COMPONENT BASED COMPUTER AIDED LEARNING FOR STUDENTS OF ARCHITECTURE AND CIVIL ENGINEERING

Anton C. Harfmann, AIA

Department of Architecture
State University of New York at Buffalo

Stuart S. Chen, Ph.D., P.E.

Department of Civil Engineering
State University of New York at Buffalo

ABSTRACT

The paper describes the methodology and the current efforts to develop an interdisciplinary computer aided learning system for architects and civil engineers. The system being developed incorporates a component oriented relational database with an existing interactive 3-dimensional modeling system developed in the School of Architecture and Planning at SUNY Buffalo. The software will be used in existing courses in architecture and civil engineering as a teaching aid to help students understand the complex 3-dimensional interrelationships of structural components. Initial implementation has focused on the modeling of the components and assemblies for a low-rise steel frame structure. Current implementation efforts are focusing on the capability to view connections in various ways including the ability to "explode" a connection to better understand the sequence of construction and load paths. Appropriate codes, limit states of failure and specific data will be linked to each specific component in an expert system shell so that the system can offer feedback about a student generated connection and perhaps offer other possible connections from a library of standard connections.

Future expansion of the system will include adding other "systems" of a building, such as mechanical, electrical, plumbing, enclosure etc., to help students visualize the integration of the various parts.

1. INTRODUCTION AND RATIONALE

The teaching of building technology and design in schools of architecture and civil engineering has and will continue to focus on the successful, sensitive and well integrated assembly of the parts that make up the whole of the structure [Rush 1986]. The process of design and particularly the educational process of integrating building technology with design is complicated by several factors outlined below:

1.1. Complexity.

Most coursework relative to building technology usually occurs at the undergraduate level in both schools of architecture and civil engineering. Typically students at this level have little knowledge of construction technology or structural issues and therefore find it difficult to comprehend all of the 3-dimensional complexities and implications of even "simple" assemblies, let alone their integration with other systems within the building. Consider, for example, a simple shear tab beam to column connection as shown in Figure 1.

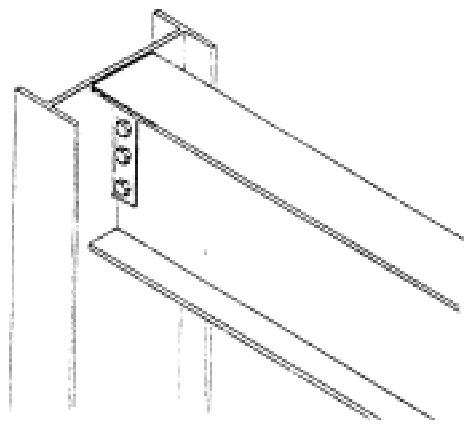

Figure 1. Shear tab beam to column connection.

The shear tab is the plate shown, welded to the column face and bolted to the beam web. It is possible for this connection to fail in any one of six ways and each mechanism of failure is governed by limit states of the element under stress. The applicable limit states for the shear tab connection are as follows; [Astaneh 1989]

(1) shear yield of the plate
(2) bearing yield of web or tab plate at bolt holes
(3) fracture of plate by bolt tear-out through plate edge

(4) fracture of plate net section
(5) fracture of bolts
(6) fracture of welds.

Understanding and visualizing the method of failure of any one of the above limit conditions is in itself a difficult task for undergraduate students. However, all of the above possibilities must be considered when the connection is designed which increases the level of complexity of the design process.

1.2. Fragmentation.

Increased complexity and the amount of new information being generated by the explicating of design knowledge has resulted in the division of the process of making a building into discrete disciplines controlled by "experts" [Harfmann 1987] [Fenves et al 1988] [Howard et al 1989]. This fragmentation is also evident in the curricular structures in schools of architecture and civil engineering. Courses in building technology are usually taught independently from the design courses in architecture. In civil engineering, the courses typically focus on the analysis of building components, such as beams and columns, assuming that the building has already been designed. The separation of building technology into discrete areas of knowledge fosters the isolated view of overall building design from technological issues on the part of the student. The problem of fragmentation also crosses several other disciplines such as mechanical engineering, electrical engineering, industrial engineering etc..

