how the first ideas originate. Only after the designer has a clear view of what must be designed, which is certainly not the case at the beginning of the process, these theories can be used to explain the rest of the process. The all important start of the process remains vague. A second flaw is that a false impression is given that the design process is well ordered. Again this may be true later in the process but it is not at the beginning. It can hardly be expected that an unstructured problem like design can be solved by well ordered techniques.

It may be clear that existing theories can not be applied to the early design phase without modification. Study of design drawings and design processes has convinced us that there is a limit to the complexity of a design. This is true not only for the entire design but also for intermediate stages. For instance only few designs consist of more than four recognizable parts. Parts, on their turn, are seldom composed of more than about 8 to 10 sub assemblies. If during the design process the design exceeds these limits to the complexity (i.e. too many parts) some elements must be combined into a new meaningful entity [de Vries & Wagter 1989]. This process of combining leads to a hierarchical description of the design and also to a rather fragmented design process since the parts are constantly changed during the design process.

When the basic subdivision of the design is completed the first design stages are completed. The rest of the design process is concerned mainly with implementing the design brief in this basic design and with attaining the architectural quality of the design. In this respect the early design phase can be regarded as a process of creating a basic 'organization (lay out) and 'hierarchy of building parts and functional entities'. These two aspects together are in dutch architecture often called 'structure' or 'concept'. Students learn that without a good concept no quality in design can be achieved and must learn for themselves to see when a concept fits the problem and when it does not. CAAD programs must concentrate on helping in the appraisal of a conceptual design as this forms the root of the entire design. When the starting point is good, quality in architecture can more easily be achieved. For our theory of the design process we have returned to the most basic description of design [Maver 68]. We are only interested in the design information and this can be described by the simplest 'generate and test' loop. We are aware that this leads to a simplistic view of the design process, but for our research goals we do not yet need to know how the design process is structured. It is sufficient to regard the design process as the generation and appraisal of design information.

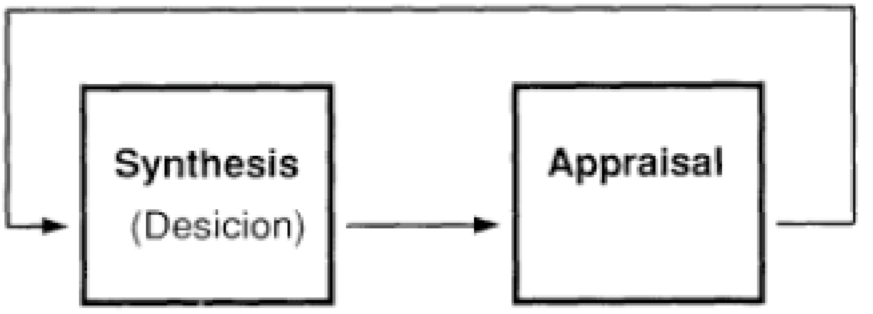


Figure 1. Primitive model of the design process

This model describes the lowest level of design at which some information is generated and successively checked in an endless repetition. At every cycle some extra information about a design is added either by deciding about a new feature or by changing an existing feature.

Design Decisions

The 'synthesis' activity that was introduced in the previous paragraph can be regarded as a 'decision about a feature of the design'. Every cycle the designer makes a decision to change a feature. This is a primitive in the design process. It does not mean however that the feature that is decided about is simple or singular or a detail. Decisions are made about arbitrary complex and global entities in the design. The model of the process does not invoke any restriction to the decisions. We will extend this very broad description to make it more useful.

The main question that arises now is: how can a decision about an entire building be the same as a decision about e.g. a doorknob? To architectural designers there is just a decision about one element. To them it makes no difference whether it is complex or not. The solution to this situation can be found in the important notion of 'hierarchical subdivision'. Each entity is part of a assembly and is not connected with other entities outside that assembly. This means that the number of interactions of an element is the same no matter what hierarchical level the entity is on and this effectively hides away the complexity of design. At any point you can either see broad or deep but never both. The following schema may clarify this. In it each box is connected with 5 other boxes and with its parent. The level of complexity (or interactions) is constant at every level in the hierarchy.

