CONCEPTUAL MODELING IN ARCHITECTURAL DESIGN

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ABSTRACT:
This paper discusses conceptual design from the perspective of U.S. architectural practice. During the previous twenty years of computer-aided architectural design, the underlying paradigm has mimicked a paper-based technology. As a result, the computer has not significantly impacted conceptual design approaches. The future of design, however, is proposed to be in building modeling. A short review of building modeling is provided. Some prospects for conceptual design, based on building modeling and new technologies, are proposed.

1. The Initial Conception of Computer-Aided Architectural Design

Computer have been used in architectural design for twenty years. A generation of architects and other design professionals have been trained in the computer era.

The initial conception of computer-aided design was that the representation being developed, jointly through man-machine collaboration, were drawings and other specifications. Because computer-aided drafting (CADD), as it came to be called, had the same conceptual foundation as manual design, most of the design development techniques used in manual drawing were potentially available to CADD.

In practice, the fluid and fast changing development strategies used in most aspects of conceptual design were not well supported by the structured capabilities of CADD; the computer was relegated to the production drawing phase of architectural practice. There were some important exceptions: managing complex programs in such building types as medical and laboratory facilities was helped by the use of databases for managing requirements and specifications [Teague and Davis, 1972]; site planning and land development options could often be explored using several types of computer tools, including cut and fill, rain run-off and other evaluation techniques [Bijl and Shawcross, 1975]. Most other efforts such as in space planning, and other forms of conceptual design development, [Hales,1985] have tended to be curiosities for most designers and have not gained widespread use.

2. The Concept of Building Modeling

It was in the mid-1970s that computer-aided drafting was recognized as being fundamentally limited. Drawings fragment information into multiple 2-D views, different graphic projections at different scales and require manual generation of performance data used in analyses. Any design action must be reflected in many drawings, updated manually. Analyses require specially formatted data, some extracted from the drawings, which is expensive to prepare and thus seldom used; visual representations not needed for construction documents are also expensive to develop and thus used sparingly.

Automated overlay drafting really did not change these limitations. Only in plan views was it practical to share information across multiple drawings and reduce updating. Interfaces to analyses from CAD systems were usually not practical because drawings carried insufficient data to provide automatic translation. Schedules and bills of material in interior design were the only commonly integrated application. Elevations and details still required manual coordination with plans.

It was recognized that a larger opportunity resulted from structuring information for a building project in a fully integrated fashion. Design information should be organized cohesively by components, so that geometry, material and other properties of components are logically related. Several benefits were postulated [Eastman, 1976]:

- design refinements would be facilitated, because a change could be made once to impacted components, with all drawings of those components updated automatically.
- use of analyses, visual evaluations and other types of applications would be facilitated, because the data they require could be prepared automatically;
- drawing production could be automated, allowing any type of view to be created on demand, reducing time and costs;

The initial recognition that such an approach was possible came with pre-fabricated building systems, especially the British hospital systems. For such a building system, the components could be defined and their properties of interest, their geometry and graphic representation in different types of drawings could all be pre-entered into a building parts library [Hoskins, 1973], [Paterson, 1974]. CAD provided for composing these components and for extracting the appropriate information for presentation in different drawings and as input to analyses. Several of these systems included conceptual design tools for laying out the parts of a hospital on the appropriate grid and comparing the design to the programme [Meager,1973].

This integrated data approach involved the development of a **model** of the architectural project and came to known as building modeling. Geometric modeling of closed shapes was required, so that the logical consistency of geometric data could be verified [Baer et al, 1980] To some people, the development of a 3-D model alone has come to be mistakenly considered synonymous with building modeling.

To most architects, design based on a pre-fabricated system was not very interesting and in some cases was shown to have significant cost or performance disadvantages. The challenge that has faced architectural CAD research for the last ten years has been how to develop a technology that supports building modeling for custom, one-off designs. That challenge has not been satisfactorily answered. Only a few systems are based upon this organization; examples are RUCAPS and the Calma DDM system. Part of the unmet challenge involves conceptual design practices within both this new medium and new information environment.

Initial efforts at building modeling assumed that all graphic information could be extracted as sections or projections from a 3-D model of the building [Eastman, 1976]. These efforts failed as full production tools because this treatment of geometry is inherently too restrictive. Components are often represented in 2-D, symbolic and other forms of representation, as well as sections of a 3-D model and attributes [Eastman, 1988].