1.3. Representation and Abstraction.

The current methods for communicating the complex interrelationships of building components and construction rely heavily on graphic abstract representations of the assemblies. Students have difficulty understanding abstractions of the proposed building model, such as floor plans and section drawings, and have equal difficulty generating a correct abstraction of actual 3-dimensional connections between components [Eastman 1985]. In architecture this is most evident in the building technology courses where students are expected to draw the assembly of their buildings using standard drafting techniques. In civil engineering, this is most obvious in structures courses where students are expected to correctly identify and abstract the load path of a given structure in order to analyze a particular component. Students can best understand 3-dimensional drawings that are realistic in their representation of the elements that make up the structure as shown in Figure 2 [Rush 1986].

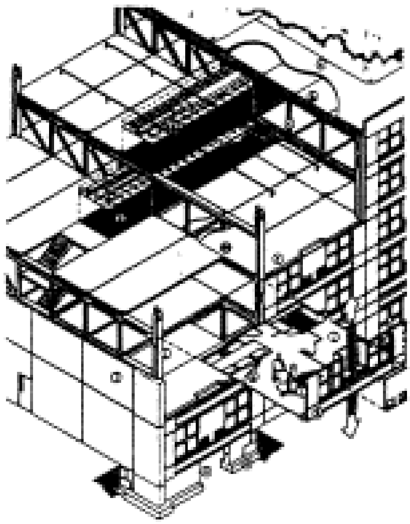

Figure 2. 3-dimensional representation.

The shortcoming of these drawings from an educational point of view are two fold; the drawings are in static nature in that once the image is generated, the students cannot explore other facets or further dismantle components to better understand the construction and, the drawings don't function at multiple levels of abstraction.

One potential solution to the difficulties in teaching the related building technology coursework lies in the use of a computer aided learning system. A highly interactive, graphic, three dimensional modeling system tied to an object oriented, database and knowledge base could allow students to develop a model of the assemblies of materials and view them 3-dimensionally and two dimensionally at the same time. Manipulation of an assembly would also allow students to develop a design, visualize any conflicts or inconsistencies as well as understand how representation would change as the design evolves. In addition to the representation of the assembly, the components could be related in an expert system shell that could also detect interferences, code violations, structural inadequacy, etc.

This paper describes current efforts to model the structure of a steel frame building one component at a time within the existing AiSys modeling system developed in the department of architecture at SUNY Buffalo. The paper also describes efforts to develop rules that relate components together in a dynamic way that will offer "expert" feedback to students as they "construct" their building in the memory of the computer.

2. PEDAGOGICAL AND SYSTEM GOALS

The key pedagogical goal steering the development of the system is for students to develop a qualitative "feel" for the structural behavior and constructability of structural assemblies within buildings. To accomplish this goal the system concentrates on modeling a modest two story moment resisting steel frame structure. The rationale for this type of building is centered about the two courses that the software will be used in. In the department of architecture, the system will be used in the construction technology II course as a teaching aid in a laboratory situation to help students understand the complexities of integration of light commercial and heavy construction. In the department of civil engineering, the system will be used in the senior elective structural steel design course to help students develop the ability to understand an entire structural system of a building while concentrating on the design of specific structural components.

The computer aided learning system being developed should have the following characteristics to address the educational concerns of building technology within the existing curricular structure of the school of architecture and civil engineering;

> Comprehensively model and represent all structural components of a building in a realistic, accurate relationship to each other (Figure 3).

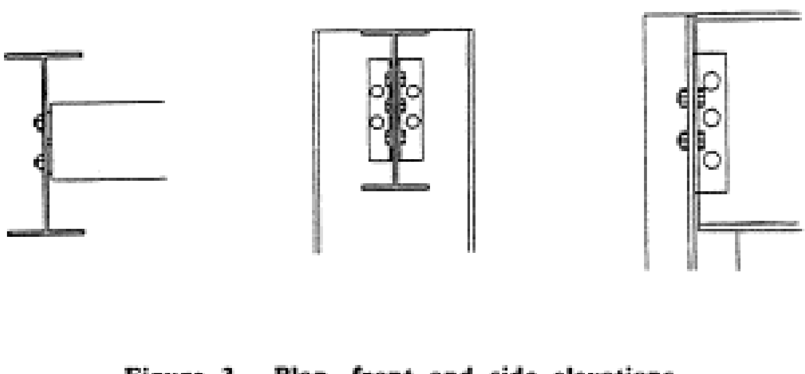

Figure 3. Plan, front and side elevations.