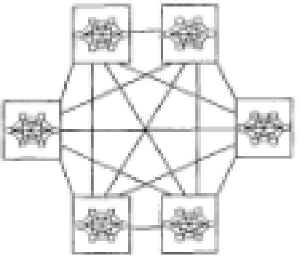


Figure 2. Hiding away complexity

To describe this kind of information a concept of Marvin Minsky is adopted: 'Frames' [Minsky 85]. Frames are a useful way to represent information and knowledge, especially if organized hierarchically. The use of frames makes it easy to construct 'is-a' and 'has-a' hierarchies with are important for representing architectural knowledge [Carrara 85]. If frames are used as values to fill a slot of a certain frame this type of organization is easily achieved. Every decision in the 'synthesis' activity of the design process concerns a single frame or a single frame slot. Now can be understood why architects see no difference between the high level and low level decisions. The kind of information they are dealing with is the same: a single frame and its slots. A design can be regarded as a web of frames that are all linked through slot-filling relations. Every decision in the design process alters this frame hierarchy but can not invalidate it entirely, only parts of it can require modification after a change.

Minsky pointed out that frames in fact are a means to represent knowledge. It is used to link properties to things. This enables humans to derive meaning from observations. They notice properties and their 'knowledge' frames are activated if these properties fill its terminals. Activated frames quickly suppress other possible interpretations thus leaving only one single interpretation active. This active interpretation fills in the default values for all slots that do not yet have a meaning and also pre-activates words and memories which are represented by other frame like structures in the brain.

It is not a single frame that forms the knowledge but the frame and its connection to other frames. Therefore the construction of new frames is very difficult. It is likely that most frames used in architectural design are based on other frames that were constructed earlier in life. Most likely new slots are appended to existing frames to add knowledge about the design process. This close connection with earlier knowledge has an advantage to, as it makes it easy for the designer to 'understand' how his design will be experienced by its users.

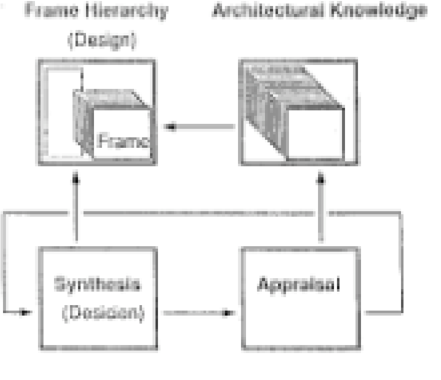


Figure 3. Design knowledge in the design process

The important frame for 'design rooms' is most likely based on the frame that allows people to interact with rooms in daily life. The principles of enclosure, entrance, walking through, usage and so on are necessary for any human being. In the same way the knowledge of building types and styles is based on the common knowledge frames that allow people to see the difference between offices and domestic buildings. Not all design knowledge can be based on existing frames however. There is no direct equivalent to 'constructional organization or 'functional hierarchy'. This kind of frames must be developed by experience and the thorough understanding of the knowledge that is required to do that is one of the most difficult parts of learning to design.

Design Frames

In the previous paragraph design information and knowledge was described as a hierarchy of frames. Out attempts to represent all this knowledge in this structure lead to unexpected problems and proved to be very difficult. In fact we were unable to find a satisfying description. The reason we found for this is that some subframes need to refer to each other. This implies that the network of relations can not be shaped as a tree but must be a network with circular references. The following is one of our attempts to define a hierarchy of design information of a simple 'room' frame.

'Design Room' frame
-> Space
  -> shape
  -> edges
  -> spatial relations *
-> Position
-> Orientation
-> Size *
-> Height
-> Atmosphere
-> Relations
  -> functional *
  -> technical
  -> routes
-> Function
  -> activity
  -> furniture
  -> size *
  -> orientation *
  -> Space *

The subframes that are marked with an asterix are in some respect frame crossing. Some of their information will be used by other frames or subframes as well. Although this may be feasible from a neurological point of view, this leads to difficulties when one attempts to reason on these structures.

