CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

PMAPM: An Object Oriented Project Model for A/E/C Process with Multiple Views

by
Kenji Ito, Kincho H. Law and Raymond E. Levitt

TECHNICAL REPORT
Number 34

July, 1990

Stanford University

CIFE Center for Integrated Facility Engineering • Stanford University

PMAPM: An Object Oriented Project Model for A/E/C Process with Multiple Views

Copyright © 1990 by
Kenji Ito, Kincho H. Law and Raymond E. Levitt

If you would like to contact the authors please write to:

c/o CIFE, Civil Engineering,
Stanford University,
Terman Engineering Center
Mail Code: 4020
Stanford, CA 95305-4020

PMAPM: An Object Oriented Project Model for A/E/C Process with Multiple Views

Kenji Ito [1], Kincho H. Law [2] and Raymond E. Levitt [3]

Abstract

Generating, sharing and maintaining project data among multiple disciplines and throughout a project life cycle is a difficult task in the highly fragmented Architecture/Engineering/Construction (A/E/C) industry. Presently, the A/E/C industry lacks a common standard for exchanging project data to allow applications to share graphical and non-graphical information produced and consumed at the various stages of a project cycle. The object-oriented paradigm provides a useful mechanism to organize and structure complex information and offers a powerful approach for sharing information and knowledge. This paper describes an attempt to develop an object-oriented project model to facilitate information sharing among multiple disciplines and across project stages from planning, design, construction to management of a facility. The feasibility of employing this model for information transfer from CAD to various knowledge-based expert systems will be discussed.

Key word

Object-Oriented Programming, Project Model, AI, Knowledge-based Expert System, Relational Database, Multiple View, Frame, A/E/C Process, CAD.

---

[1] Senior Research Engineer, Shimizu Corporation and Visiting Research Fellow, Center for Integrated Facility Engineering, Stanford University

[2] Assistant Professor of Civil Engineering, Stanford University

[3] Professor of Civil Engineering and Associate Director, Center for Integrated Facility Engineering, Stanford University

1. Introduction

Large amounts of information are generated and consumed during the various phases of a project life cycle from planning to design, construction and management of the facility. Sharing and maintaining these project data among multiple disciplines and throughout a project life cycle is a complex and difficult task. The project data needs to be stored, retrieved, manipulated, and updated by many participants, each has his/her own view of the information.

A number of computer-based systems such as CAD, analysis and simulation software have been developed for the A/E/C industry. However many of these systems can only be utilized within narrow application domains. Efforts have been attempted to integrate these application software by linking systems and providing data transfer interfaces so that a richer communication among applications of different domains can be realized. Efforts to establish data exchange standards for CAD applications have also been initiated [Howard 89, Warthen 88]. Most of these efforts are still in the early stages of development. We believe that a project model that can properly describe a facility and is accessible by multiple participants of different disciplines is a very important ingredient for integration.

Object-oriented programming paradigm offers many useful features to facilitate the description of a constructed facility. Some of the benefits include:

- To define data, programs, or data and programs in a unified manner as objects;
- To store an atom, symbol, list, character strings, method or function in the object as the value of each slot;
- To inherit information from the abstract level to the detail level;
- To define a relationship, such as supported_by, consists_of or others, using the slots of a related object.

With these features, we can define several kinds of objects. In our model, we define four kinds of objects -- *data-object*, *scope-view-object*, *eval-view-object* and *create-view-object*. These four kinds of objects are collectively termed *multiple purpose objects*. In addition, the relationships among the objects are defined not only for inheritance, demons or methods of an object but also to facilitate the search for information.

The scope of our research is to establish an object-oriented project model supporting multiple views that are shared by the various participants of an A/E/C project. The objective is an eventual development of an integrated system which includes activities from project planning through design, estimation , construction and facility management. The object-oriented project model is intended to link CAD systems, relational databases, knowledge-based systems and other conventional application software; these applications can easily be treated as a view-function embedded in a view-object.

2. Related Research

In building design, we can benefit from using databases for storing a large amount of independent but interrelated data about design elements and their relationships. The objects observed in a building project are best modeled by an object-oriented model. Elements (such as columns and beams) can be defined as individual object types, and their properties (such as length and weight) are defined as attributes. Operations on the objects can be defined using methods. Many researchers have attempted to develop product models or project models using the object-oriented methodology. In this section, we briefly review some of the relevant work related to product and process modeling of a constructed facility.

To manage the vast volume of data inherent in building design, a formal representation is needed to organize the data. The concepts of aggregation and generalization are useful tools for describing design information [Eastman 78, Law86, Garrett89]. The database integrity issue of this abstraction concept for engineering modeling has been studied and an implementation using the object oriented programming paradigm has been proposed [Law 87]. Recently, a formal approach based on a semantic structural data model to manage engineering design objects using a relational framework has been introduced [Law90]. The benefit of this data modeling approach is that information can be shared among different applications through multiple views while maintaining data integrity in the database.

Recently, product models for building design have attracted considerable interest. An object-oriented data model for steel frame structures using a top-down approach according to the concept of PDES (Product Data Exchange Specification) has been proposed by Howard and Lavakare [Lavakare 89]. A significant effort is currently underway at the Technical Research Centre of Finland to develop a building product model (RATAS) using relational databases and hypermedia [Pentilla 89]. Their main target is to describe the architectural elements as the product model and to store this model into a relational database with relationships among elements.

Recently, a formal approach for product modeling of building design information has been proposed by Eastman et.al. [Eastman 90].

Despite all the attention that has been devoted to modeling product design information, additional research is needed to establish a product model that not only represents the physical elements but also the processes involved in an A/E/C project. In structural engineering, Sause and Powell proposed a design process model based on a problem decomposition approach [Sause 90]. A top-down approach for the integration of the building process has been suggested by Sanvido et. al. [Sanvido 89]. In this paper, we describe an object-oriented concept for modeling the product design information as well as the processes, using a multiple view approach. We believe that this object-oriented multiple-view approach is sufficiently flexible to support the development of a project model for an integrated environment for planning, design, construction and management of a constructed facility.