Manipulate and view the structure and to visualize the connections. This will be done using established techniques within the AiSys modeling system including, overlays, layers, windows, etc..

"Explode" any specific assembly to better understand the complexity and sequence of construction (Figure 4).

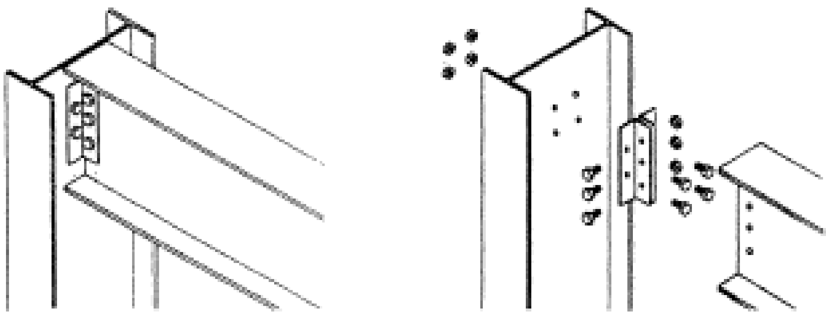

Figure 4. Axonometric and exploded axonometric.

Offer feedback to the students about the efficiency of the design, load path diagrams, methods of failure and other information relative to any of the components in the building .

3. CONCEPTUAL FRAMEWORK

The framework proposed for the system is centered about a *component oriented* database that contains knowledge about every individual item used to construct the structural frame of a building, including welds and bolts. The intent is to describe the assembly of materials of a structure and to represent them as rationally and accurately as possible [Rush 1986]. The structure of the framework shares some similarities with other object oriented models proposed in architecture [Kalay 1983, Bjork 1988], structural engineering [Powell et al 1989] [Fenves 1988] and mechanical engineering [Dixon 1987]. The system will differ only in what is considered to be an "object". In the component based model, every discrete element, or component, is an object. Components, or objects, can be grouped together in order to alter the level of abstraction one is working at. This is different than other approaches that treat the assembly of objects as new objects. In the component based scenario, the building itself is not an object but rather a very large group of individual components. The system framework is organized in terms of the following aspects:

(1) the individual components and networks representing physical connectivity of those components at several levels of description/abstraction,

(2) a database, and

(3) a "reasoning mechanism" consisting of collections of object classes containing methods for physical and functional reasoning about the components.

The elements of the proposed framework are briefly described in the following sections.

3.1. Components.

Individual components are the atomic building blocks of the model/system. They correspond to the physical elements used in constructing the building, such as beams, columns, clip angles, bolts, welds, base plates, etc.. Individual components are similar to instanced objects in an object-oriented representation scheme, except that they represent only the physical aspects of the physical elements used in constructing the building. This departs from the conventional object-oriented approach, where both the physical and functional descriptions are aggregated within an object. The functional information resides in the "collections", described subsequently in the reasoning mechanism section.

A component "knows" about its own physical attributes such as geometrical data. Using that information, it thus knows how and where to draw itself by inheriting graphics routines residing in the reasoning mechanism. Components represent the structure rather than the function or behavior of the building blocks of construction. The general design guideline employed in describing components is to avoid locating functional knowledge (e.g., loads) at the component level. This technique still enables inquiries directed at individual components since each component is linked to various collections of components within the reasoning mechanism.

3.2. Component Network.

The component network represents, at several levels of detail, the physical "parts" that make up the structure being designed and their interconnectedness. An example is developed for the portion of a steel framed building shown in Figure 5.

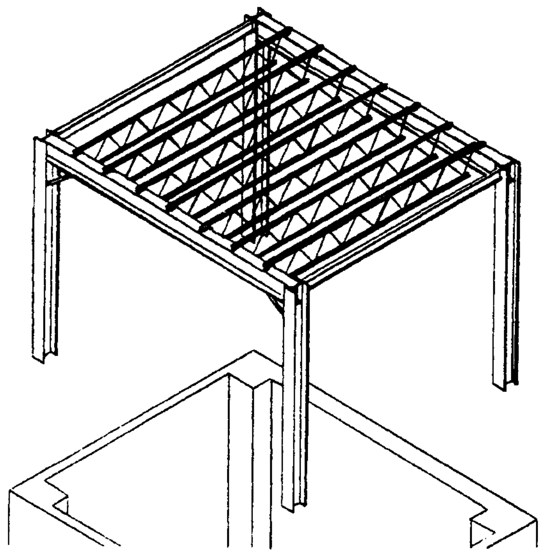

Figure 5. AiSys model of steel frame building.