Different frame structures lead to similar self referential structures. We therefor adopted a different organization for part of the design knowledge, partially giving up the hierarchical structure. The design information was split in two parts, one describing the actual organization of the design, the other describing the components used in the design. The first part of the design information still can, and should, be described as a hierarchy in order to

overcome the problems of design complexity. This tree is stored mainly in short and long term memory. The second, more static, part of the design information can be described by a three dimensional frame array [Minsky 85, p293]
Frames of similar subjects are stored in levelbands, each band is used to represent a certain amount of abstraction. Frames are also grouped in different domains. A number of domains may share a single meta-frame representing a similar operation on all corresponding frames in the various domains.

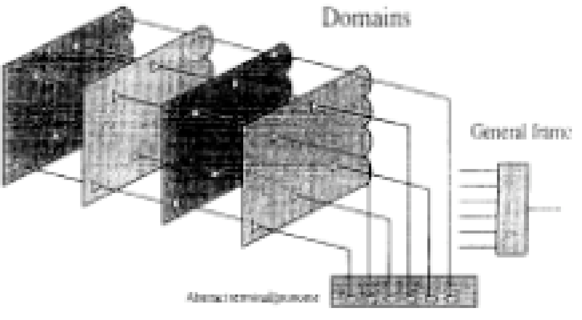


Figure 4. Related knowledge organized in a frame array

So far we have not developed a 'final' description of design frames according to this domain based scheme but preliminary results are promising. The following is our latest attempt, but it is likely to be changed considerably.

Domains:
- Functional
- Morphological
- Social
- Technical / Physical

Meta frame (abstraction)
- Boundaries
- Type
- Application
- Relations

Each of the terminals of the metaframe will be connected at the same time with frames in all corresponding frames in the different domains. When the abstraction gets activated all frames that are linked with it will be activated at the same time. Similar if one of the domain dependent frames gets involved in some reasoning process all connected frames in other domains will be forced to undergo the same process, although this may have entirely different meanings in the other domains.

This description not only explains how certain design information can be shared by different frames, it also helps explain why design sketches can contain so little information.

Since all information is connected in the frame array activating one part of the information will immediately also activate the corresponding information in the other domains. That information therefor does not need to be coded in the symbolic representation of the design decision as it is automatically derived.

Design Sketches

One aspect of the design process that is often somewhat neglected in theories about design is the design sketch. Yet it is virtually impossible to design without making sketches. They are usually considered as a side product of the design process but their role is more important than that. There are two major reasons for making sketches in the design process.

The first reason is that in buildings there are many spatial relations and constraints. It is very difficult to imagine these and it is much more efficient to sketch them and *see* if everything is correct. The second reason is similar to an often used explanation that sketches are a means of communicating the design. This can not be the real reason because most designers work alone and therefore do not need to communicate about the design. Fact is however that the design process takes considerable time and that it is frequently interrupted, either scheduled (e.g. at the end of each working day) or unscheduled by telephone, colleagues and so on. All these force the designer to concentrate on other things than the design. It would be very inefficient if he had to start all over again after being disturbed. Every designer must therefore take brief notes of the design process and this is exactly what the sketches are. After being interrupted the designer can look at his sketches and see what he had been working on and in effect this restores his state of mind and allows him to continue at the point he was disturbed.

One can state that until recently most buildings, even buildings like the cathedrals, were designed without the use of sketches and sometimes even without plans. This criticism does not hold however as these buildings were not designed in the same way as buildings are designed today. The building process of them depended on the knowledge of master craftsmen. These had learned how to lay out and construct buildings and taught this knowledge to their pupils. The main thing they did was to adapt a scheme to the given environment or to enlarge it if a larger building was required. If this failed measures to adjust the construction were taken and this knowledge was then passed on. In fact many cathedrals have collapsed at least once during construction and the same goes for some of the more ambitious Greek temples. This is in strong contrast with the current situation that requires that buildings have a different lay out and are built as fast as possible. It would be unacceptable today if a building collapsed during construction and had to be reconstructed using thicker walls and additional columns and supports. It is also difficult to rely on old designs that have proven to be useful. This has its influence on the way buildings are designed and in the new methods design sketches are inevitable.