Fenves and his colleagues [Fenves 88] are developing an integrated environment for building design and construction (IBDE) using a number of AI techniques to model the process and information flow from architecture design to construction planning. Presently, IBDE consists of seven knowledge-based modules: ARCHIPLAN (Architectural Planning), CORE (Spatial Layout), STRYPES (Structural System), STANLAY (Preliminary Analysis), SPEX (Structure Component Design), FOOTER (Preliminary Design of Foundation), and PLANEX (Construction Planning System). They have successfully developed a partial integration of the facility engineering process, combining knowledge-based expert systems and conventional systems used from conceptual design through construction planning. However, presently this integration is a batch serial process and does not use the concept of a product model.

Another related effort on object-oriented CAD is the BUILDER system which generates a symbolic model as a graphic drawing is created on a LISP machine [Cherneff 88, Logcher 89]. The data generated through the manipulation of the KEE-Pictures interface becomes an object-oriented model within the KEE environment. The object model then serves as the input to a prototype system for knowledge-based planning and scheduling implemented in KEE. Moreover, the concept of this object-oriented model has been incorporated in an integrated engineering environment (DICE) as part of its global model [Sriram89]. In DICE, an architect and a structural engineer each has his/her own object hierarchy to access the global data model, installed in the GEMSTONE database system. Using multiple object hierarchies and a blackboard architecture as the control mechanism, DICE provides a constraint management environment to resolve potential conflicts among several participants. This concept is very similar to ours in defining multiple views for project participants. However, we primarily focus on the development of a project model that supports an integrated system environment.

3. An Object-Oriented Project Model Supporting Multiple Views (PMAPM)

The object-oriented project model (PMAPM) described herein is an extension of a project model (PMAP) initially developed as a vehicle to share project information for a mid-rise building project between a CAD system and two knowledge-based construction planning systems [Ito 89, Ito 90]. While PMAP was implemented using Framekit [Nyberg 88], PMAPM has been implemented using Allegro Common Lisp, Parmenides and FRulekit [Shell 88, Shell 89] on a Macintosh II computer. The system supports not only graphic information but also the non-graphic or attribute information including the relationships among the building elements. In this section, we first review the basic capability of PMAP. We then describe the extension of the model to support multiple views and the implementation of multiple purpose objects.

3.1 PMAP - An Object-Oriented Project Model

In the PMAP model, an object represents a building element or a non-building element. Each building element consists of eight basic attributes: material, finish, size, position, rotation angle, offset and relation. The attributes of a non-building element include: project code, project name, user id, client name and site location. Included in each building element is its relationship with other elements. Some examples of the relationships between the building elements are:

- Girder is supported by Columns.
- Beam is supported by Columns or Girders.
- Exterior Wall is connected with Columns or Exterior Walls.
- Interior Wall is connected with Columns, Exterior or Interior Walls.
- Slab is supported by Girders or Beams.
- Door and Window is attached on Exterior or Interior Walls.
- Space (Room) is consisted by Exterior or Interior Walls.
- Floor is consisted by Spaces.

Four basic access mechanisms are available for the user to extract object data:

- Using the frame or slot access functions in FRulekit and Parmenides with methods embedded in the object. For example, the size of an object can be determined with the following (Lisp) function:

  ```
  (defun get-size (frame-name)
          (get-value frame-name 'size)
  )
  ```

  Figure-3.1.1 shows a function to access the size of a specific column by providing the column's name as the value of the "frame-name" argument.

- Using the relationship among the building elements. Figure-3.1.2 illustrates the extraction of information about an object via the relationship definitions. In this example, a room is said to be enclosed (consisted) by a series of walls (see Figure-3.1.2a). In Figure-3.1.2b, an opening (such as a window or a door) is defined as attached to a wall. The composition of these relationships then yields the information about the openings of a room (see Figure-3.1.2c). In fact, we can issue a query to request the information about the size of a room's opening.

- Generating a file as an interface to an external application program. For example, if a construction planning system needs information about a specific relationship between the building elements, the planner can issue the relationship such as supported-by and specify an output file:

  ```
  (get-relationship-inf 'supported_by 'list-form "temp.txt")
  ```

  The system will look for the "supported-by" relationship from all object instances in a product model and return the values in terms of a series of list-expressions like the following

  ```
  (Supported_by  Girder-1 Column-1 Column-2)
  ```

  These lists will be put it into the file "temp.txt". As will be seen in the next section this is the mechanism that has been used in integrating PMAP with AutoCAD via a CIFECAD interface program. If the user does not specify the file name, the system will show the value on the screen window.

- Using the graphic interface of PMAP as shown in Figure-3.1.3.

PMAP has been used as an interface to various knowledge-based systems, a CAD system, and a relational database system (ORACLE). The basic configuration of PMAP as an interface to multiple application programs is schematically depicted as shown in Figure-3.1.4.

3.2 PMAPM: An Object-Oriented Project Model with Multiple Views

Each participant of an A/E/C project has his/her own view of the information about a constructed facility. In general, for each project, there is one facility and the object representing the facility has only one physical value but many functional values depending on the various views of the information by the participants of different disciplines.

In the PMAP model, we define an object hierarchy describing the physical elements used in the design and construction of a facility. Only three views -- architect's view, structural engineer's view and construction engineer's view -- about the physical objects are currently defined. As shown in Figure-3.2.1, in PMAPM, a project can be viewed in terms of a global view (concerned with the social and labor types of information), a project view (defining the perspective of various phases of a project) and an object view (defining the physical building elements of the facility). While the object view representing the physical elements is similar to the object hierarchy in PMAP, we introduce a global view and a project view in PMAPM to represent the functional views corresponding to the processes of an A/E/C project. In an object oriented programming environment, we can treat the views as objects defined with data and methods.