At this point in time, I believe that the early efforts at conceptual design, based on computer-aided drafting, must be considered history. Also, CAD based on solids modeling alone is not sufficient. The next step in history, however, has not yet been written. The current generation of architects that have been raised with computers have witnessed a set of trial system designs that are not adequate to their needs. Few designers have truly benefitted from the computer's impact; that is still a future event. Instead of a review then, I see it more important to talk about the future.

In order to project what are likely to be meaningful future methods of design conceptualization, it is useful to first understand the underlying notions of building modeling and to anticipate the computer environment that will become available in the near future. Both of these will have a major impact, I believe, in design conceptualization.

3. The Structure of Building Models

Current methods of design rely on multiple representations that each partially describe the elements making up the design. Elements are described in varying detail; individual elements are aggregated hierarchically. See Figure One. As another example, walls are defined at some scales and stages of design as monolithic elements and other times as aggregations of components. Thus any element used in design has multiple geometric representations, as well as varied sets of performance properties and material specifications. Each is a description of the same element, but structured for use in different types of documents or analyses.

In manual design, each of the descriptions of an element is represented and managed separately, leading to issues of coordination and translation. See Figure Two. The opportunity of building modeling is to bring all such element descriptions together. Each element groups together its multiple geometric and property descriptions. See Figure Three.

Designing, in both the traditional and new form, consists of defining elements and one or more of descriptions of them and composing the elements in the multiple dimensions of their interaction with other elements - geometric, structural, electrical, acoustic, etc. using varied descriptions. New descriptions can be added to existing elements, in order to depict the additional performances in which the designer is interested. Elements are defined at different levels of detail and aggregated or disaggregated in different ways.

Design deals with two types of structure, which is captured by this organization of data. See Figure Four. One is defined by the traditional representations used for composing or analyzing elements so as to satisfy various intentions or performances. Various elements' descriptions may be modified in response to the evaluations made. The other structure covers the different descriptions of a single or hierarchically organized set of elements. It requires that they all must be consistent. Until recently, all efforts have been directed to the analysis of a composition's behavior. Here, we add explicit structure for managing the multiple descriptions of elements.

Working in this new environment is somewhat different than traditional design. It more explicitly involves the definition and composition of elements. Elements may be spatial (void) or material (solid). A session involving a particular representation, say a 3-D model, site plan or energy analysis, extracts the description it needs for a set of elements. These are evaluated, modified and otherwise used in a manner similar to current CAD usage. When some task is completed and the session is complete, the changed description is used to update the rest of the data. As the updates are entered, the other descriptions are modified so as to be consistent with the changed one. See Figure Five.

In some cases, update utilizes automatic routines to modify existing descriptions or create new ones. For example, routines might exist to maintain the consistency between a single line description of a wall and its 3-D envelope description, as well as its detail construction section and thermal performance data. As walls are modified, the spaces they bound will be automatically modified. Similarly, the design performances in piping, electrical networks and other distribution systems can be aggregated and disaggregated between individual components, branches, and whole systems. In other cases, the different descriptions may have to be managed interactively.

New elements must be easily created. It is assumed that new elements can be defined within any description format, eg. a drawing type, with the necessary linkage structure to relate its initial description with other descriptions generated later of the same element. Elements are classified according to their performances of interest, which are used to determine the property sets that must be associated with them.

Drawings and analysis input are defined as queries that select elements with particular properties and/or that are located within a specified region. These elements are sorted for the element descriptions used in the particular representation. Annotations, dimensions and other presentation information can be stored with the elements and all directed to a particular type of drawing. In some cases, the geometric information is computed from 3-D projections of elements.

This outline of building modeling describes only its most general features. The features described can be implemented in many ways. The data can be structured literally as I have described, or alternatively, each element description can be grouped with the others used in a particular type of drawing or analysis, and cross-linked to the other descriptions of the same element. Symbol definitions may be referenced by the elements or copies made for each one. For the purpose of this discussion, however, the important point is that the basic representation of a building is going to change. Future conceptual design tools need to be based on this new organization of design data.

4. <u>Implications of Building Models on Conceptual design</u>

Modeling provides many new opportunities for designers. Some of these opportunities are obvious. Designers will be able to work directly in 3-D, then extract desired drawings from the geometric model. Form composition based on either solid elements or on spaces can be supported. Automatic interfaces to applications, for energy, structural and other forms of analysis and quantity surveying will integrate these aspects of design closer with decisionmaking. New forms of analysis will become effective because of the availability of model data; examples include lighting and acoustics for most types of jobs.