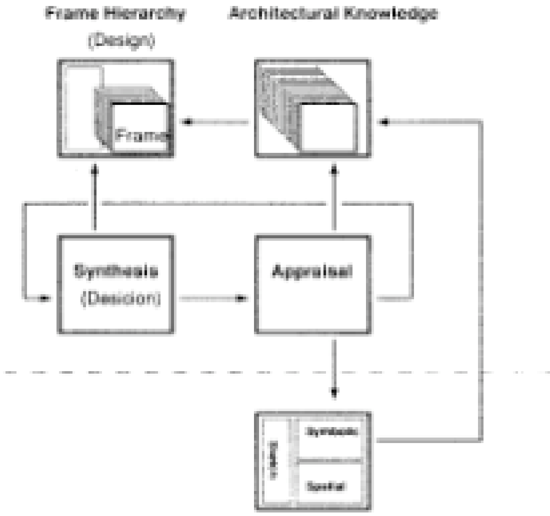


Figure 5. Sketches in the design process

The use of sketches to remember the design process is not infallible though. One of the things that cannot be expressed in symbols is the strategy of the design process. This governs which actions will be performed but is not a part of the decision cycle and will therefore not be included in the sketches. In fact it can be observed that designers tend to finish their current design strategy before turning to a disturbance. If this is not possible because of the nature of the disturbance the design process is often changed abruptly. The designer can remember what he was doing but has forgotten why and what his plans were. He has no other option than to think of new goals and new plans for the design.

Theory

The theory to develop must make a connection between the design process and computers. As already pointed out in the previous paragraphs it must be based on the methods used by architects and be applicable at the early design phases. It is not the task of cad research to define new methods of design and it can certainly not be the intention of a tool to force a designer to adapt an unnatural method.

The first research goal is to define a system that is capable of interpretation of design sketches. This allows the designer to work in his normal fashion but at the same time enables the computer program to construct a more formal description of the design in a database. This database can be interrogated by various programs that the designer uses to assist in his appraisal of the design. This process should preferably require no extra attention from the designer other than a request for some information. If the designer must constantly turn to the computer to give some instruction the design process is interrupted too often to be performed properly. In the next figure the theory of how such system could be operating is given schematically. The various parts of this theory have been introduced in the previous paragraph.

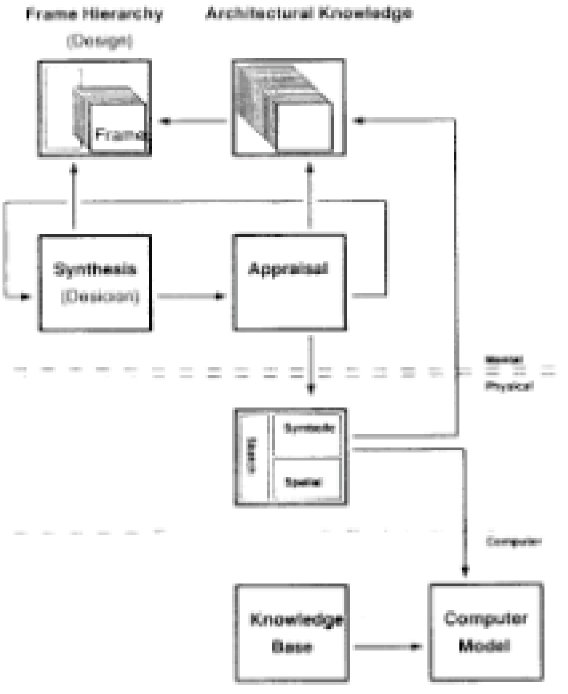


Figure 6. Principle of automated design interpretation

At the center of the design process is the synthesis-appraisal cycle with its connected sketch activity. At the synthesis activity a frame in a frame hierarchy is modified. This frame hierarchy is in effect the design. After a decision is made the results are checked using architectural knowledge. This is a large body of frames including relations and default slot values that forms the designers knowledge about architecture. Part of this knowledge is closely related to common knowledge about buildings yet other has to do only with architecture or with the activities of design.

The principle of appraisal might be to try to match the design frame hierarchy with this general knowledge to *see* if some conflict arises. This is closely related to the way human beings normally reason and can be performed quite fast. Most of the process can be performed simultaneously by different 'agents' in the brain. A conflict may then activate some frames that describe how a particular problem could be solved, or what strategy must be adopted to solve it. Strictly spoken these strategic decisions should be a separate part in the theory but they are left out so far to keep things simple and because for CAAD purposes there is no particular interest in the way the design process is planned.

