ICADS: A COOPERATIVE DECISION MAKING MODEL WITH CLIPS EXPERTS

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Abstract. This paper describes a cooperative decision making model comprising six concurrently executing domain experts coordinated by a blackboard control expert. The focus application field is architectural design, and the domain experts represent consultants in the areas of daylighting, noise control, structural support, cost estimating, space planning, and climate responsiveness. Both the domain experts and the blackboard have been implemented as production systems, utilizing an enhanced version of the basic CLIPS package. Acting in unison as an Expert Design Advisor, the domain and control experts react to the evolving design solution progressively developed by the user in a 2-D CAD drawing environment. A Geometry Interpreter maps each drawing action taken by the user to real world objects, such as spaces, walls, windows, and doors. These objects, endowed with geometric and non-geometric attributes, are stored as frames in a semantic network. Object descriptions are derived partly from the geometry of the drawing environment and partly from knowledge bases containing prototypical, generalized information about the building type and site conditions under consideration.

INTRODUCTION

Commencing in 1987 with the participation of an interdisciplinary team of researchers the CAD Research Unit at the California Polytechnic State University, San Luis Obispo, undertook the development of a prototype working model of a computer-based environment supportive of the design function as it is practised in architecture and engineering. Impetus for the project came directly from the shortcomings of current CAD systems that focus almost entirely on the production of drawings rather than the design decisions that produced the artifacts represented by the drawings.

The CAD Research Unit team proposed an intelligent computer-aided design system (ICADS) model comprising three integrated components: an intelligent CAD DBMS, an Expert Design Advisor, and a Multi-Media Presentation Facility (Fig.1).

The CAD DBMS component provides on-line access to information resources in direct support of the design function. From the perspective that design involves predominantly the refining, adapting and combining of prototype solutions of previous similar projects, the ICADS model includes several knowledge bases in the CAD DBMS component. These knowledge bases are intended to capture design context experience and serve as a basis for reasoning during the earliest decision-making stages.

Within the CAD DBMS component the evolving design solution is represented as a network of hierarchically related objects. Collectively, these objects provide a comprehensive description of the current state of the design solution. Individually, the description of each object consists of information units or design entities comprising an integrated set of geometric definitions and non-geometric attributes. This information representation drives a network of intelligent design tools (IDTs) coordinated within the Expert Design Advisor by a Blackboard Control System.
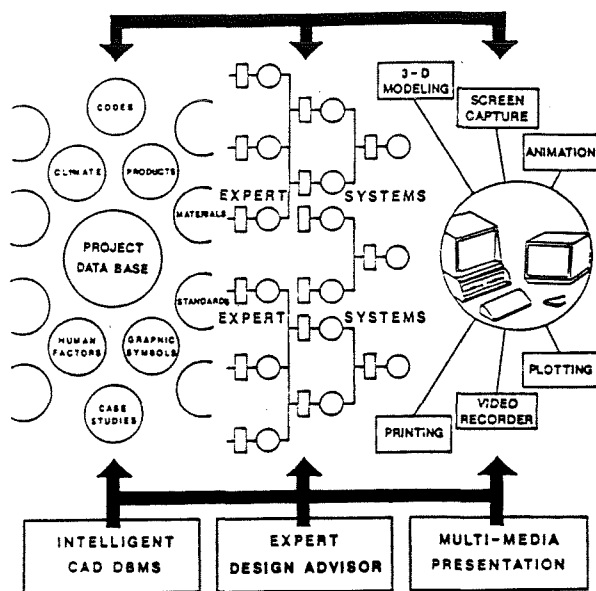
Figure 1.
Conceptual ICADS Model
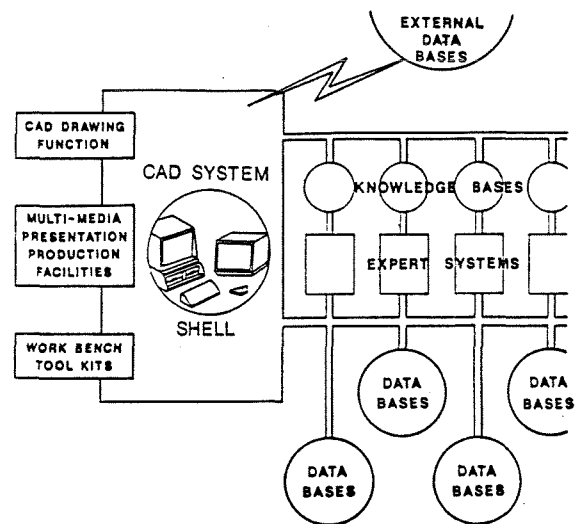
Figure 2.
Intelligent CAD System Shell