In a building modeling environment, formal methods of composition will be facilitated. For example, design based on explicit rules of composition can be developed that realize in detail the theories of composition only approximated in manual design. These theories of composition may operate on the materials used to create spaces or the properties of the space themselves. Shape grammars and other forms of grammars provide a structure for implementing these formal composition rules [Stiny, 1980],[Flemming, 1981].

Current practice with CADD limits designers to work in pre-defined representations, following predefined conventions. It is now possible to define ones own abstract representation of architectural elements and to use different rules to compose them, but difficult to implement. Considered broadly, such an approach develops a new design vocabulary. Examples of current designers using such vocabularies include Eisenman [1982] and Gehry. Such vocabularies will be easier to define and implement and made more readily a part of all design, in a model environment.

Today, standalone software packages exist many other aspects of design, such as structural, site planning, HVAC, facilities etc. There is no standard means to tie them together other than manual intelligence and labor. Modeling provides an attractive environment and strong justification for resolving these standards and compatibility problems+. When that occurs, I expect to see application packages with standard interfaces that can interconnect both to a shared user shell and also to a shared building model.

The modular organization of CAD systems is an important topic of research. An attractive method of organization is by properties [Eastman and Kutay, 1986]. Properties are significant or not depending on the types of performances desired of an element. Only a few properties, such as shape are used by many performances. Well conceived packages that incorporate:

- one or more classes of properties,
- methods to assign or compute instance values of the properties
- methods to aggregate and manage instances of properties,
- analyze systems of elements with instantiated properties
- check compositions of elements with these properties so that they satisfy necessary codes or construction practice design rules

provide the basis to compose and analyze elements capable of a particular performance. Here, a spatial representation is only another type of property. Thus Bezier surfaces are only a class of spatial properties used if they are needed in a project.

The CAD system incorporates the capability to combine different sets of properties into a spatial or physical object and incorporates rules for managing the consistency of various property descriptions.

+ The current efforts of the STEP and P-DES groups in developing standards for architectural life cycle product descriptions are important examples.

Such a CAD system organization allows incorporation of both standards and expert knowledge. It allows for choice as to the types of performances assigned to individual elements. At the designer's disposal will be a variety of such packages, for different types of design. Customizable CAD will thus become a practicality for individual projects, at the level of selecting among the design modules to use. I expect such modules to become an important means to transmit design knowledge to various users.

A small step from configurable CAD modules will be systems that not only allow for manual composition of designs, but that also do high quality but conventional automated design. Many of us would appreciate an automated designer that would generate a good parking plan or structural layout. Systems already exist for kitchen cabinet layout and mechanical equipment selection. These systems could be extended to do layouts within a modeling environment. In each of these cases, the module is a packaging of design knowledge typically used by people not specializing in that aspect of design or that wish to have conventional design capabilities available and only address themselves the exceptional or selected problems.

I expect the same process to be applied to architectural design. Solid but conventional design procedures will be developed for rest rooms, elevator cores, office layout, laboratory space, conventional housing and so forth. Such automated design would be highly parameterized, allowing mixes of design modules and parameters so that each result could be unique. With such modules available, a designer will have the choice whether to utilize automated, conventional design or do a custom design. Such automated design tools would raise the level of conventional design and allow more thoroughly developed and analyzed design to be available widely.

This prospect only emphasizes a distinction existing already; most design today is adapting conventional practice to different contexts. But all too often, this adaptation is done poorly. Automating the process would control and allow systematic improvement of the quality. It will truly distinguish conventional design from that which is custom.

5. The Computational Environment for CAD

We are watching the end of the first generation of personal computers and the beginning of the second. PCs have already increased in speed and general performance many times. The quality of graphics continuously improves. The price of storage decreases. These improvements are not about to end.

Several significant changes are expected to emerge in the next few years:

- a significant proportion of the increased speed of computing will be directed toward graphic interaction; as one result, real-time dynamic interaction will become standard for CAD workstations; announcements to this effect have already been made by Silicon Graphics and IBM.
- graphic quality will continue to improve, so that 1024x1024x24 will become the standard resolution for CAD, and at a nominal cost. This improvement will be driven by high-resolution TV, now being developed.
- disk output rates will increase, to the point that images can be displayed from them at video rates. This will allow much faster development of animated sequences and also support interactive navigation along pre-defined paths about a proposed project, for visual review.
- scanning of paper documents will become widely used as an easy way to capture any type of graphic information in raster format; high resolution and color scanning will become commonplace.
- image processing chips will allow conversion of scanned data: letters into ASCII and drawings into IGES or other vector CAD formats, to become semi-automated. This will allow drawings to be converted to line drawings, then to 3-D shapes, with only moderate amounts of effort;
- mass storage will continue to drop in price, with the result being that electronic storage of CAD and scanned paper documents will become the norm; drawings, text, photographs and other media will easily be stored in an integrated manner; paper and film will disappear as an archiving medium.