In order to fully realize the model description of an A/E/C project, we need to consider not only a product-based description but also a process-based description. From the process point of view, a project consists of the following stages corresponding to the view definitions in our PMAPM model:

- Project Management View
- General View
- Project Planning View
- Sales View
- Design View
- Estimation View
- Construction View
- Facility Management View

- Maintenance View

The project management view (for the project manager) and the general view (to store the general information about the project) provide the high level control and support of project information. The other views about a project follow the various phases of an A/E/C process. For each view object, we can further define object subclasses. For example, the design view can be divided into six sub-views:

- Conceptual View
- Architecture View
- Structural View
- Mechanical View
- Electrical View
- Coordination View

The coordination view is intended to support negotiation when conflicts occur among the various design views. Figure-3.2.2 shows the decomposition of views into subviews and the definition of slots for each view. Details of the PMAPM hierarchy that have been implemented are summarized in Appendix-A.

PMAPM includes all the access mechanisms of PMAP as described in the earlier section. The major difference between PMAPM and PMAP is the inclusion of the view definition for each participant in the A/E/C process. A view consists of not only the data but also many kinds of methods, functions and rules in order to extract or update the information according to each participant's needs. For each view, PMAPM needs to assign to the user the mode of access (i.e. update or read only) as illustrated in Figure-3.2.3. Most users (except for the project manager and PMAPM designer) have only limited access to the various views. For example, a sales person can access the global-view, management-view, general-view, planning-view and sales-view with the read-only mode but is allowed to access sales-view and general-view with the previlege of updating the information. Similarly, a client can access to the global-view, management-view, general-view and facility-management-view with the read only mode but is allowed to access the facility-management-view with the update mode. This view facility can facilitate the management and presentation of information to the users.

3.3 An Illustrative Scenario for Multiple View Definition

The multiple view definition and the data access mechanisms described in the previous section may best be illustrated using a scenario for a simple project. At the beginning of the project, the project manager was assigned and the project code and the project name are entered into the PMAPM model. The sales person obtains information about the clients (number of clients and their names) and the site location and stores this information into PMAPM through the general-view using the update mode as shown in Figure-3.3.1.

From the project site information, the project manager can now evaluate the applicability of various structural and construction methods, extract information from the "Structural and Construction Methods Database" and store this information into the structural-technology-view and construction-technology-view under the technical-strategic-view of the management-view (See Figure-3.3.2). The state-of-the-art information about the material and facility (such as smart building or automated factory) are stored in the new-material-view and the new-facility-view. Some of these evaluation functions are implemented in terms of production rules which are defined as methods imbedded in an object and can be accessed from the multiple views through messages. For example, a construction method selection expert systems may be used by the project manager, the structural engineer, the construction manager or construction engineer; this expert system may use the information created at every stage of the AEC process. As the project proceeds, the system will provide increasingly reliable and appropriate selection as the amount of unknown and missing information decreases and as the quality of the information improves (see Figure-3.3.3). This illustrates the importance of the process-based view description of a project model.

With the information about the available technology, the sales person can extract the information (such as the name of the technology, applicable domain and the characteristics of the technology) from the sales-technology-view of the sales-view so that they can explain the technology to the client. After the decision on the technologies to be used in the project has been made, the sales person stores this information as the sales-design-construction-constraints in the project-construction-views under the general-view. These constraint information will then propagate to the other views as depicted in Figure-3.3.4.

At the structural design stage, when the structural engineer recalls the structural-constraint-view, a method would be initiated to check upper-level constraints that would affect the structural design process. The structural engineer can further re-evaluate the structure and construction methods from the structural-technology-view via the structural-building-view. It is worth noting that the sales person and the structural engineer both have access to the same object but obtain different information according to their own view.

3.4 Multiple Purpose Objects (MPO)

In order to realize the multiple views that are needed to capture or update the model information, we use the notion of multiple purpose object (MPO) in our project model. A multiple purpose object can be one of the following four basic object types (see Figure-3.4.1) :

1. Data-Object: This object contains the basic data, such as numeric, symbol, character strings or list expression (data list). The following objects are defined as data object:

   1.1 Class or subclass object which dose not have any functions or rules defined as its slot value. For example, “project” is a data object and has 5 slots for *project code*, *project name*, *start date*, *end date* and *instance of*; each slot carries a data item as its value.

   1.2 Most of the object instances defined under object view are data objects. For example, the object instance "Columns-1" has many slot entries including *size*, *position*, *material*, etc..; each slot carries a single datum as its value.

2. Scope-View-Object: This object type contains both data and functions written in Lisp or some other language. With the functions, the object can extract data from other objects or update the slot value of its own or other objects. In addition, some of these functions can create or remove a data object. For example, the column-object has not only the default value to be inherited by its instances but also a method to create, upon request, an instance automatically.

3. Eval-View-Object: This object type contains not only data or functions but also rules written in Lisp or another language. Production rules are embedded in an object as slot values. The difference between the functions in the scope-view-object and the rules in the eval-view-object is their purpose and use. The purpose of a function is to extract or to update the slot value with some calculation, while the purpose of a rule is to evaluate not only the slot value but also the object, group of objects or relationships of objects. For example, the progress-view is a eval-view-object consisting of six slots:

• *Start_Date*	(Date1 Date2)
• *Required_Duration*	(Duration1 : pre-if-set '(ask-duration1)
• *Temporal_Duration1*	(Duration2 : pre-if-set '(ask-duration2)
• *Temporal_Duration2*	(Duration3 : pre-if-set '(ask-duration2)

• *Fixed_Duration*	(Duration4 : pre-if-set '(ask-duration3))
• *Instance-of*	(Management-View)

In the above definition, "Date1" is a start date of the project and its value is stored by the project manager using the *Start_Date* value of the project-view. "Date2" is a start date of the project after contract agreement with the client and its value is stored by the sales person or the project manager. "Duration1" is a required duration by the client; when the user asks for the *Required_Duration,* the method named "ask-duration1" sends a message to the required-duration slot of the sales-view, extracts the data from the other object and stores the data into its own slot.This procedure is a common way of using a method or demon in an object-oriented environment. For "Duration2", "Duration3" and "Duration4", however, we define the functions in terms of rules. These functions evaluate the preliminary duration which in turn depends on the total area of the building, the ground condition of the site, number of the stories and usages of the building etc.. Such information may at times not available depending on the current phase of the A/E/C process. This function must be able to respond to unknown and missing information using heuristic knowledge acquired from a human expert, in this case, to estimate the duration based on the information available.