The availability of appropriate design knowledge is central to any computer-based design environment. In this respect the ICADS model is foremost an information management and synthesizing system, and may be viewed as a shell that binds together an assortment of internal and external design resources (Fig.2). The drawing function, which dominates existing CAD systems, assumes the secondary role of providing a medium for visualizing and communicating the design decisions that have been made within a largely non-graphical problem-solving context.

The work described in this paper represents the first version of an ICADS working model (Pohl et al. 1988, Myers and Pohl 1989). ICADS DEMO1 has been developed mostly with off-the-shelf software systems. Where the necessary tools were inadequate, enhancements were added and modifications made. The relational DBMS, SQL-RT (Oracle), was found to be entirely adequate for accommodating the Building Type, Site/Neighborhood and Reference elements of the design knowledge component of the ICADS model. The CLIPS expert system shell, developed by the Artificial Intelligence Section at NASA/Johnson Space Center, was used for all parts of the Expert Design Advisor (NASA,1989). Availability of CLIPS source code ('C' language) allowed several enhancements to be made to the basic CLIPS package to permit the Blackboard Control System to execute in a distributed environment with several CPUs.

The CAD Research Unit was fortunate to obtain permission from Accugraph Corporation (El Paso, Texas) to incorporate its MountainTop computer-aided drawing package in ICADS DEMO1. Some modifications were made to this commercially available CAD system to provide direct access to the data structure of the drawing currently displayed on the screen.

THE ICADS EXPERT DESIGN ADVISOR

The principal component of the ICADS DEMO1 model is the Expert Design Advisor, consisting of six domain experts (IDTs), the Blackboard Control Expert, two knowledge bases and several sources of reference data (Pohl et al. 1989).

103

The scope of the implementation environment has been restricted in terms of both the breadth of information available to the designer and the range of design functions supported. The information resources provided by the working model are drawn from the architectural design application area and include Building Type and Site/Neighborhood knowledge bases, as well as a Reference database containing material and constructional information.

A schematic diagram of the ICADS working model is shown in Fig.3. The Expert Design Advisor is responsible for the evaluation of the evolving design solution and the resolution of conflicts that may arise when solutions in one domain interfere with solutions in another domain. It consists of advisory components, a control expert and operational components, as shown below:

advisory components: Geometry Interpreter
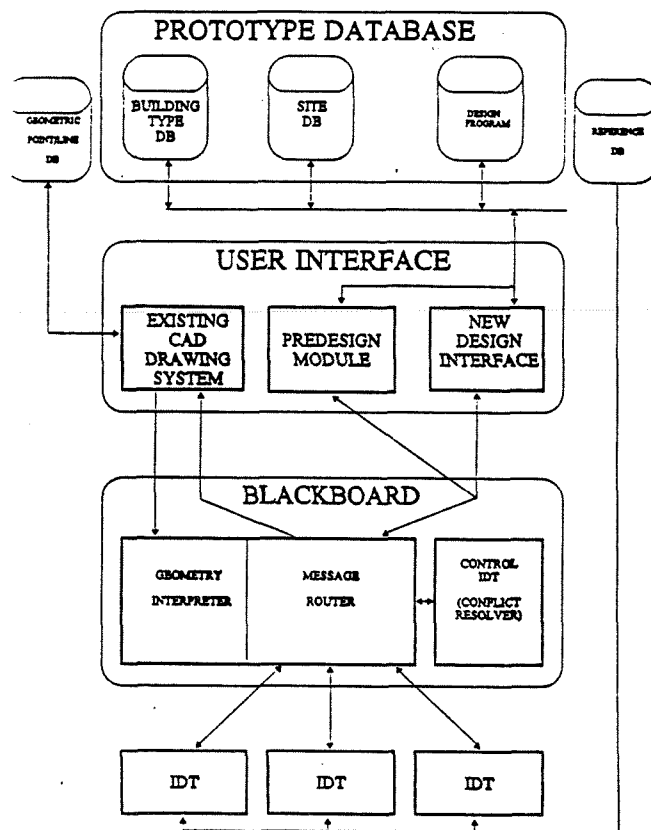   Access domain expert
                              Climate domain expert
                              Cost domain expert
                              Lighting domain expert
                              Sound domain expert
                              Structure domain expert

control expert: Conflict Resolver

operational components: semantic network of frames
                              Message Router
                              Attribute Loader

