INTEGRATED COMPUTER-BASED APPROACH TO SUPPORT CONCEPTUAL BUILDING DESIGN

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ABSTRACT: *Much of the construction industry in the world today, certainly in North America, is still characterized by fragmentation. Even though computer support for construction is available in a multitude of ways, effective integration across actors, over the entire life cycle and covering all components that compose building projects is still in its infancy. At the present time, commercial integrated solutions are more prevalent at the detailed design stage in the form of "design suites" of applications for drafting, structures, HVAC, estimating etc. The authors have developed, over many years, a number of integrated building design prototypes at the preliminary stage by means of novel computing techniques derived from AI and product/process modelling. The purpose of this presentation is to push the exploration further upstream at the conceptual design stage, when decisions involving only few individuals have the greatest impact on the life-cycle performance of the building delivery process. On the basis of an extensive literature review, analysis of current design environments and protocol analysis of designers actually engaged in such work, we will identify key concepts and activities that are essential at the conceptual design stage, with the view to propose and implement a computer-based prototype capable of providing effective support.*

KEYWORDS: Building design, integration, conceptual design, computer aided building design, CAD.

1. INTRODUCTION

The design and construction of buildings is a complex interdisciplinary activity accomplished in several phases. The initial phases of feasibility and design are very crucial for the success of the project because data concerning building type, operations, construction, management and design are collected or created. This provides a framework on which all other stages are completed against.

In the Feasibility phase the owner works with the designer to establish design goals and provide resource information such as finances and site. Teams of professionals from different areas of speciality are also assembled or identified as needed.

In the Design phase, potential solutions are assembled and detailed by this diverse group of professionals in an effort to produce a harmonious environment where the different systems required in a typical building can exist and perform their different but interrelated duties. The design phase is divided into 3 stages: conceptual, preliminary and detailed design.

During conceptual design fundamental decisions are made in all aspects of the project, including form and space usage, structural, mechanical, electrical and site issues. In general providing a large number of alternatives betters the chances of success in producing a final quality product.

In preliminary design, these fundamental issues are developed into a more finished physical or visual object that can be used to more precisely assess the fulfilment of the owner's need. This stage basically tidies up and brings together the numerous parts of the project created, in a form appropriate for presentation to the owner and other involved parties. The ultimate goal of the preliminary stage is to identify a single most desirable design option that best satisfies the need and budget of the owner.

In detailed design, this single option is elaborated and broken down into a set of construction documents that provide directions to the contractor on how to manufacture and construct the product.

The necessity to involve an interdisciplinary team of professionals introduces the need for a properly co-ordinated and integrated work process. Integration is necessary in order to guarantee the smooth execution of a project sequence with the shortest time schedule, most likely to produce a successful product that is invariably comprised of many different building systems that must exist and function co-operatively.

2. THE PROBLEM

Traditionally, one or two professionals, usually in the areas of architecture and structures, complete the two earlier phases outlined above. Under such circumstances there are many decisions made in isolation that effectively lock out any consideration by other critical specialists so that by the time they become involved later in the design process, there are no adequate accommodations for their input and remedies are difficult to implement. This introduces high costs, low performance levels and generally disrupts the building delivery process [Fazio 1990].

In projects where there are more than one professional from different areas of speciality, the tools available do not support such multidisciplinary environment and therefore force interpretations of work into different formats. This increases the amount of work as well as the potential for errors. It also limits the number of ideas introduced or formulated.

Finally, there is no provision in the available tools for a smooth transition of work from the conceptual stage to the later stages of design. Most work done in the conceptual stage is accomplished in a vague and unstructured manner using a combination of text and graphic elements. In order to use such data in later design stages, it must be reorganised and interpreted into mostly graphic digital elements. This is largely repetitious and therefore very tedious.

Computers have come a long way in providing tools for efficient communication. Their ability and speed at managing and transferring data makes them ideal for the co-ordination and integration of the many professionals and complex activities that must be performed in the building design process [Rivard et al. 1999] and [Bedard et al. 1991].

It is therefore not surprising that there are numerous CAD solutions available today. The problem, however, is that these solutions are not based on the knowledge of what actually occurs at this stage of early design. The reason is because it is only recently that this type of knowledge has become available in the form of protocol analysis. As a result, these tools do not address the problem effectively. The support they provide is fraught with incompatibilities or limited support to the relevant processes and involves overly complex methods of use and manipulation.