4. Create-View-Object: The main purpose of this object type is to create a new object or slot according to the user's requirements. Although PMAPM has its own object hierarchy which is designed to support a wide variety of building projects, this hierarchy cannot exhaustively include all the possible views required by each project participant. Therefore, PMAPM provides a method to define a new Scope-View-Object. By turning on a trace mode, PMAPM will make a trace of the user's operations to extract the data from other objects and will store the set of operations as a function in the new object.

This concept of a "multiple purpose object" provides the flexibility to accommodate unforeseen situations and to expand PMAPM's applications in the future.

4. Automatic Model Generation with CAD Application

PMAPM, as an extended version of PMAP, includes a high level user interface, CIFECAD, for defining building elements and their attributes. CIFECAD is a customized AutoCAD system written in AutoLisp [Ito 89, Ito 90]. AutoCAD is basically a computer-aided drafting system rather than a computer-aided design system. Although several third party vendors have developed interfaces to facilitate drafting in specific domains, there is no high level way to input building elements, such as "Column", "Exterior Wall", "Beam" etc.., even in graphical form via the original AutoCAD interface. In order to define non-graphics or attribute information to the object model, we need an interface to input these building elements. In our approach, we first define the building elements using the BLOCK data storage facility of AutoCAD with attributes. CIFECAD has its own object hierarchy definitions (See Figure-4.1.1) and its own high level interface to carry out the A/E/C design (See Figure-4.1.2). AutoCAD data are stored in a binary file termed a *.DWG* file. To extract data out from the .DWG file, a set of AutoLisp functions have been implemented to read the .DWG files and write the information in ASCII format onto an external file. With CIFECAD, a user can input the building elements with non-graphic information and obtain the drawing information not only in the DXF format for AutoCAD but also in customized ASCII formatted list-expression for other application programs.

Currently, CIFECAD supports the definition of the following elements and their attributes:

• Columnline	Number of x-Columnline, Span size of x-Columnline, Number of y-Columnline, Span size of y-Columnline, Coordination.
• Foundation	Center position, Size, Material, Intersection of Columnline.
• Foundation Beam	Size (W x D), Material, Start and End position, Connection Information, Offset, Rotation Angle and so on.
• Column	Size (X x Y), Material, Center position, Finish code, Offset, Connection Information, Rotation Angle, Floor name and so on.
• Round Column	Same as Column.
• Exterior Wall	Thickness, Material, Start and End position, Finish code, Offset, Connection Information, Rotation Angle, Floor name and so on.
• Interior Wall	Same as Exterior Wall.
• Girder	Size (W x D), Material, Start and End position, Finish code, Offset, Connection Information, Rotation Angle, Floor name and so on.
• Beam	Same as Girder.
• Slab	Thickness, Material, Finish code, Floor level, Connection Information, Area, Floor name and so on.
• Roof	Same as Slab.
• Window	Width, Height, Floor Level, Type, Connection Information, Floor name, Center position and so on.
• Door	Same as Window.

•	Space	Name, Finish Code, Uses, Connection Information, Floor name, Area, Floor Level, Ceiling Height and so on.
•	Floor	Connection Information, Area, Floor Height, Floor Level and so on.
•	Desk	Size (X x Y), Center position, Connection Information, Material, Type, Floor name and so on.
•	Table	Same as Desk.

Although CIFECAD has many limitations, it does have sufficient functions and capabilities to be used as a computer aided design system with object data structure and high level user interface suitable for a prototyping environment.

PMAPM obtains most of the physical object information about a building from CIFECAD. The major building elements of the architectural and structural design can be defined using CIFECAD and the information about these objects is stored under the object-view in PMAPM (see Figure-4.1.3). The procedure for model generation from the CIFECAD to PMAPM can be summarized as follows:

1. Create the drawing using the CIFECAD and its high level user interface.(See Figure-4.1.4)
2. Create a temporary file to store list-expressions derived from the drawing data using AutoLisp functions.
3. PMAPM reads the list-expressions and stores the information into the object model.
   - 3.1 Read the general description and check if the value exists in the target slot. If there is no value in the model, the system stores the data into model. However, if there is already a value in the target slot, the system would request whether the previous information should be replaced.
   - 3.2 Read the default value of each element. The process of checking existing value is the same as above.
   - 3.3 Read the number of each building element,and create an instance for each element.
   - 3.4 Store the relationship information into the instances.

Hence, the user does not need to worry about transfering design data from CIFECAD to the PMAPM. This process is automatically done by a file interface between CIFECAD and PMAPM (see Figure-4.1.5). In future efforts, we will try to obtain design data from other CAD systems into the PMAPM object model.

5. Overview of the Data Storage Mechanism in PMAPM

Including the interface with CIFECAD, there are altogether five different ways that one can store the data into PMAPM:

- Enter data using the textual interface of PMAPM. (see Figure-5.1.1)
- Create and store data using the graphical interface of PMAPM.
- Transfer data from the relational database system; presently, we are using ORACLE for storing cost, actual result, personnel and client information in the PMAPM environment.
- Transfer data from a CAD system , such as CIFECAD.
- Create and store data using a method or rule.

These interface facilities allow PMAPM to capture project information from the participants of different disciplines who are involved in an A/E/C project. PMAPM can be used in the planning and design phases in the following manner:
At the beginning of a project:

- The project manager defines the project using textual interface of PMAPM;
- The sales person inputs the client and site information using textual interface of PMAPM as well as the relational database interface;
- The project evaluates and stores the duration information using rules and methods of PMAPM;
- The sales person stores the client's requirements for usages of the building using the textual interface of PMAPM;
- The sales person evaluates and stores the information about the building usages and the building cost using rules, methods or other application programs.

During the preliminary design phase:

- The architect evaluates the site and stores the information using a CAD system or other application programs.
- The architect considers the layout and the grade of the building using CAD or application programs.

- The structural engineer evaluates and stores the above-ground as well as under-ground information using the relational database interface, application program and the textual interface of PMAPM.
- The mechanical engineer evaluates the concept of the heating system using the relational database interface, rules and other application program, etc...