Figure 3.
ICADS DEMO1 System Diagram

Central to the operation of the Expert Design Advisor is a semantic network of frames that represent the current state of the design solution within the context of the project. The term semantic network is used here to refer to a classification framework of design object frames. Each frame incorporates slots that may contain several types of information, such as values of geometric and non-geometric attributes of the current solution model, and relation linkages (Fig.4).

The attribute values represent a fact-list that drives the domain experts and the Conflict Resolver. Indeed, attribute slot names have identical counterparts among the fact names in the latter. This provides a direct interface mechanism that allows the domain experts and the Conflict Resolver to react quickly to any changes in the current state of the design solution. Values in the fact-list are derived from two sources:

1. Geometric facts describing the geometry of the design solution are extracted by the Geometry Interpreter in terms of the nature, physical dimensions and relative locations of the following seven design objects:

FLOOR, SPACE, WALL, DOOR, WINDOW, SEGMENT and SYMBOL

The SEGMENT object refers to any part of a WALL object that is demarcated either by the intersection of another wall or has been drawn by the designer as a distinct wall component. The SYMBOL object represents directly by name any closed shape or icon within a SPACE object (e.g., column, chair, table).

2. Attribute facts describing the context of the project and the non- geometric characteristics of the current design solution. These attribute facts are derived from the Building Type and Site/Neighborhood knowledge bases, directly or indirectly through the extrapolation of several information items. Non-geometric attribute values are included in the fact-list in association with the following five design objects:

PROJECT, NEIGHBORHOOD, SITE, BUILDING and FLOOR

The differences between the geometric and non-geometric design object sets are entirely consistent with the nature of the information they contribute to the fact-list. The design knowledge bases that support the design process in the ICADS model encompass a much wider view of the design space than can be represented by any instance of the geometric design solution. For example, while regional and neighborhood parameters are an important part of the design decision-making process they are no longer discernable as discrete information items in the drawing of the geometric model. At that level they are embedded under several layers of synthesis and are therefore an implicit rather than explicit part of the geometry of the artifact.

In the ICADS working model the distinction between design context and design solution has led to the separation of the semantic network of design objects into two logical sections (Fig.5).

PROJECT DESIGN OBJECT FRAMES: comprising one frame for each design object represented in the design program (design specifications), which is a subset of the Building Type and Site/Neighborhood knowledge bases. Slots in these frames are used to store non-geometric attributes that have either direct equivalents in the Building Type and Site/Neighborhood knowledge bases, or are inferred from several values by the Attribute Loader.

SOLUTION DESIGN OBJECT FRAMES: comprising one frame for each (geometric) design object analysed by the Geometry Interpreter. Slots in these frames represent the geometric descriptions of the particular design object identified by the Geometry Interpreter and the solution evaluation results generated by the domain experts under the coordinating role of the Blackboard.
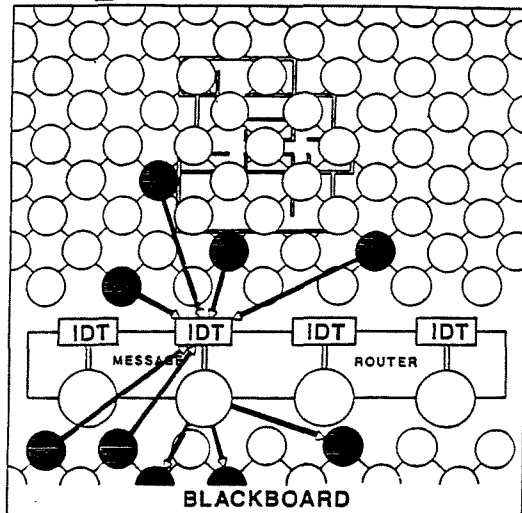
Figure 4.
Semantic Network of Design Objects
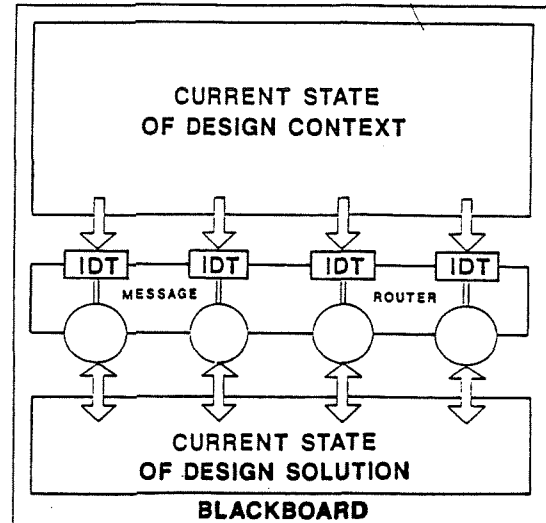
Figure 5.
Logical Division of Design Objects