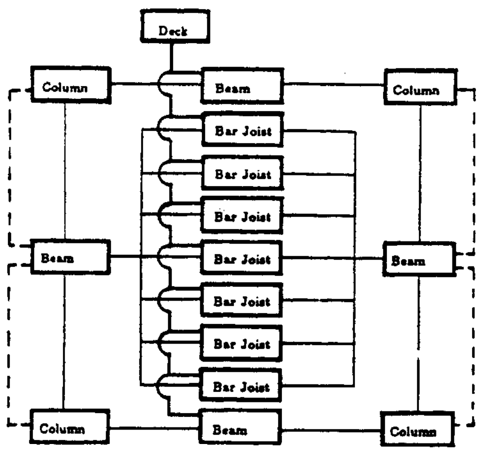

Figure 6. Component network of steel frame building.

A metal deck (not shown) provides a floor supported by steel bar joists resting on steel wide-flange beams and columns. Figure 6 shows the component network corresponding to the graphics display shown in Figure 5.

The network makes explicit the connectivity of the various components: 7 bar joists and 2 end beams, two main support beams and 4 columns. This connectivity network will enable qualitative reasoning about load path: it can be reasoned that loads applied to the floor will end up in the foundation, by traversing the applicable links in the network.

Figure 7 shows a zoomed-in view of a portion of the steel frame shown in Figure 5: one of the beam-to-column connections. The connection consists of two clip angles bolting the web of the beam to the flange of the column, and a bolted knee brace to provide rigidity against lateral loads. This display illustrates the localized higher level of detail (i.e., lower level of abstraction) that a designer may be interested in when design focus shifts to localized concerns.

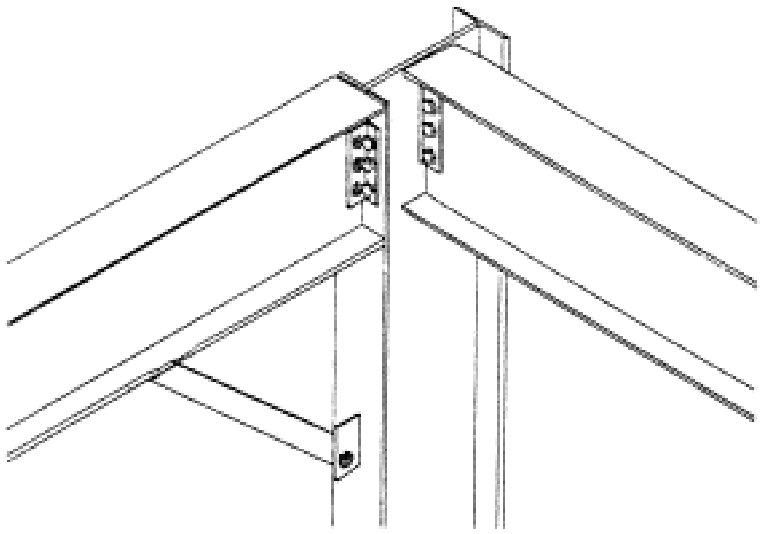

Figure 7. Detail of connection.

A declarative description of the zoomed-in level of graphical detail requires a more detailed component network than that shown in Figure 6. Figure 8 shows the requisite detailed component network representing the connectivity of the zoomed-in view of the individual parts that make up the beam-column connection.

At this level of detail, as with the other component network example, the connectivity links can be traversed to support reasoning about transmission of load through the connection. Vertical load is transmitted from the beam through a set of bolts into one leg of the clip angle, through to the other leg of the clip angle into another set of bolts and into the web of the column.