During the conceptual design and design development phase:

- The architect and engineers store the graphic information using the CAD interface.
- Engineers evaluate and store data using the rule facility of PMAPM, its relational database interface and other application programs.
- The project manager evaluates the duration information using PMAPM's rule facility.

In this process, there will be information conflicts among the project participants. These conflicts are stored as constraints in views and propagated and resolved by the constraint management system in PMAPM.

6. An Example of Using PMAPM

In this section, we describe the use of PMAPM using a small room in an office building as an example. The process from the planning phase to the construction phase will be described to demonstrate the various views of the project model. Furthermore, the information sharing among the multiple participants and the mechanism for information retrieval using views will be illustrated. In this example, the participants are an architect and a structural engineer, and the shared object is a room of an office building. The shape of the room is shown in Figure-6.1.1 and the basic data information are stored in PMAPM as shown in Figure-6.1.2.

Various disciplines require different types of information about a room. For architectural design, an architect may be interested in attribute information about the room (such as area, uses, grade, color, ceiling height and other spatial information), its elements (such as the enclosing walls, openings, size, finish, color , etc.) and cost information (about the materials and finishes). On the other hand, a structural engineer may be interested in the overall system of the room (including the basic structure of the room, span size, live loads, etc..), its structural elements (including size of each element, material, bearing wall if any, opening information, etc..). The architect and the structural engineer can access these data directly from PMAPM through each view, (such as architectural-space-view, structural-element-view and so on).

As an example, Figure-6.1.3 shows how each participant can extract or update the PMAPM information through his or her own view. From the architectural-space-view, the user can access information as follows:

• area of the room	"38400 square inches" via path-A.
• uses of the room	"OFFICE" via path-A.
• basic color of the room	obtained from the material of finish via path-A, path-C and others
• ceiling height of the room	"120 inches" via path-A.

From the architectural-element-view, the following information can be accessed as follows:

• the walls enclosing the room	"E_Walls-11, E_Walls-12, I_Walls-6, I_Walls-7" via path-A.
• openings on the enclosing walls	"Windows-10, Windows-11, Doors-20" via path-A, path-C and path-E.
• size of each element	via path-A, path-C, path-D, path-E and others.
• finish of each element	via path-A, path-C, path-D, path-E and others.

From the architecture-cost-view, the architect can obtain the cost information in the following manner:

• cost of material	obtain the cost of each material via path-A, path-C, path-D, path-E and others.
• cost of finish	obtain the material of finish and cost of finish via path-A, path-C, path-D, path-E and others.

Through the structural-space-view, the structural engineer can acquire the following information:

• basic structure of the room	"Reinforced-concrete" via path-B, path-C, path-D, path-E and others.
• basic span size	obtain the columnline information by via path-B path-C, path-D and others.

From the structural-element-view, the following information can be obtained:

• size of each structure element	"30.0x30.0" via path-B, path-C, path-D and others.
• material of each structure element	"Reinforced-concrete" via path-B, path-C, path-D and others.

That is, multiple participants of a project are sharing the same information of the design and they can extract or update the information of PMAPM according to his/her own view.

7. Other Application Programs Interfacing with PMAPM

OARPLAN: A Knowledge-Based construction planning system.[Darwiche 89]

OARPLAN is a prototype knowledge-based construction planning system based on the notion that activities in a construction project plan can be viewed as intersections of objects, actions and resources at several different levels of abstraction. OARPLAN generates the needed activities in a project plan by elaborating a high level activity such as <build> <building> into a set of project activities at one or more finer levels of detail, guided by activity scale reduction and activity sub-plans. Therefore, OARPLAN needs design data to generate the activities in a project, and to generate the needed sequencing constraints among the activities. In general, OARPLAN is used mainly at the end of a design stage or at the construction planning phase. That is, OARPLAN has its construction-planning-view for extracting information from PMAPM. In fact, a user can use OARPLAN from the construction-planning-view of PMAPM through the system menu. The result of an activity network generated by OARPLAN is illustrated in Figure-7.1.1.

SIPEC: Knowledge-Based construction planning system.[Kartam 89, Kartam 90]

SIPEC is a prototype knowledge-based construction planning system using SIPE (System for Interactive Planning and Execution) which developed by SRI International. SIPE is a domain-independent AI planner, to hierarchically planning projects involving multiple agent tasks. Although SIPEC has the same construction-planning-view as OARPLAN, the needs of information format is different from OARPLAN. PMAPM can support these different needs from different applications because of its multiple views function and object hierarchy.

FCOST: Finish cost Estimation and Counseling expert system.

FCOST consists of two basic modules, FINISHES and FINISHCST. FINISHES is a knowledge-based counseling system which evaluates the finishing material based on the usage of the room and the grade of the building. This information can be directly accessed through the architectural-view of PMAPM (See Figure-7.1.2). FINISHCST is a cost estimation system which calculates the preliminary finish cost using the information from the detail-cost-view. The information required by FINISHCST can be obtained via the architectural-view and the estimation-view. Both FINISHES and FINISHCST can be directly accessed from the system menu of PMAPM.

DURATION: Knowledge-Based Construction Duration Evaluation system.

DURATION consists of a set of rules to evaluate the construction duration from the total area, floor area, building structure, ground condition, etc.. After the evaluation, the following duration information is given to the user:

- Under Ground Construction Duration.
- Super Structure Construction Duration.
- Finish Work Duration
- Total Duration.

A user can run this system from many views or directly from the PMAPM's system menu.

8. Conclusion and Discussion

In this paper, we have described an object-oriented project model that supports multiple views for building projects. We have implemented the basic model hierarchy of PMAPM as described in Appendix-A, and integrated it with various applications as described in Sections 4 through 7. Various interfaces to store and access information from PMAPM have also been developed and illustrated. The overall integrated system is schematically depicted in Figure-8.1.1.