The general idea is that since every sketch activity is in fact a symbolic representation of a design frame, the interpretation of these symbols can be used to form a copy of the frame hierarchy in a computer database. The information that is available to do this interpretation is: the design made so far and a knowledge base of architectural knowledge. The usage of the design is crucial for the success of the interpretation. A program that scans a design sketch and tries to interpret it cannot gather enough information to be successful.

Most frames / decisions are changed a number of times during the design process. Normally a changed decision is symbolized on top of the previous symbol. This makes sketches cluttered with lines and hatches. Without chronological information this is can not be interpreted. Another reason why chronological information is essential is that there exist only few different symbols and much more possible meanings. Almost every design sketch can be described by closed polygons, bubbloids, lines (usually straight), arrows and few highly specialized symbols without dividing a single symbol in different primitives. It is not only the shape of the symbol but also its location and time (in the design process) that defines the frame it is representing. This information can not be derived exclusively from a final sketch. In a sense sketches can be regarded as a language. Only when the entire 'sentence' is heard the meaning of it can be understood.

Design sketches are used by designers to help regain track of thought after a disturbance. This implies that not all design information can be derived from the sketches. This is not a major problem to the interpretation of sketches since they must contain enough information for the designer to identify the various frames of a design. Given a sufficiently large knowledge base this is all that an sketch interpreter must do to be able to construct a computer model of the design.

Product Models

Frames are a possibility to represent knowledge on an artifact derived from a psychological angle of incidence. It can be the basis of a design theory and offers a structure for formalizing. A product model is a similar method for structuring applied to computers. It is inspired and based on the product life cycle approach. A product model offers a structure that probably will be of great use to formalize theories. The basic is a hierarchical decomposition of an artifact, or product, (e.g. a building) in sub assemblies and parts [Turner 88]. Every part is regarded as functional requirements (FU) that require a technical solution (TS). This method however lacks an approach to problems related to the design process itself. Formulating into functional requirements and technical solutions the design process seems to be omitted. The result of the proposed research should clarify and contribute to the description of what happens inside the so called 'hamburger structures'.

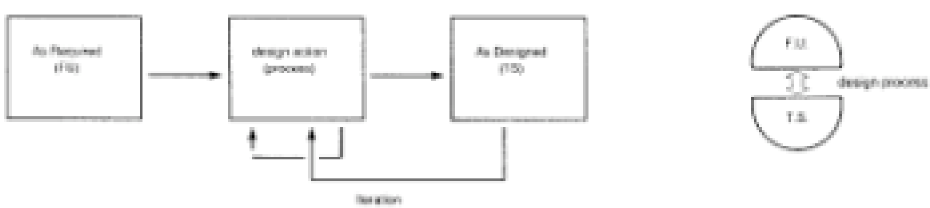
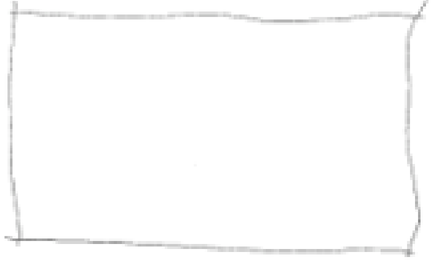


Figure 7. Product modelling

Design Interpretation

The following example of an automated sketch interpretation is based on a prototype program that is developed at Calibre. The program is capable of the interpretation of a certain class of simplified designs. The entire interpretation is performed automatically and requires no user supervision whatshowever. The prototype works by keeping track of every sketch action from the beginning of the design process. From each sketch action certain features are recognized and used in the interpretation.

The program is based on the assumption that every step in the design process can be monitored and is sufficiently small to be unambiguous (that is if enough context variables have been identified). In this prototype program 3 major variables were sufficient but for a more realistic program many more will be needed. The prototype recognizes the 'Shape', the 'Context' and the 'Phase'. The second feature describes the element that entirely or partially encloses the new shape. The third feature describes the probable phase the design process is in. This gives the program a hint of the most likely interpretation of the symbol.