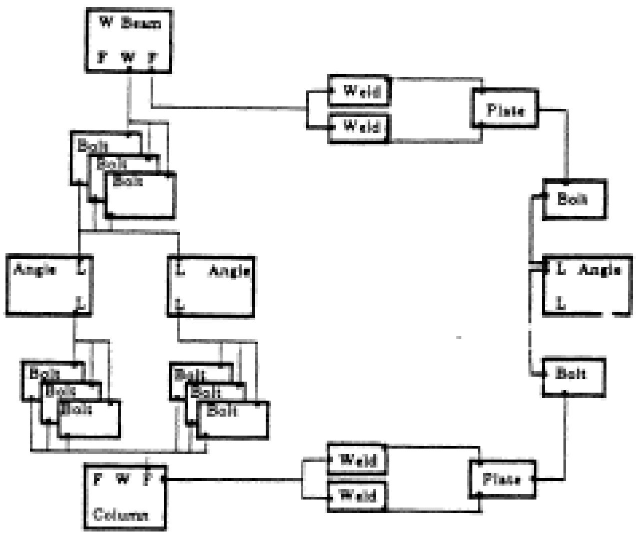

Figure 8. Detailed component network.

3.3. Database.

The role of the database is to store predefined components in a catalogue format and to serve as a central repository of information that may see multiple uses in the component network. For example, more than one column component may be generated from a W8x31 steel section. Through the use of links to the database containing engineering and dimensional data about W8x31 columns, the component need not store this data within itself. Also stored within the database are the relevant codes that govern the design of any of the elements. This information resides independent of the actual components in order to incorporate revisions in the code or the addition of new or altered components.

3.4. Reasoning Mechanism.

The reasoning mechanism provides the ability to *reason about* the building (or portion thereof) being designed. In a traditional expert system, the knowledge base is kept separate from the inference mechanism. In the same way, the reasoning mechanism in our scheme is kept separate from the component network and database.

A typical chain of inferences about structural integrity of a proposed configuration involves a traversal of the component hierarchy. Appropriate conclusions are drawn about load accumulation, stability, interferences, etc. through rules that reside within various collections of components. The types of collections of components are; classes, physical and functional and are described below.

3.4.1. Classes.

Classes contain rules and common information about the components contained in the class. This combines techniques from traditional object-oriented organizations and properties of a semantic net [Barr and Feigenbaum 1981]. An example is the "beam" class, where one rule (method) would contain procedures for calculating moment strength for a beam component in the component network. Thus, a specific beam component can determine its moment strength only by virtue of its membership in the "beam" class.

One type of procedure would be to check appropriate building code compliance. Explicitly representing particular building code provisions in the database [Garrett and Fenves 1987] will enable the procedures within the class to be code-independent, able to utilize whichever code applies.

3.4.2. Physical and Functional Collections.

While the topology of the structural components and their interconnections are represented explicitly in the component network, the functional knowledge about their behavior resides in overlapping collections. It is in the collections and classes that rules reside, rather than in the components themselves Thus, the "no function in structure" principle of qualitative physics [Davis 1985] is inherent in our approach.

Examples of collections in our scheme include gravity load resisting system, spanning system, lateral load resisting system, and foundation system. Functional collections reason about behavior, e.g. load path, making inquiries as needed of the appropriate physical collections. Physical collections reason about orientation and assemblies. Collections thus represent both physical aggregations of components (e.g., "floor system") and functional aggregations (e.g., lateral load resisting system).

The resulting information architecture minimizes duplication of information by expressing what is needed at the appropriate description/abstraction level.

An example of how the various parts of the framework function can be illustrated through the following inquiry about the structural adequacy of a single bolt. A designer may wish to know the stress that a specific bolt in a connection experiences and directs the question at bolt 1 Since bolt 1 belongs to the class of "Bolt", the bolt inherits the knowledge about its limit states of failure. The bolt also belongs to the collection of components describing the vertical load resisting elements where the rules about load path reside. The vertical load group will therefore be able to "accumulate" loads to the point of the specific bolt under investigation. The physical collection of components that describes the connection of which bolt 1 is a part will be able to compare the limit conditions in the Bolt collection and the actual load calculated from the functional collection with the appropriate code issues in the database.

4. IMPLEMENTATION

Currently, parts of the component network and database are implemented as a separate mode within the AiSys software. As an initial test of the framework, the components are limited to the structure of a low-rise steel frame building. The components, such as wide flange beams, can be generated dynamically from the database information. The modeling system supports generation of the cross section of a steel rolled shape from the AISC data on steel shapes and subsequent extrusion to the desired length. The main frame of a building can be modeled by assembling individual components into the whole.