There are many implications arising out of these changes, regarding how we will in the future store and manage design data and how it will be archived. I would like to discuss one fairly obvious opportunity for conceptual design, based on these developments.

6. Environmental Simulation

The hardware required to compute high quality images will continue to decrease. Computing scenes with surface textures, highlights, shadows and secondary reflections will become practical, allowing truly impressive simulation of the visual qualities of an environment, before it is built. Interior spaces can be simulated in a similar manner, using these techniques for lighting analysis. Realistic visual impact studies will become common, as well as visual review of interior and lighting designs, before a design is implemented [Cohen et al, 1988].

Also in existence today is circuitry that allows modeling of different acoustical environments. The circuitry introduces reverberations and absorption for different frequencies to taped sound in a manner similar to a room or concert hall. Several of the large acoustic research firms provide simulation of spaces before they are built. This technology can be scaled for use in architectural practice. Clients will have the opportunity to "hear" the background and transmitted noise in a designed space before it is built. Clients might be able to specify beforehand the "deadness" of an environment they wish to have by listening to various degrees of reverberation in an architect's office.

Thus a visual, lighting and sound simulation of an environment could become an almost standard form of evaluation prior to construction of an actual space or environment.

Within a building modeling environment, such powerful simulation techniques can be utilized in a variety of ways. The conventional way is to evaluate a candidate design. But I have seen significant interest in those organizations where such tools are now available to use them in quite a different manner. The interest is to create a simulation directly, as a series a spaces, with materials and color, lighting conditions and possibly sound. The sensory experience is the conceptual design. The later task is to figure out a design that achieves the modeled sensory experience.

Such simulations provide an excellent way to communicate the implications of decisions to clients and to examine critical alternatives. Significant development must still take place to make such systems easy enough for everyday use, along with the hardware cost reductions.

7. Conclusion

I remember ten years ago presenting the prospect of modeling as a means of design, rather than multi-overlay drafting. The prospect was treated as revolutionary, completely outside the culture of architectural practice. Now the possibility is becoming widely known and initial level systems are on the market. Like the first computer drafting systems, the concept is there, but implemented poorly. In the next few years, I expect more suitable system configurations for building modeling to emerge.

The development of such modeling schemes, in parallel with the seemingly inevitable trends in increased CPU capabilities, suggest major changes for conceptual design practices. The means of architectural development now used have existed for hundreds of years. It is likely that the impetus for a new set of conceptual design procedures is now emerging. The future of conceptual design will be rich indeed.