3. REVIEW OF PROTOCOL ANALYSIS

In an effort to understand the real nature of early design, it is important to study design sessions using a procedure called protocol analysis. This is the collection of data generated as a designer performs design tasks. The data, which include audio and visual recordings, is then studied and analysed to determine what transpires during the design process. The following section summarises reports on numerous publications on protocol analysis.

Report 1: Designers at work constantly interact with their drawings. The absence of the need to communicate with an external observer leaves the designer free to use incomplete or vague diagrams that reduce drawing time while encouraging design exploration. This type of activity produces many design solutions, none of which are necessarily sequential or recorded. Nonetheless the designer follows a step-by-step process [Goldschmidt 1994].

Report 2: Sketches progress from vague, unstructured and simplistic representations such as bubble diagrams. This provides an overview of the problem space for easy navigation and perception. Text is better used in defining functions [Purcell and Gero 1998].

Report 3: Thinking about non-visual functional issues is fundamental to early design and sketches provide a means of manipulating and perceiving such issues. Sketches provide external memory holders for design ideas [Suwa et al. 1998].

Report 4: In a design session, sketches are used in trying out new decisions, comparing alternative issues and capturing fleeting ideas. These are accomplished using transformations. Transformations exist in three forms: lateral, vertical and duplicate. Lateral transformation creates more than one alternative solution and usually involves restructuring of drawings or images. Vertical transformation is used when developing or elaborating on a solution. Duplicate transformation reproduces some decisions or parts of it, for example when they are copied or combined [McGown et al. 1998, Verstijnen et al. 1998].

Report 5: During design there are two types of knowledge being used: active and passive. During lateral transformations when there is a lot of restructuring, active knowledge is utilised in which designers produce sequential sketches. During duplicate transformations and parts of vertical transformations, passive knowledge is utilised where the designer does not need to externalise or produce sketches. These transformations are accomplished mentally before the results are recorded [Heylighen et al. 1999].

Report 6: In a design session, designers are usually engaged in collecting and creating information in more than one area of the design problem. This result in numerous solutions and time spent at the end tying loose ends. Visual analogy helps in perception and designers usually prefer customised or personalised design styles. However, the designers that vary their personal style depending on the type of design problem provide the best solutions. [Atman et al. 1999, Casakin and GoldSchmidt 1999, Eisentraut 1999].

Report 7: Characteristics of good designers are that they a) spend significant time clarifying functions, b) summarise the problem, prioritise the issues and revisit them frequently, c) create many solutions, and d) show competence in advanced engineering knowledge as well in design heuristics. Clarification of functions enables the designer to certify requirements so as to increase the accuracy of assumptions. Prioritisation helps in giving the designer an excellent overview of the problem space and also provides a means of justifying concepts produced as well as retracing steps in the design if solutions are unsatisfactory [Fricke 1999].

In summary, knowledge obtained from protocol analysis recommends various ways of dealing with data to support the different professionals involved. The most important decisions in early design relate to functions and are represented mostly by non-graphic means. Precision does not encourage exploration or an interactive design process as opposed to vague unstructured forms. Transformations are used frequently. These can be classified in three categories: lateral, vertical and duplicate.

4. REVIEW OF RESEARCH-DERIVED DESIGN SYSTEMS

After the above literature review of protocol analysis, we must ascertain whether these requirements have already been satisfied in existing CAD tools. A comprehensive review of tools has been performed under the categories of modelling systems, visualisation systems, integrated systems, research-derived systems and interface systems. Many of these systems provide little or no support for the early building design phases, although some systems in the research-derived category introduce unique procedures or processes that are relevant.

These unique procedures can be broadly grouped into two categories: data processing or software-based techniques, and user-interface or hardware based techniques. In the first category, researchers have experimented with the use of object-oriented paradigms, developing hierarchically related design objects [Bharat 1993]. They have used relational modelling techniques that introduce relationships in the behaviour of design elements [Gross 1990]. They have used autonomous digital agents that report or perform tasks in a design environment [Kurmann and Engeli 1996] and they have used knowledge-based techniques that anticipate what the designer is doing in order to provide the best tool at the right time [Do 1996].

In the second category, attempts to support early design activities have been reported by means of techniques that mimic traditional sketching such as use of hand gestures to create simple geometry or non-photo realistic objects [Zeleznik et al. 1996], imitations of hand made drawings using digital elements [Rieman 1997], use of layering techniques that can be manipulated similarly to drawing sheets or tracing paper [Gross and Do – internet accessed 1998] and the use of non-immersive virtual reality techniques that provides a natural 3D interface to the design environment [Dorta and Lalande 1998].