The user interface utilizes a menu driven series of commands. Initially, four windows showing the top, front, side and an axonometric are generated.

Components can be selected and manipulated in any one of the two dimensional views and viewed three dimensionally in the axonometric.as shown in Figure 9

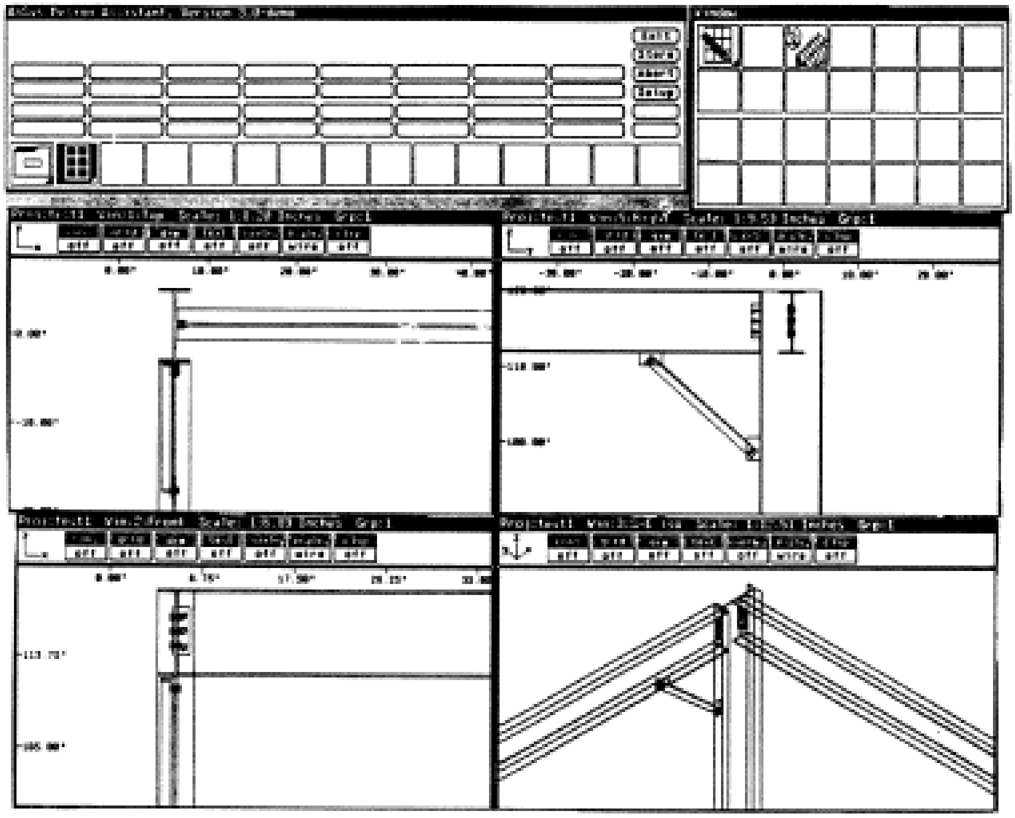

Figure 9. User interface.

Current implementation efforts are being focused on the functional and physical collections within the reasoning mechanism. Initial attempts are being made to explicate reasoning about load path and structural adequacy. Further exploration into code related relationships has also begun.

5. CONCLUSIONS AND FUTURE DIRECTIONS

The software under development attempts to provide architecture and civil engineering students with an accessible, easily manipulable, graphical system for studying the complex relationships in building technology. The most useful method for providing students with a thorough understanding of structural and construction principles combines traditional classroom instruction with exploratory manipulation of scale models (e.g. changing loading conditions on a beam and observing the resulting deflection and stress patterns along the beam). These exercises are typically carried out by the students using physical scale models and computer simulations that neglect graphics or interdisciplinary integration. Although this method is still essential, time and cost limit the exercises to small isolated building elements and connections. The current fragmented method of teaching makes it very difficult to impart spatial visualization and holistic "systems thinking". With the use of a high power, 3-dimensional computer graphics system integrated with functional reasoning abilities, students will be able to study the individual building components as well as their relationship to the building as a whole. The computer aided learning system proposed attempts to support this more comprehensive understanding of the inter-relationships of building components and systems and could also provide unlimited, on demand, instructional time to students outside normal class hours.