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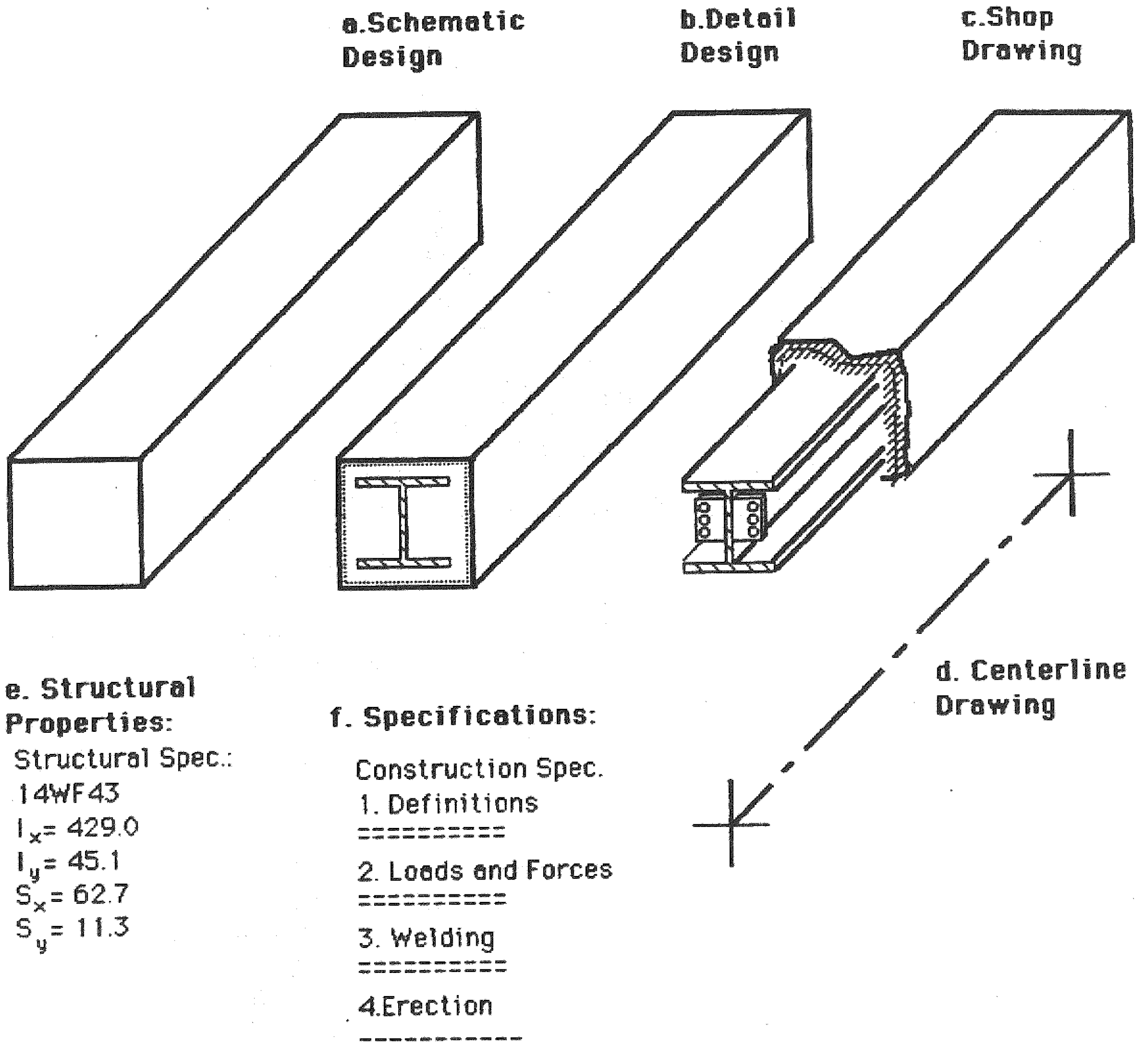

FIGURE ONE: The multiple representations of a design element..