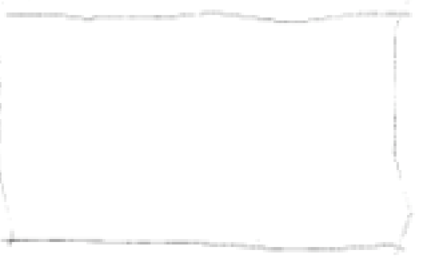
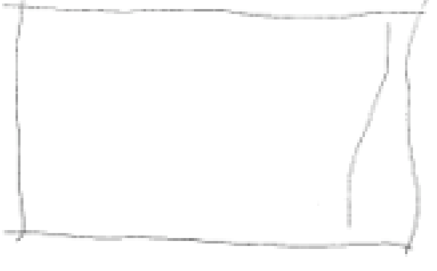


Figure 8. left: Current sketch right: current environment as seen by the computer. Interpretation: 'Lot'.



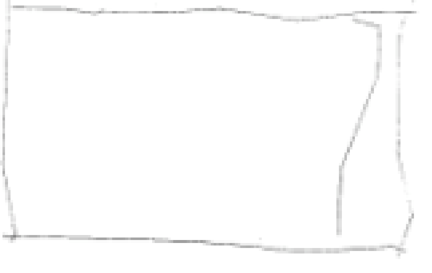


Figure 9. left: New symbol sketched right: New symbol as seen by the computer

This new symbol is recognized by the three sensors as follows:
'Shape' => Straight_Line; Vertical
'Context' => In_Lot; In_Buildable
'Phase' => Site_Layout
In the next illustration is shown how these features fill terminals of the frames that represent the different possible elements of the design.

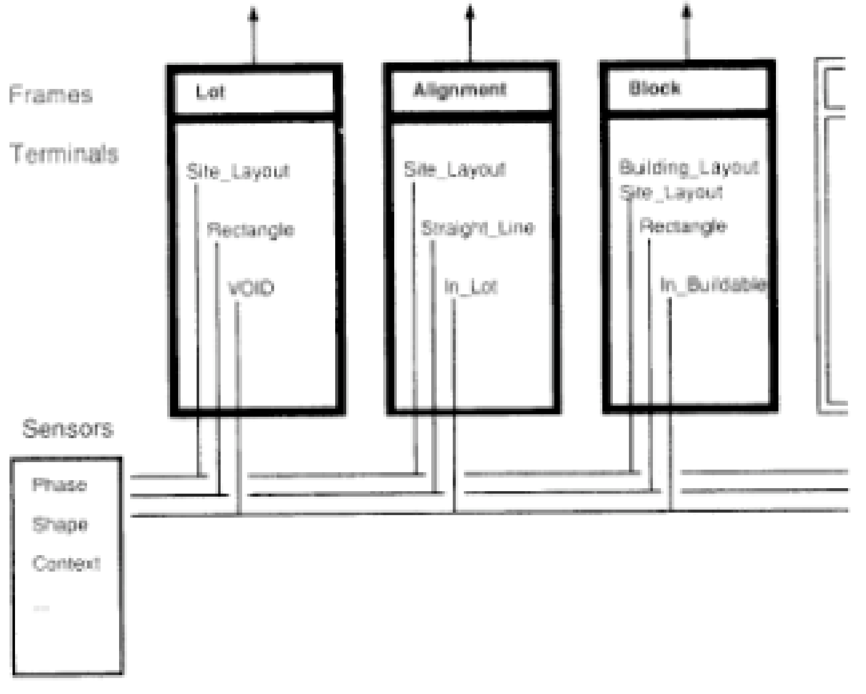


Figure 10. Recognizing frames from sketches

The symbol will clearly activate the 'Alignment' frame. This frame will be connected to the sketch information in a hierarchical tree that forms the description of the design. The sketch will be straightened since the prototype can only handle orthogonal information. The information of the design is stored separate from the information of the elements. The first is modifiable whereas the latter is fixed. The information that is derived from the sketches can at any time be used to reactivate the proper frames.
In the prototype program the 'Alignment' frame is connected not only to the three sensors but also to some other frames. These describe some design information that is generally not sketched but derived from the information. For instance the 'Buildable Area' frame has four terminals that can be activated by 'Alignment' frames.