In the current ICADS working model the slot values of the 'project design object' frames cannot be changed by the designer during the design process. They are established by the Attribute Loader at the beginning of a design session and remain as static members of the input templates of individual domain experts, and to a lesser extent the Conflict Resolver, throughout the design session.

THE DESIGN KNOWLEDGE BASES

The structure of the Building Type and Site/Neighborhood knowledge bases in the ICADS model have been reported previously (Pohl et al. 1988). These knowledge resources are intended to capture the experience and standard solution strategies associated with a given building type, and the specific conditions of the site and its surrounding environment, respectively. Collectively, they provide views of the design project from several vantage points represented by different interest groups (e.g., owner, user(s), designer, community and government authorities).

The Building Type knowledge base is included in the Expert Design Advisor to provide prototype information relating to the type of building under consideration. In this context a prototype is defined as a body of knowledge relevant to the definition and solution of a related set of design problems. The prototype includes generalizations derived from specific instances, elements of previously tested solutions, decriptions of typical solution components, and solution boundary constraints. The boundaries within which the prototype is applicable is provided by the Site/Neighborhood knowledge base, in terms of the requirements and characteristics of the owner, and the physical, environmental, social and economic context of the project location.

THE DOMAIN EXPERTS

The current state of the design solution, represented as object descriptions (containing both geometric definitions and non-geometric attributes), drives six domain experts with evaluation capabilities in the areas of space access determination, construction cost projections, daylighting, sound control, structural system selection and thermal behaviour. Each domain expert, executing continuously in background under a separate process, extracts information pertaining to the particular design object under consideration from the available design knowledge bases and commences to evaluate the design solution based on its expertise (Fig.4).

For example, the Lighting expert will evaluate the degree to which each space in the current design solution satisfies the requirement for daylight. The evaluation consists of two components. First, the requirements are established. This may be a trivial task, requiring only the generation of a simple query to a Reference database to obtain recommended task and background illumination levels for the type of space under consideration. Or, it may be a much more complicated undertaking involving the analysis of qualitative and quantitative design criteria such as:

      OWNER considers energy efficiency to be very important;
      USER GROUP (A) consider energy efficiency to be optional;
      USER GROUP (B) consider energy efficiency to be desirable;
      DESIGNER considers energy efficiency to be important;

      Recommendations for each SPACE based on past experience:

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      x% of background illumination by daylight;
      y% of task illumination by daylight;

Second, the Lighting expert will estimate the daylight illumination on the workplane at the center of each space in two parts. The Daylight Factor is estimated based on the geometry of the space, the geometry of windows in external walls and the reflectances of the internal wall, ceiling and floor surfaces. This Daylight Factor value is converted into an equivalent illumination level subject to an external daylight availability calculation for a particular month, day and time.

The results obtained by each domain expert are added to the appropriate design object frames. In the current ICADS working model both the input and output templates of each domain expert are predetermined sets of attributes and only the values of these attributes are variable. The Conflict Resolver, resident in the Blackboard, examines the values posted by the domain experts and arbitrates conflicts. For example, the Sound expert may have generated the requirement that the north wall of the conference room should have no windows. This is in conflict with the current design solution (based on the Geometry Interpreter) and the Lighting expert who has determined that the '% of background illumination by daylight' for this room is already 15% below the 'requirement'. Based on its own rules the Conflict Resolver determines that the windows in the north wall should be reduced by 20% and double glazed to minimize noise transmission. Apparently the reduction in the availablity of daylight is warranted in view of the noise transmission problem.