During the course of developing PMAPM, we have found many benefits of using an object-oriented paradigm to describe project model and to provide multiple views of the project model. Particularly, with the definition of multiple views, we can analyze and recognize the various requirements throughout the A/E/C process. Furthermore, this process-based approach is very useful to discover the information flow among the participants from different disciplines. In summary, we have demonstrated two important concepts:

- The usefulness of an object-oriented project model for system integration in an A/E/C project -- we need not only a product model but also a project model.
- The usefulness of the multiple view concept for the project model -- we need not only a product-based model description but also a process-based description of a constructed facility.

Finally, our purpose in this work is to realize the plausibility of a project model that can be referenced by multiple disciplines throughout the A/E/C process. In order to achieve this purpose, continuing effort is needed to evaluate the requirements of each discipline and their needs from PMAPM so that the high level project model with multiple views can be established. Furthermore, investigation of the most appropriate view for each domain and a detailed description of the objects are needed to complete the model. Nevertheless, we believe that we have shown the usefulness of our new concept of an object-oriented project model supporting multiple views for an integrated system. We plan to extend the building element types, the information about each element and the views. Furthermore, we plan to continue to examine the feasibility of using PMAPM as an integration tool for other projects, including IPCM (an Intelligent Project and Construction Manager), a Knowledge-based Constructibility Evaluation System [Fischer 89] and PENGUIN (an object interface with relational database system) [Law 90].

Acknowledgment

This work has been supported in part by the Center for Integrated Facility Engineering of Stanford University. At CIFE, we continue to investigate and develop new theory and system for the integration of facility engineering and management.

References

[Barsalou 88] T. Barsalou, "An Object-Based Architecture for Biomedical Expert Database Systems," *The Twelfth Symposium on Computer Applications in Medical Care*, IEEE Computer Society, PP. 572-578, 1988.

[Cherneff 88] J. Cherneff, "Automatic Generation of Construction Schedules from Architectural Drawing," *unpublished S.M. Dissertation*, Department of Civil Engineering, M.I.T., 1988.

[Darwiche 88] A. Darwiche, R. Levitt and B. Hayes-Roth, "OARPLAN: Generating Project Plans by Reasoning about Objects, Actions and Resources," *The Journal of Artificial Intelligence in Engineering Design*, Analysis and Manufacturing, 2(3), pp. 169-181, 1988.

[Eastman 78] C.M. Eastman, "The Representation of Design Problems and Maintenance of Their Structure," in *Artificial Intelligence and Pattern Recognition in CAD*, Latombe, ed. North-Holland Publishing Company, 1978.

[Eastman 90] C. Eastman, A. Bond and S. Chase, "A Formal Approach for Product Model Information," Technical Report, University of California, Los Angeles, October, 1989.

[Fenves 89] S. Fenves, U Flemming, C Hendrickson, M Maher and G. Schmitt, "A Prototype Environment for Integrated Design and Construction Planning of Building," *CIFE Symposium Proceedings*, Stanford University, March 1989.

[Fischer 89] M. Fischer and B. Tatum, "Partially Automating the Design-Construction Interface: Constructibility Design Rules for Reinforced Concrete Structures," 6th International Symposium on Automation and Robotics in Construction, pp.127-132, San Francisco, California, June 1989.

Howard 89] C. Howard, R. Levitt, B. Paulson, J. Pohl and B. Tatum, "Computer Integration: Reducing Fragmentation in the AEC Industry," *ASCE Journal of Computing in Civil Engineering*, Vol. 3, No. 1, pp. 18-32, January 1989.

[Ito 89] K. Ito, Y. Ueno, R. Levitt and A. Darwiche, "Linking Knowledge-Based Systems to CAD Design Data with an Object-Oriented Building Product Model," *CIFE Technical Report*, No. 17, Stanford University, August 1989.

[Ito 90] K. Ito and Y. Ueno, "An Object-Oriented Building Model for A/E/C Process," *6th Symposium on Organization and Management of Building Construction*, AIJ, Tokyo Japan, July 1990 (written in Japanese).

[Garrett 89] J.H. Garrett, Jr., J. Baster, J. Breslin and T. Anderson, "An Object-Oriented Model for Building Design and Construction," in *Computer Utilization in Structural Engineering,* ASCE Structures Congress, 1989.

[Kartam 89] N. Kartam and R. Levitt, "Intelligent Planning of Construction Projects with Repeated Cycles of Operation," *ASCE Journal of Computing in Civil Engineering, Special Issue: Knowledge-Based Approaches to Planning and Design*, Fall 1989.

[Kartam 90] N. Kartam, R. Levitt and D. Wilkins, "A Centralized Approach for Representing and Resolving Interactions Among Multi-Agent Tasks While Planning Hierarchically," *The Sixth Conference on Artificial Intelligence Applications*, IEEE, pp. 250-256, Santa Barbara, California, March 1990.

[Lavakare 89] A. Lavakare and C. Howard, "Structural Steel Framing Data Model," *CIFE Technical Report,* No. 12, Stanford University, June 1989.

[Law 86] K. Law and M. Jouaneh, "Data Modeling for Building Design," *Fourth Conference on Computing in Civil Engineering*, ASCE, pp. 21-36, 1986.

[Law 87] K.H. Law, M. Jouaneh and D.L. Spooner, "Abstraction Database Concept for Engineering Modeling," *Engineering with Computers*, 2:79-94, 1987.

[Law 90] K. Law, T. Barsalou and G. Wiederhold, "Managing of Complex Structural Engineering Objects in a Relational Framework," *Engineering with Computers (to appear).*

[Logcher 89] R. Logcher, "Better AEC Products: Directions Research at M.I.T.," *CIFE Symposium Proceedings*, Stanford University, March 1989

[Nyberg 88] E. Nyberg, "The FrameKit User's Guide Version 2.0," *CMU-CMT-MEMO*, Carnegie-Mellon University, March 1988.

[Penttila 89] H. Penttila, "A Scenario for The Development and Implementation of A Building Produce Model Standard," *CIFE Symposium Proceedings*, Stanford University, March 1989.

[Sanvido 89] V.E. Sanvido, S. Kumara and I. Ham, "A Top-Down Approach to Integrating the Building Process," *Engineering with Computers,* 5:91-103, 1989.