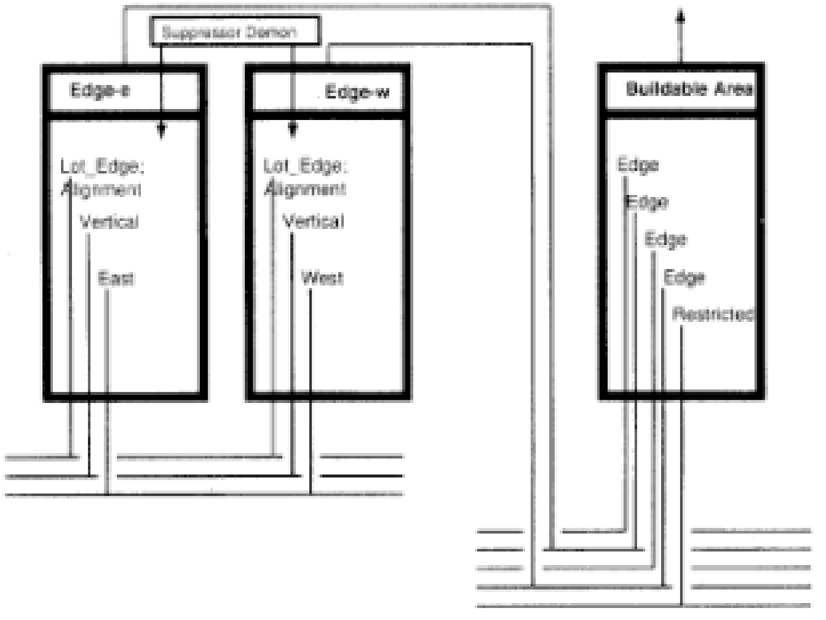


Figure 11. Deriving additional information from linked frames

In this case two frames, 'Edge-w' and 'Edge_e' will get activated and the 'sensor demon' will get active because only one interpretation can be allowed. In this example there is not sufficient information and the demon will suppress the 'East' interpretation in favour of the west interpretation because of its relative position to the centre of the 'Lot' symbol. Another 'Alignment' frame may later of course overrule this interpretation.
The activated 'Edge_w' frame will fill the appropriate 'Edge' terminal of the 'Buildable Area' frame. This has the effect of replacing the previous edge of the buildable area.

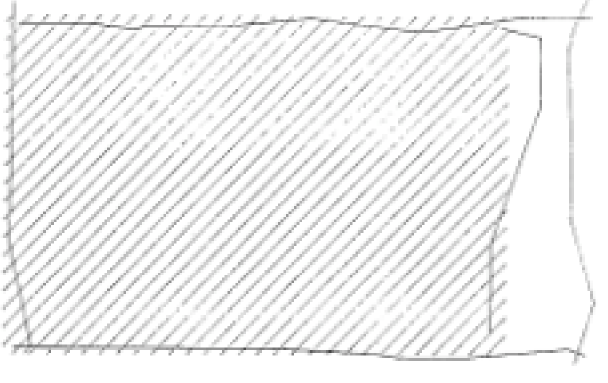


Figure 12. sketch environment as seen by the computer

Conclusion

So far we have tried to develop a theory of design that can be applied to the earliest stages of design and does explain how design information originates. Over the next period of time the definition the architectural knowledge that is needed to do the actual interpretation of design sketches is planned. Most of this research will be performed through prototype programs. These will be programmed to perform one specific task of the interpretation process and will be compared with human experts performing the same task. The final results of this research project are expected in approximately three years.

Literature

[Alexander 64]Alexander, C. "Notes on the synthesis of form." Harvard University Press.

[Carrara 85] Carrara, G. Novembri, G. "Constraint bounded design search."In Pipes, A. (ed.) Computer Aided Architectural Design Futures. London: Butterworths

[Maver 68] Maver, T. "The strathclyde model of design process".

[Minsky 85] Minsky, M. "The society of mind." New York: Simon & Schuster inc.

[Negroponte 70] Negroponte, N. "The Architecture Machine." Cambridge, Mass: MIT Press, 1970

[Turner 88] Turner, J. "AEC Building Systems Model, ISO TC 184/SC4/WG1 doc 3.2.2.4."

[de Vries & Wagter 89] de Vries, M. Wagter, H. "A CAAD model for use in the early design." , in McCullough, M. (ed.) the electronic design studio, Cambridge, Mass.: MIT Press, 1989.