The Blackboard posts these new values to the appropriate frames and thereby initiates a new round of evaluations by those domain experts whose previous results are now in conflict with the Blackboard's determination. If the Blackboard had decided that the windows must be deleted from the north wall of the conference room then it would have requested permission for this radical action from the designer. The interaction between the designer and the Blackboard is limited to extreme circumstances in the current ICADS working model. Such circumstances may arise:

1.   If the decision of the Blackboard requires a modification of the drawing. In the above example, during the conceptual design stage a 20% reduction in the window area of the

north wall can be accommodated without modification of the 2-D representation of the space. However, the deletion of all windows from the wall would require the drawing to be changed.

2.   If the Blackboard cannot resolve a conflict set. Again, in the conference room example, it is conceivable that certain design specifications could mandate daylighting and sound control requirements that will not allow a compromise to be made. Under these conditions, the Blackboard will interrupt the designer and request guidance.

At any time during this evaluation process the designer can request to review the current conflict state of the Expert Design Advisor (i.e., the interactions of the Conflict Resolver with the six domain experts). This is accomplished through the Design Interface on a second monitor.

THE CONFLICT RESOLVER

The Blackboard Control Expert is primarily implemented as the Conflict Resolver in the ICADS DEMO1 model.   While it is envisaged that 'planning' will play an important role in future implementations of the ICADS model, at this time the resolution of conflicts appears to be sufficient to coordinate the activities of the advisory components in the Expert Design Advisor.

The principal purpose of the Conflict Resolver is to assert 'current value' frame slots, representing the current state of the evaluation process performed by the domain experts, onto the semantic network resident in the Blackboard. To accomplish this the Conflict Resolver requests from the Message Router all of the 'solution design object' frames which contain results generated by the domain experts. Current values fall into one of three basic categories: values which result from solutions proposed by a single domain expert; values which result from solutions proposed by several domain experts for a common current value; and, values which must be inferred from solutions proposed by several domain experts.

In the case of the first category, which represents solution values unique to a single domain expert, the Conflict Resolver does not change the values proposed by the expert. The proposed solution values are simply asserted as current values into the appropriate frame slots. In the second category two or more domain experts propose differing values for the same solution parameter. In such direct conflict situations it is the responsibility of the Conflict Resolver to either determine which of the values is most correct or to derive a compromise value. The process of resolution may cause the Conflict Resolver to change several current values in addition to those in direct conflict. An example of such a change is given below:

<div style="margin-left:2em">

Structural expert: 'suggested roof material type' = A
Climate expert: 'suggested roof material type' = B

      Rule 1: if A == B then
current value   'suggested roof material type' = A

      Rule 2: if A == timber and B == concrete then
current value   'suggested roof material type' = concrete

      Rule 3: if A == concrete and B == timber then
current value   'suggested roof material type' = concrete
                  and
current value   'suggested roof struct.system' = concrete plate
                  and
current value   'required roof struct. depth' = 4
                  and
current value   'roof insulation thickness'   = 3

</div>

The Conflict Resolver incorporates resolution rule sets which determine the best current values from those proposed. There is a resolution rule set for each possible direct conflict. In the development of each rule an attempt has been made to achieve a desirable balance between the various design issues. At this level the Conflict Resolver can be consider an expert whose knowledge is the ability to achieve this balanced integration. In the above example, let us assume that the Structural expert proposes 'timber' (A) and the Climate expert proposes 'concrete' (B). Under these circumstances the Conflict Resolver recognizes that:

- the solutions for the roof structure proposed by the Structural and Climate domain experts are substantially different;

- the 'concrete' solution proposed by the Climate expert suggests a need for thermal storage;

- the 'timber' solution proposed by the Structural expert cannot be readily modified to provide thermal storage;

- in most cases a structural timber system can be replaced by a concrete system (there are exceptions to this rule of thumb (e.g., seismic risk) and the Structural expert should be able to recognize such circumstances and, if necessary, refuse to agree with the Conflict Resolver's proposed compromise);

- the energy conservation savings provided by a passive thermal building are likely to exceed the higher capital costs of a concrete roof system.