In summary, although computer support for design has advanced significantly, there is little evidence of effective support for the early design. The findings of the protocol analysis show that addressing the integration issues, by providing a universal work environment and facilitating the interchange and access to design data by all professionals at an early design stage, will be of great importance.

5. ESSENTIAL COMPONENTS

The review of protocol analysis of design activities reveals certain actions, elements and procedures used by designers in the early design stage, which are not addressed by commercial CAD tools or by the reviewed research-derived systems. These constitute the fundamental issues that would provide the basis of a cohesive or integrated design environment.

The first issue is the implementation of a universal but simple and intuitive representation of design data that will be understandable to all professionals involved while making it easy for them to contribute and exchange knowledge from the earliest possible time. Secondly, all efforts to solve any design problem from the problem definitions themselves to the steps or decisions taken and all alternatives developed should be retained and remain available for reassessment or review. Lastly, buildings do not exist in isolation. There are many external influences that must be considered and included in the reasons for the creation of design elements.

6. PROPOSED SOLUTION

This research project proposes to support conceptual design activities by means of concepts called Compositions, Continuums and Environments. These refer consecutively to the issues introduced in the previous section. Figure 1 shows the relationship between some of these concepts which are described in detail elsewhere [Meniru et al. 2000].

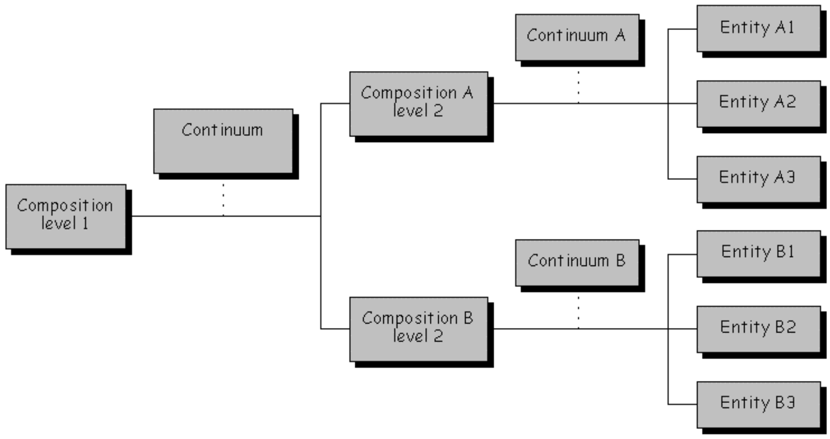

Figure 1: Compositions, Continuums and Entities

Compositions are an aggregation of objects that maintain hierarchical relationships necessary to influence and communicate with each other. It provides access to the design data in a user-friendly manner that facilitates effective editing, viewing or creation of design entities by accepting input and feedback in many forms such as text, graphics or relations. In this way, all graphic and non-graphic information can be recorded and transferred between two professionals or offices. An entity is any element that can be specified and represented or taken into account in a design, for example a column, a room or a house [Rivard and Fenves 2000].

Continuum is an object that automatically records ongoing sets of actions. They also allow the input of notes by the designer. These can be attached to any element in the design such as an Entity or Composition. As illustrated in Figure 1, Continuums exist with each Composition in the design. It records the activities performed on that Composition but at the same time it can request for other activities performed elsewhere by asking the relevant Continuum. This provides a way of reviewing the history of a design item and can be used to study, correct, elaborate or select optimal design alternatives.

At each level of composition there are external influences. These constitute the Environment within which the composition must exist. External objects do not communicate or influence each other but they determine how the Compositions function. Figure 2 shows an example of the relationship between Compositions and Environments in a three level residential housing unit.

These concepts provide a powerful means of implementing a smooth transition from the conceptual stage of design to later ones. They also allow the illustration of the entire problem space, which makes it possible for all teams in the design process to have proper access to the design. The use of relations in Compositions and documentation of actions in Continuums also serve to automatically keep the design accurate and inform anyone working in any particular area of changes or additions.