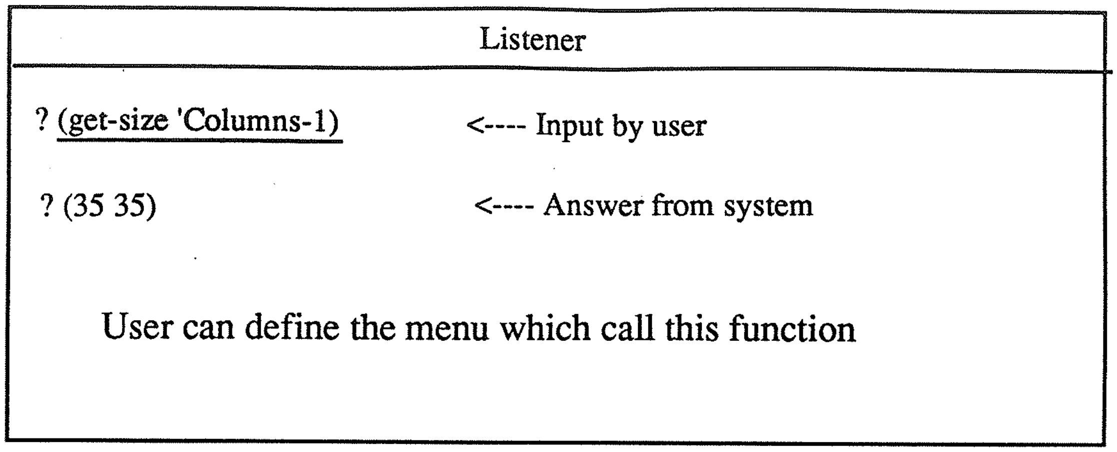
[Sause 90] R. Sause and G.H. Powell, "A Design Process Model for Computer Integrated Structural Engineering," *Engineering with Computers,* 1990.

[Shell 88] P. Shell and J. Carbonell, "FRULEKIT: A FRAME-BASED PRODUCTION SYSTEM," *User's Manual*, Carnegie Mellon University, December 1988.

[Shell 89] P. Shell and J. Carbonell, "PARMENIDES: A CLASS-BASED FRAME SYSTEM," *User's Manual Version 1.4*, Carnegie Mellon University, March 1989.

[Sriram 89] D. Sriram, D. Logcher, N. Groleau and J. Cherneff, "DICE: An Object Oriented Programming Environment for Cooperative Engineering Design," *IESL Technical Report No. IESL-89-03*, Department of Civil Engineering, Massachusetts Institute of Technology, April 1989.

[Warthen 88] B. Warthen, "PDES: A CAD Standard For Data Exchange," *Unix World*, December 1988.



Listener

```
? (get-size 'Columns-1)        <---- Input by user

? (35 35)                      <---- Answer from system
```

User can define the menu which call this function

Figure-3.1.1 Example of the Slot Access Function

$$\begin{tikzcd}
\text{Room1} \arrow[r] \arrow[dr] \arrow[ddr] \arrow[dddr] & \text{Ewalls-1} \\
 & \text{Ewalls-2} \\
 & \text{Iwalls-1} \\
 & \text{Iwalls-2}
\end{tikzcd}$$

In this network $\longrightarrow$ means "contains"

Figure-3.1.2a Relationship between Space and Wall

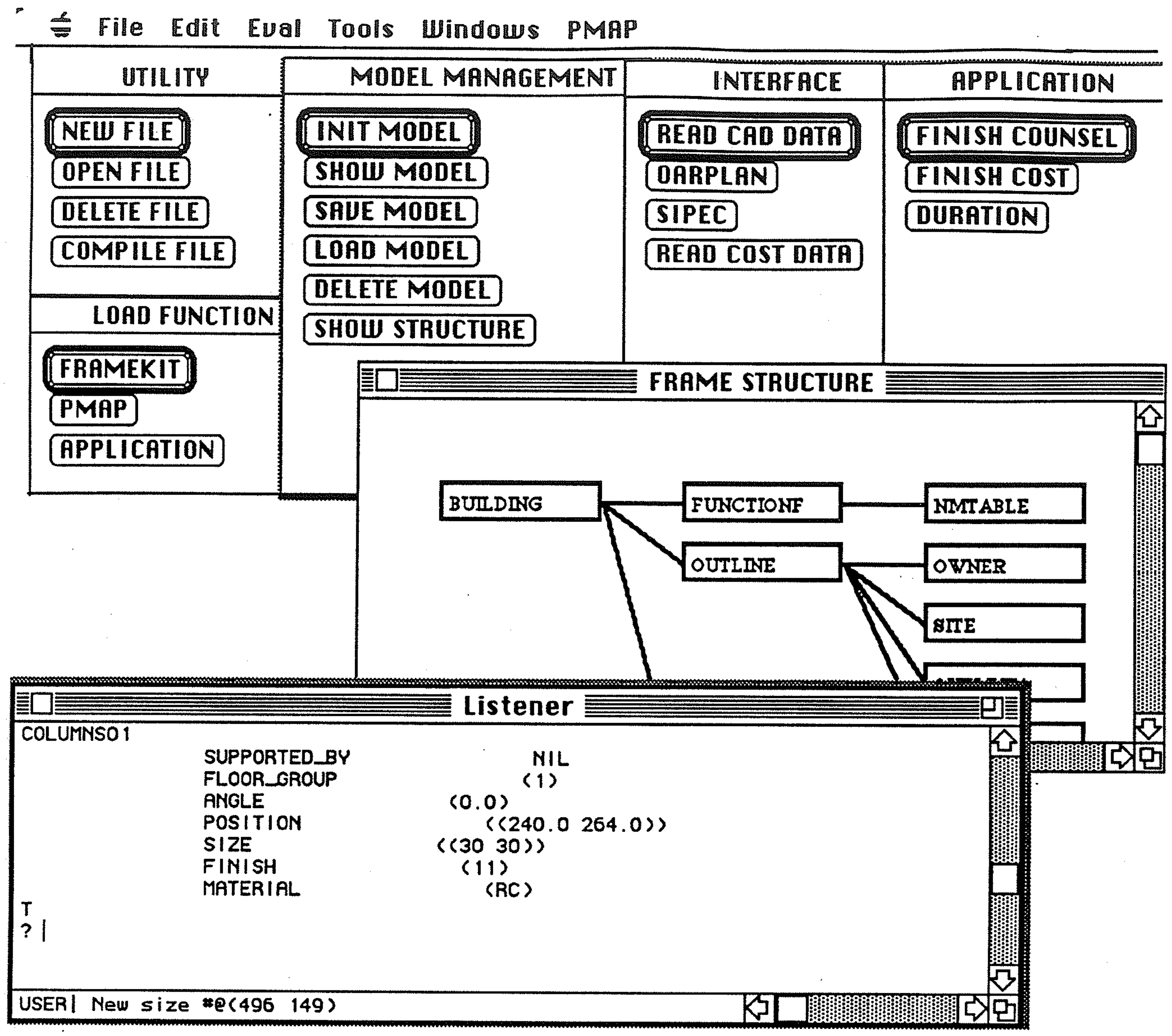
$$\begin{tikzcd}
\text{Ewalls-1} \arrow[r] & \text{Windows-1}
\end{tikzcd}$$