The practical goal of framework being developed is to be flexible enough to add the knowledge and information about other systems in a building such as mechanical, electrical, enclosure etc.. The conceptual goal of the system is to model an entire building by its aggregated components within the memory of the computer. Once this model exists, several additional operations could be performed such as cost, energy analysis etc.. Furthermore, higher level functions could be performed, such as interference checking etc., in order to minimize the on-site construction dilemmas that currently occur due to the incomplete understanding of the abstract representation of the building.

AKNOWLEDGEMENTS

This research project is supported in part by the Lilly Endowment Inc., Indianapolis, Indiana.

REFERENCES

AISC [1980] American Institute of Steel Construction, **Manual of Steel Construction**, 8th edition, 1980.

AISC [1986] American Institute of Steel Construction, **Manual of Steel Construction**, **Load and Resistance Factor Design,** 1st edition, 1986.

AISC [1986] American Institute of Steel Construction, **Manual of Steel Construction, Allowable Stress Design**, 9th edition, 1989.

Astaneh , A. [1986], "Behavior and Design of Single Plate Shear Tab Framing Connections", **Proceedings of the National Steel Construction Conference**, AISC, June 1989.

Barr, A., and Feigenbaum,E.,A., [1981] **The Handbook of Artificial Intelligence,** Vol. 1, William Kaufman Inc, 1981.

Bjork, B.C., [1988] "RATAS - A Proposed Finnish Building Product Model," in **Pre-Proceedings, Knowledge-Based Design in Architecture**, TIPS-88, Otaniemi 15.-16.8.1988, edited by J.S. Gero and T. Oksala, 1988.

Chen, S., and Wilson, J., [1989] "Knowledge Representation for Fatigue Evaluation", **Proceedings of the Sixth Conference on Computing in Engineering,** ASCE, September 1989.

Davis, R., [1985] "Diagnostic Reasoning Based on Structure and Behavior", **Qualitative Reasoning about Physical Systems**, edited by Bobrow, D.,G.,, MIT Press, 1985.

Dixon, J., [1987] "Expert Systems for Mechanical Design: Examples of Symbolic Representations of Design Geometries", **Engineering with Computers** Vol. 2, 1987.

Eastman, C.M., [1985] "Abstractions: A Conceptual Approach for Structuring Interaction with Integrated CAD Systems," **Computers and Graphics,** 9(2):97-105, 1985.

Fenves, S.,[1988]"Object Representations for Structural Analysis and Design", **Proceedings of the Fifth Conference on Computing in Civil Engineering**, ASCE, March 1988.

Fenves, S., Flemming, U., Hendrickson, C., Maher, M., and Schmidt., [1988] "An Integrated Software Environment for Building Design and

Construction", **Proceedings of fifth Conference on Computing in Civil Engineering,** ASCE, March 1988.

Garrett, J.H., and Fenves, S.J., [1987] "A Knowledge-Based Standards Processor for Structural Component Design", **Engineering With Computers**, Vol 2, 1987, pp. 219-238.

Harfmann, A.C., [1987] "The Rationalizing of Design", **Principles of Computer Aided Design: Computability of Design**, edited by Y.E. Kalay, John Wiley and Sons,1987.

Howard, H.,C., Levitt, R., E., Paulson, B.,C., Pohl, J., G., and Tatum, C.,B., [1989] "Computer Integration: Reducing Fragmentation in the AEC Industry", **ASCE Journal of Computing in Civil Engineering**, Vol. 3, No. 1, 18-32, 1989.

Kalay, Y.E., [1983] "A Relational Database for Non-Manipulative Representation of Solid Objects," **Computer-Aided Design**, 15(5):271-276.

Kalay, Y.E., A. Harfmann, and L. Swerdloff, [1985] "ALEX: A Knowledge-Based Architectural Design System," in **Proceedings of ACADIA 85**, P. McIntosh ed., 1985.

Powell, G., Abdalla, G., and Sause, R., [1989] "Object Oriented Representations: Cute Things and Caveats", **Proceedings of the Sixth Conference on Computing in Civil Engineering**, ASCE, March 1988.

Rush, R.D., [1986] editor, **The Building Systems Integration Handbook**, The American Institute of Architects, John Wiley & Sons, Inc., 1986.