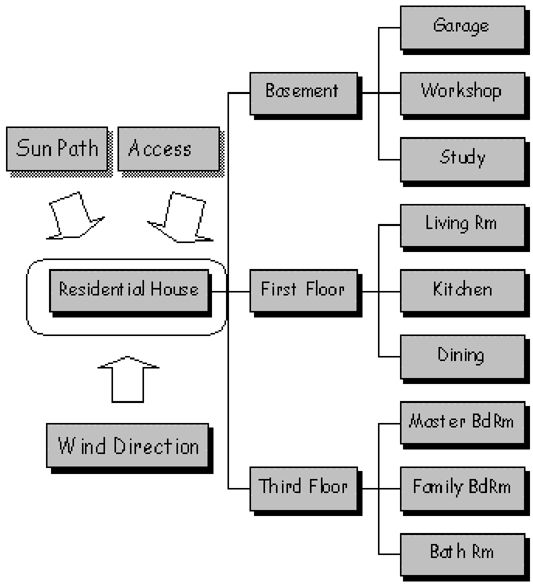

Figure 2: Compositions and Environment

6.1 Desired Functionality

From protocol analysis, two main components can be identified as part of the early design process: synthesis and analysis/evaluation [Bedard and Gowri 1990].

During synthesis designers introduce new data into the problem space. This can be in the form of physical objects like lines or abstractions like colour. To support synthesis, the design tool must provide a simple graphic representation of all possible data to be used in the problem space. This will improve visualisation feedback critical in the normally interactive design situation prevalent in early design [Casakin and GoldSchmidt 1999].

Analysis provides a form of verification or assessment of the items assembled through synthesis. This occurs in two ways: in isolation and in context. For example a Composition is analysed with regards to the different parts of its hierarchy (Figure 1, Entities A1 to A3 in Composition A), or with regards to other compositions in the design space (Figure 1, Composition B). The actions of synthesis and analysis alternate until eventually a goal or solution is reached.

It is important to bear in mind that managing the design process is not to be left to the computer but the designer. The tool should serve as glue that brings together all design decisions by organising, storing and presenting these decisions in an appropriate manner.

In summary the tool should provide the following.

- Frequent transition in the problem space: designers must have an overview of the problem space in order to easily reference and check previous decisions or requirements in any part of the design project.

- Automatic drafting capability (less effort in document preparation): designers should be able to focus all their energy in creation and decision-making while drafting should be a by-product only.

- Storage of alternative decisions for later use: the system should automatically save or collect designer's solutions in sequence. This provides a design history as well as rich source of solutions for the design problem.
- Need for visual analogy: the system should utilise vague graphic elements to encourage creativity and increase perception.
- Use of interactive imagery: decisions in a typical design session are numerous and changes are usually dynamic. The need for the designer to stay informed of the changes that are occurring and their consequences is crucial for a successful product. A major part of this responsibility can be assigned to objects themselves in such a way that they record the designers actions and inform on any omissions, dependencies or general consequences of these action.
- Use of transformations (lateral, vertical and duplicate): transformations illustrate the step-by-step progress of design decisions that lead to a solution.

6.2 Illustration of the Proposed Tool

The proposed design tool provides six separate windows as the user interface, shown in Figure 3. The following subsections describe each window including references to protocol reports described in section 3: Review of Protocol Analysis.

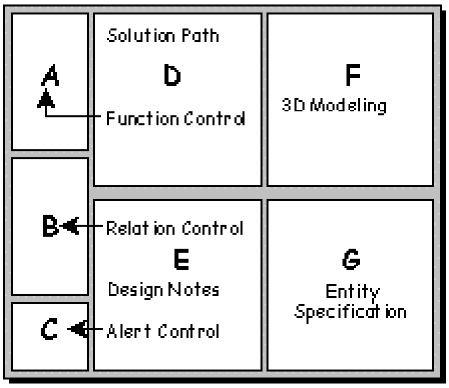

Figure 3: Proposed Integration Tool for Early Design Activities

6.2.1 Function Control (Window A)

Figure 4 provides access to the creation and editing of entities.

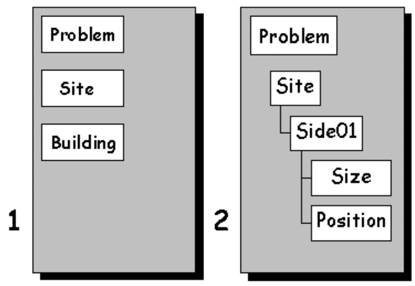

Figure 4: Function Control

The Entities can be manipulated in text or graphic mode while an overview of the parts that make up the entity is also provided. In Figure 4, view 2 is a version of view 1 showing the hierarchical parts of the site entity. This supports protocol reports 1, 2 and 3.

6.2.2 Relation Control (Window B)

Window B provides access to the relationships and constraint factors.