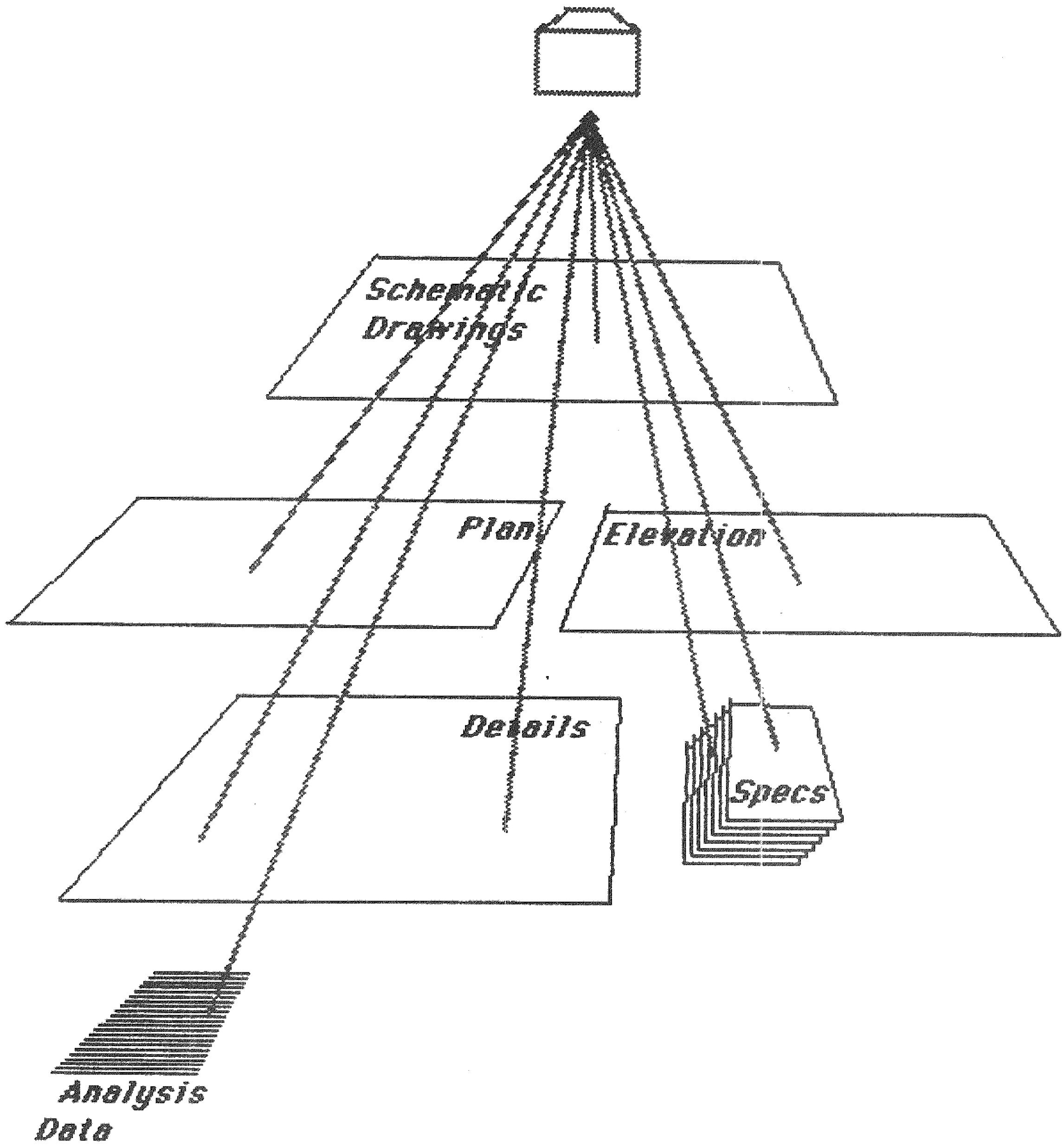

FIGURE TWO: An element's description is spread over multiple drawings, analysis data and written specifications.