In the third category the Conflict Resolver deals with proposed solution values that are indirectly in conflict with other proposed solution values and current values. The resolution rules for this category allow the Conflict Resolver to make the necessary modifications to any of the values involved. Under these conditions, in addition to changing proposed solution values the Conflict Resolver may also change current values as shown in the following example.

    current value 'roof construction system'   = A
    current value 'roof U-value (BTU/HR-SF-F)'= B
    current value 'roof insulation thickness'   = C
    current value 'roof thermal lag (HR)'   = D

Climate expert: 'suggested roof construction system' = E

        Rule 1: if A <> E then
    look up Reference database and change B, C, D to appropriate values for the suggested roof construction system 'E'

In this example the Climate expert has suggested a new roof construction system. The Conflict Resolver recognizes that several current values must be changed so that they match the new roof construction system. Similar to the direct conflicts discussed under the second category, each indirect conflict must also have a set of resolution rules.

Not all conflicts can be resolved by the system. In some cases, usually those requiring changes to the drawing or 'project design object' frames, the Conflict Resolver will ask for assistance from the designer. Under these circumstances operation of the Expert Design Advisor is suspended until the designer responds.

SOME IMPLEMENTATION ISSUES

The model of the ICADS Expert Design Advisor described above presents several issues of concern that are of an operational nature.

The first concern is to prevent the Conflict Resolver from entering into an 'endless argument' state that may arise when two domain experts always return with conflicting values for the same solution parameter. For instance, in reference to the previous example the Structural expert may insist for good reasons that the roof construction system should be 'timber'. For reasons that are different but just as persuasive, the Climate expert may be unwilling to deviate from its original proposal of a 'concrete' roof system. The two domain experts are now locked into an ad absurdum argument. In the current ICADS working model the Conflict Resolver monitors this type of situation by checking for repetitive cycles in current values.

A second concern is related to the timeliness of the conflict resolution process. In the implemented model of the Expert Design Advisor, the Conflict Resolver will not post a current value to the Blackboard until it has seen all of the 'solution design object' frames which are involved in a given conflict. In a full ICADS implementation it may be desirable for the Conflict Resolver to post a current value based on partial information (i.e., based on only some of the required 'solution design object' frames). This current value could be updated when the Conflict Resolver receives additional information. In the implemented model the Conflict Resolver waits until it has all of the necessary values from the domain experts before asserting a new current value.

The potential for a 'cascading' condition which may arise when a minor change by a domain expert causes a major re-evaluation of the current solution by several domain experts, is another concern. In the DEMO1 implementation of the Expert Design Advisor the possibility of such a condition occurring is exacerbated because domain experts will fire on any change to a current value and the Conflict Resolver will respond to any proposed changes posted by the domain experts. An attempt has been made to forsee events that could conceivably lead to this undesirable condition. Where appropriate, tests have been included in the rules of domain experts to determine whether the current divergence between the most recent suggestion and the corresponding current value (proposed by the Conflict Resolver) is sufficiently large to warrant further action by the domain expert.

CONCLUSION

The implementation of the first prototype working model represents a three-year milestone in the ICADS project. Although ICADS DEMO1 is limited in scope, it will provide a vehicle for the collection of a body of knowledge relating to the performance characteristics of a computer-based design environment. Extensive explorations can now be conducted to determine the impact of an Expert Design Advisor that dynamically responds to the actions of the designer in its continuous, unobtrusive evaluation of the evolving design solution.

REFERENCES

Myers L. and J.Pohl (1989); 'ICADS DEMO1: A Prototype Working Model'; Fourth Eurographics Workshop on Intelligent CAD Systems, Paris, France, April 24-7. NASA (1989); CLIPS Architecture Manual: Version 4.3; Artificial Intelligence Section, Lyndon B.Johnson Space Center, NASA, USA.

Pohl J., A.Chapman, L.Chirica, R.Howell and L.Myers (1988); 'Implementation Strategies for a Prototype ICADS Working Model'; Technical Report: CADRU-02-88, CAD Research Unit, Design Institute, California Polytechnic State University, San Luis Obispo, California.

Pohl,J., L.Myers, A.Chapman and J.Cotton (1989); 'ICADS: Working Model Version 1'; Technical Report: CADRU-03-89, CAD Research Unit, Design Institute, School of Architecture and Environmental Design, California Polytechnic State University, San Luis Obispo, California.