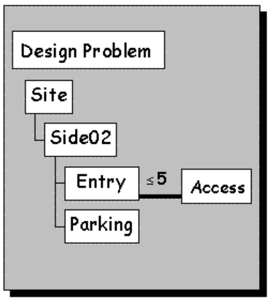

Figure 5: Relation Control

In the creation of an entry for a site relative to an access route, a constraint can be used showing a constraint of less than or equal to 5 dimensional units. This supports protocol reports 3 and 7.

6.2.3 Alert Control (Window C)

Window C provides a place for the tool to call the attention of the designer when incompatibilities or unresolved items are detected. It will provide a reference or link to these problem areas if requested by the designer. This supports in protocol report 7.

6.2.4 Solution Path (Window D)

Window D provides a view of the solution path showing steps in the progress of the design session. Figure 6 shows a typical solution path for a design problem. "AS.." in the Figure depicts alternative solutions and "S.." shows accepted solutions.

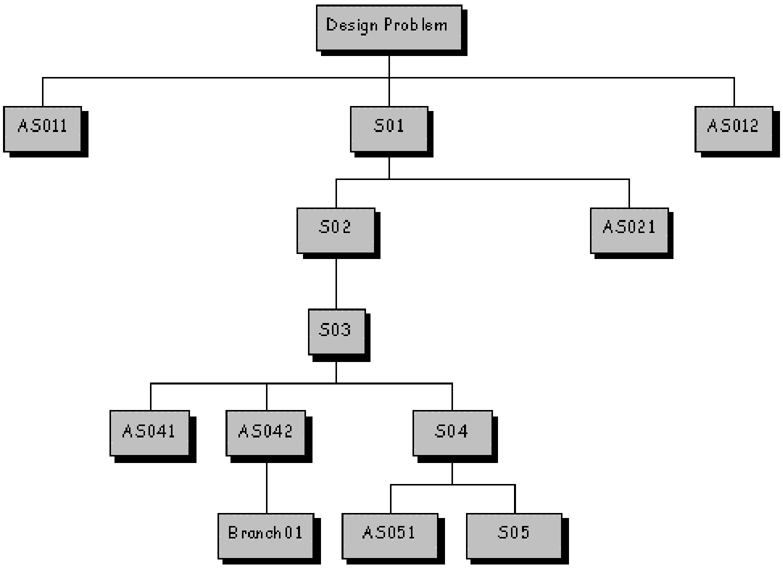

Figure 6: Solution Path

The session begins with a design problem, which is transformed to solution 01 (S01). Two other alternatives to S01 (AS011 and AS012) are generated but these development branches are halted. S01 is refined further to produce S02 and another alternative solution (AS021). This alternate direction is halted and development continues from S02. This process continues until the final solution S05 is obtained. With this type of design support, the solution path can be followed and all alternatives are made obvious and available for use in the final selection for the best design. This supports protocol reports 2, 4, 5, 6 and 7.

From the protocol analysis, lateral transformations produce alternative solutions while vertical transformations add detail to an existing solution.

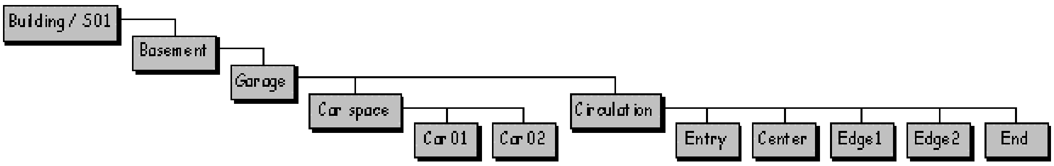

Figure 7: Design Transformation 01 (Vertical)

Solution paths are hierarchical diagrams. In Figure 6, the entire solution path is shown but each step (rectangular box) contains a hierarchical composition. Figures 7 to 9 show vertical transformations of the design problem. In step in S01 Figure 7, design of the garage in the basement is completed.

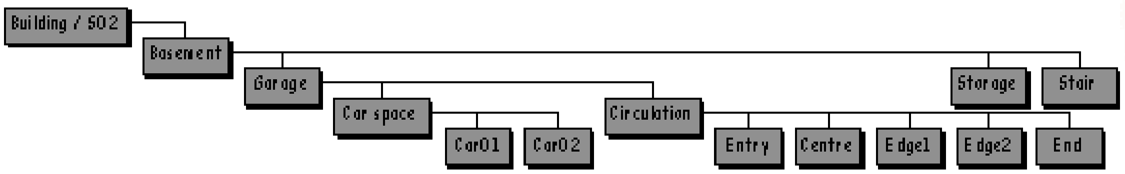

Figure 8: Design Transformation 02 (Vertical)

In S02 in Figure 8, the storage and staircase are added to the existing work.