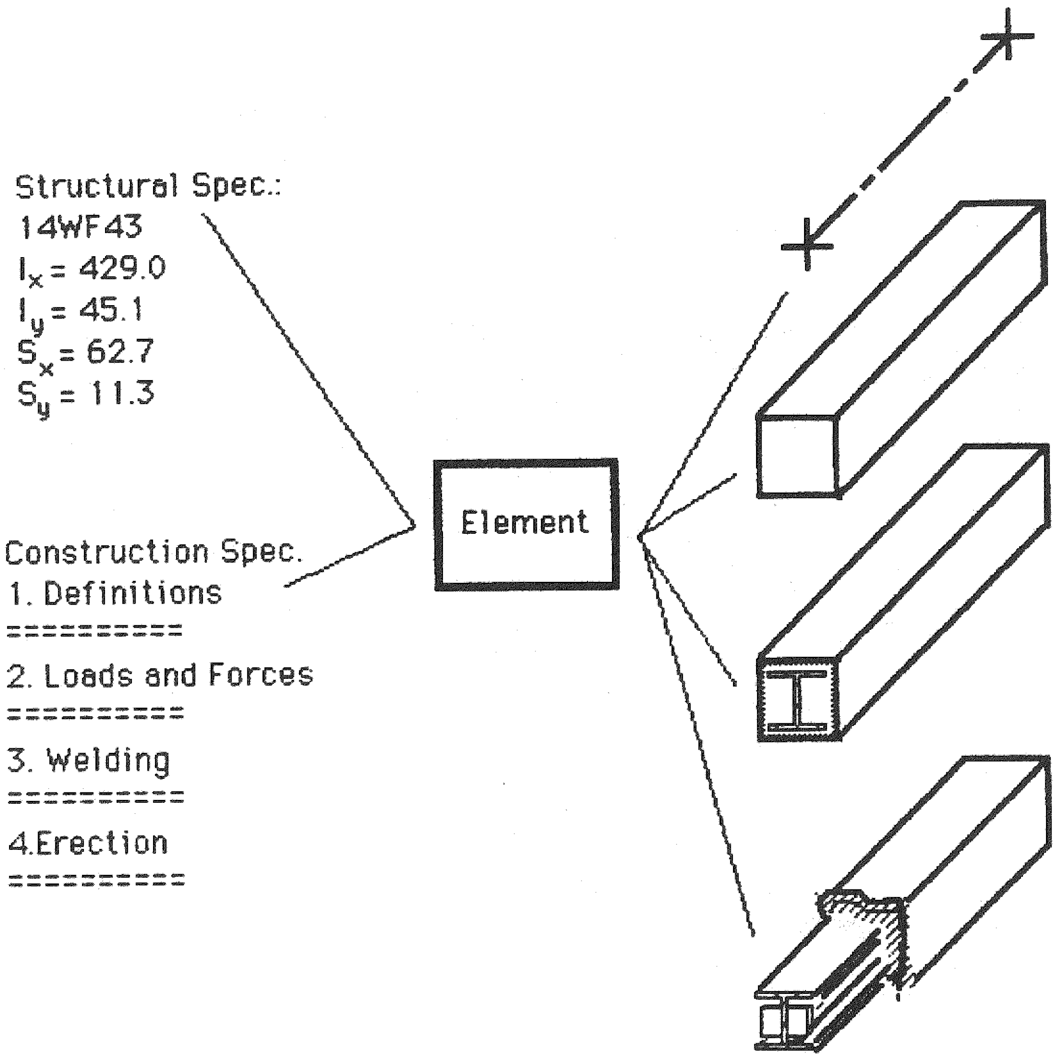

FIGURE THREE: The Element centered structure of a Building Model.

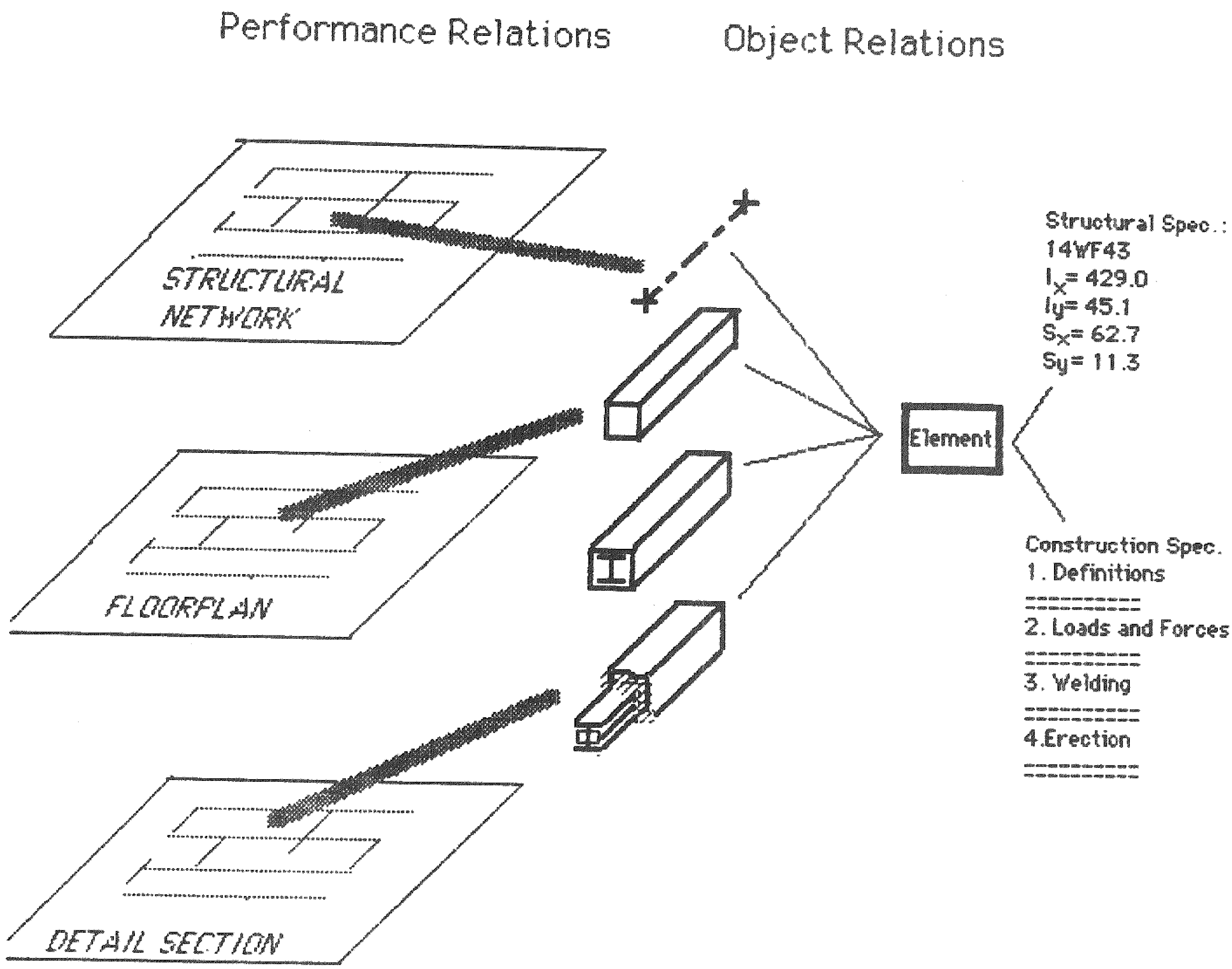

FIGURE FOUR: Two classes of structure that are embedded within a modeling system.

EXAMPLE DESIGN OPERATIONS:

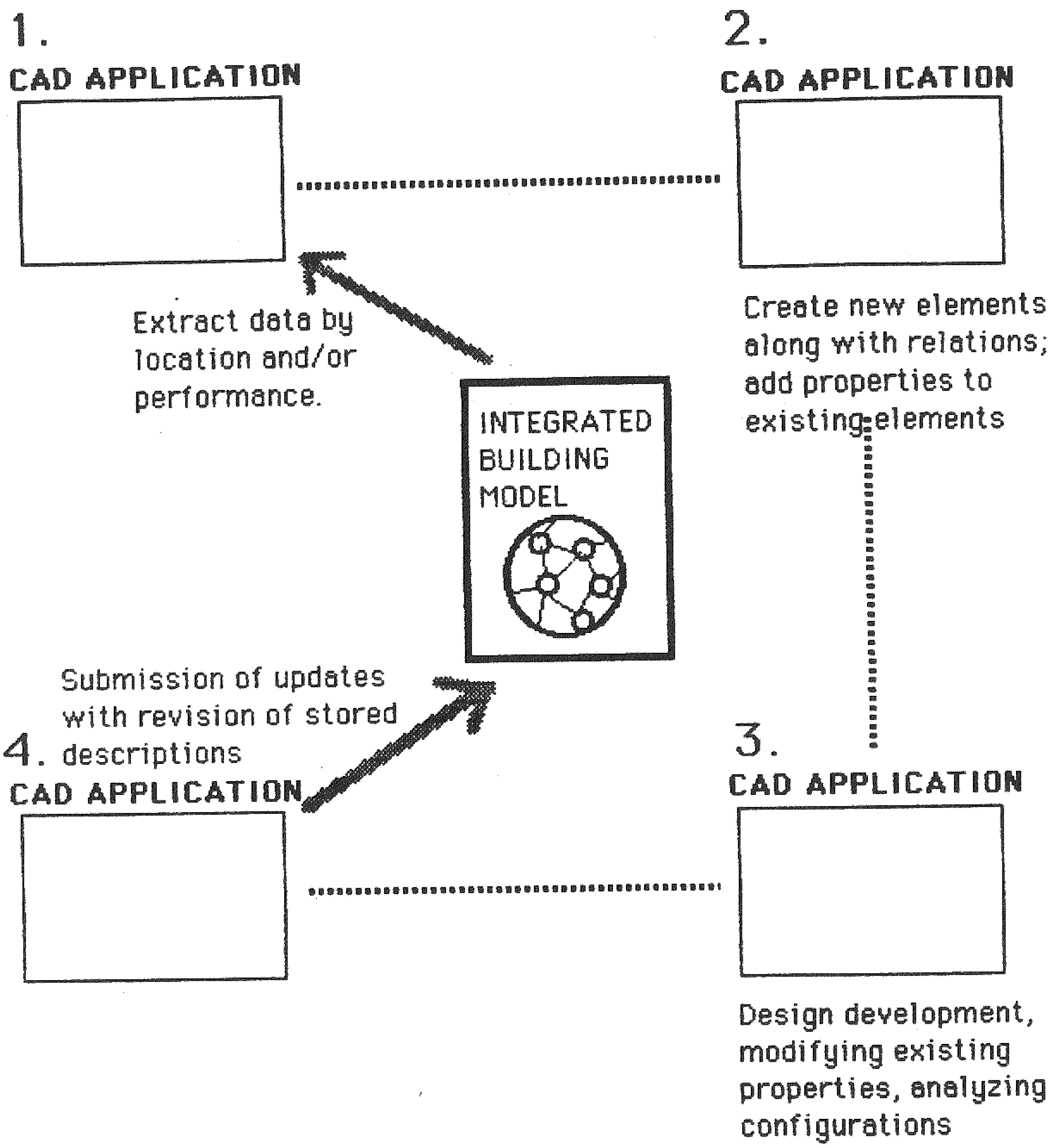

FIGURE FIVE: An example development cycle, creating modifying and analyzing elements accordinbg to one set of properties.