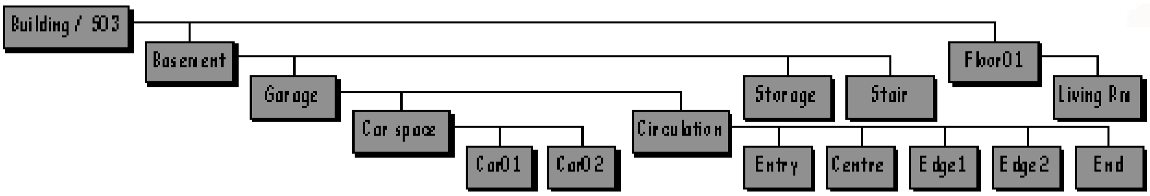

Figure 9: Design Transformation 03 (Vertical)

In S03 in figure 9, the first floor is added along with one space for that floor - the living room. This development process continues to be recorded in this manner until the final solution containing all floors and spaces are obtained.

6.2.5 Design Notes (Window E)

Window E provides a read-only section for reminders and additional information and a read/write section for designer notes to be attached to elements in the design. When elements are selected, attached notes are displayed in the information area and more notes can be added at any step of the solution path. This supports protocol reports 6 and 7.

6.2.6 3D Modelling (Window F)

Window F provides a 3D view of the active solution step or the selected entity. It will also be used for presentation of the design solution. This supports protocol reports 4 and 5.

6.2.7 Entity Specification (Window G)

Window G provides a 3 dimensional work area for graphically specifying the attributes of an entity or combining entities to form combinations. Figure 10 shows how this can be done. This supports protocol reports 3, 4, 5 and 7.

In window A, an entity “Site” is selected (Figure 10, view A). Window D automatically updates to show the hierarchy of objects contained in the "Site" entity (Figure 10, view D). Window G also updates to show the top plan layout of "Site" (Figure 10, view G). Assume that "Site" has four sides. The designer then selects the part of “Site” that is to be specified. These are illustrated as the numbered (1,2, and 3) Views of G in Figure 10.

View 1: The size and location of entrance is specified using a visual object near to the left side of the site object. The results are length and width properties.

View 2: The Entry is specified using another object. The result is a width and an entry location in relation to the side affected.

View 3: Parking space is also determined, this time using a rectangle that provides the standard vehicle size.

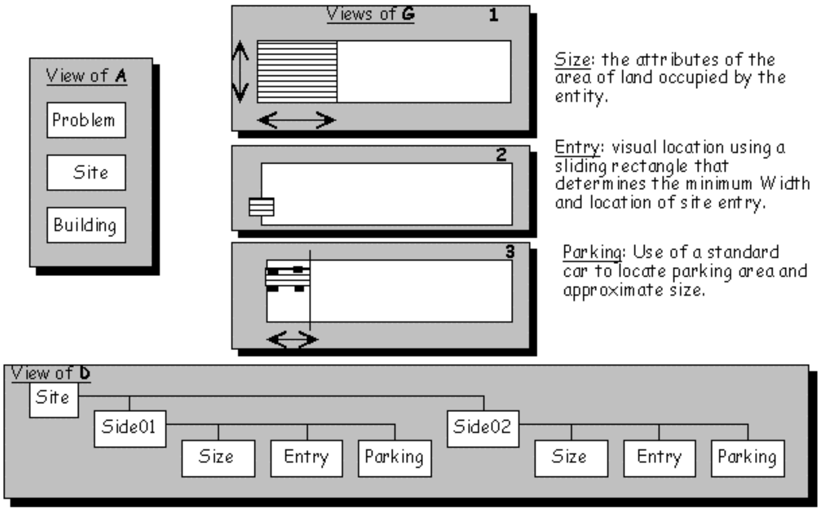

Figure 10: Entity Specification

7. CONCLUSION

Using Compositions, Continuums and Environments, a proposed computer-based design system maintains a logical and hierarchical presentation of the problem space which closely resembles real decisions that are made during conceptual building design. Such integrated approach emphasises the need to respect the diverse make up of early design professional teams. The system presented here also simplifies the manipulation and access to design data through the use of transformations and hierarchies. These provide a friendly and universally understood method of organising design decisions as well as minimising the effort and time needed to interact with them. This will promote the integration of efforts of the necessary diverse teams often involved in the early design phase of buildings.

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