Figure-3.1.2b Relationship between Wall and Opening

$$\begin{tikzcd}
\text{Room1} \arrow[r] \arrow[dr] \arrow[ddr] \arrow[dddr] & \text{Ewalls-1} \arrow[r] & \text{Windows-1} \\
 & \text{Ewalls-2} \arrow[r] & \text{Doors-1} \\
 & \text{Iwalls-1} & \\
 & \text{Iwalls-2} \arrow[r] & \text{Doors-2}
\end{tikzcd}$$

Figure-3.1.2c Relationship among Space, Wall and Opening

Figure-3.1.2 Example of the relationship.



```
COLUMNS01
                SUPPORTED_BY              NIL
                FLOOR_GROUP             (1)
                ANGLE             (0.0)
                POSITION              ((240.0 264.0))
                SIZE             ((30 30))
                FINISH             (11)
                MATERIAL              (RC)
T
? |
USER| New size #@(496 149)
```

Figure-3.1.3 Example of the Graphic Interface

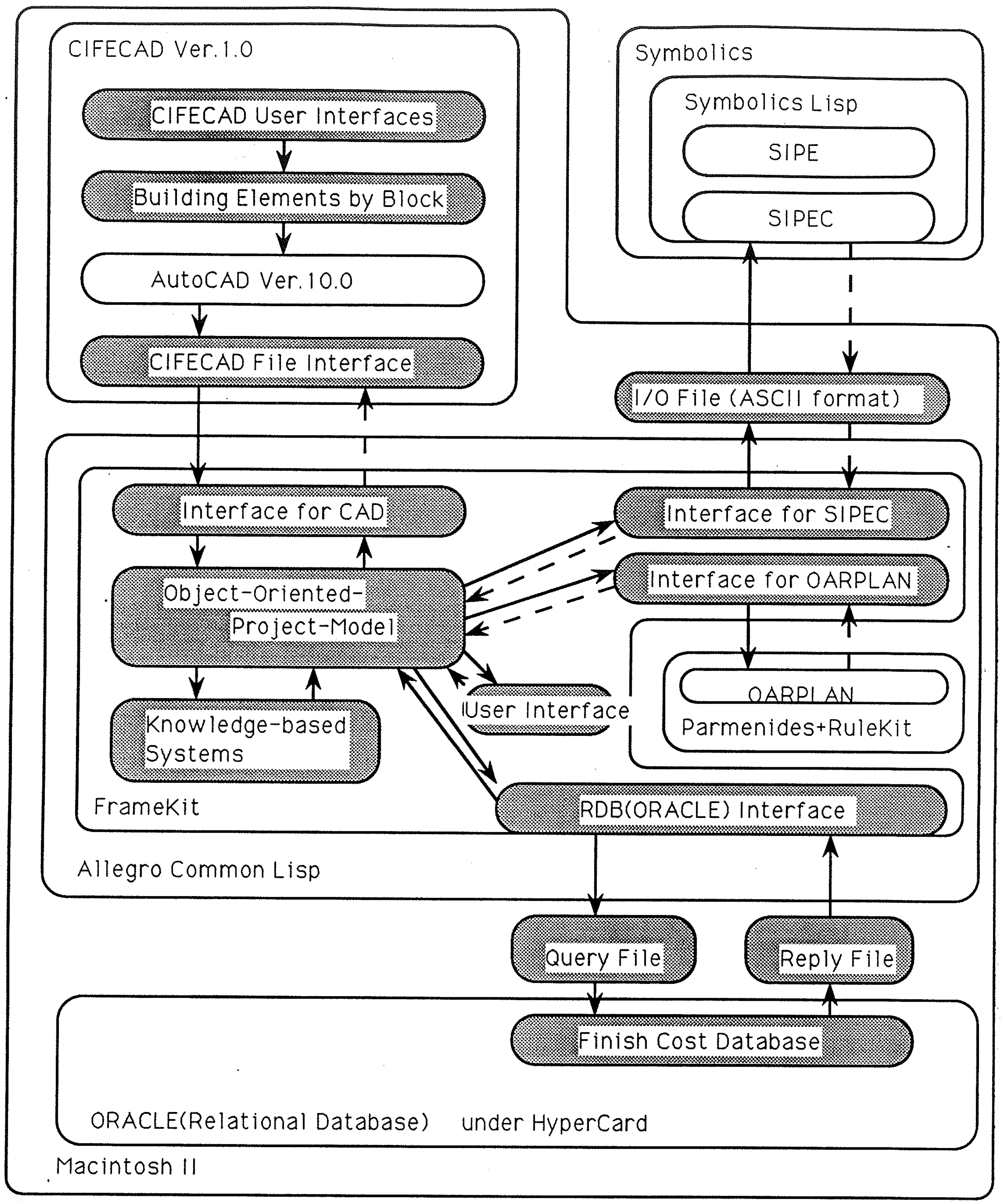


Figure-3.1.4 System Integration using PMAP

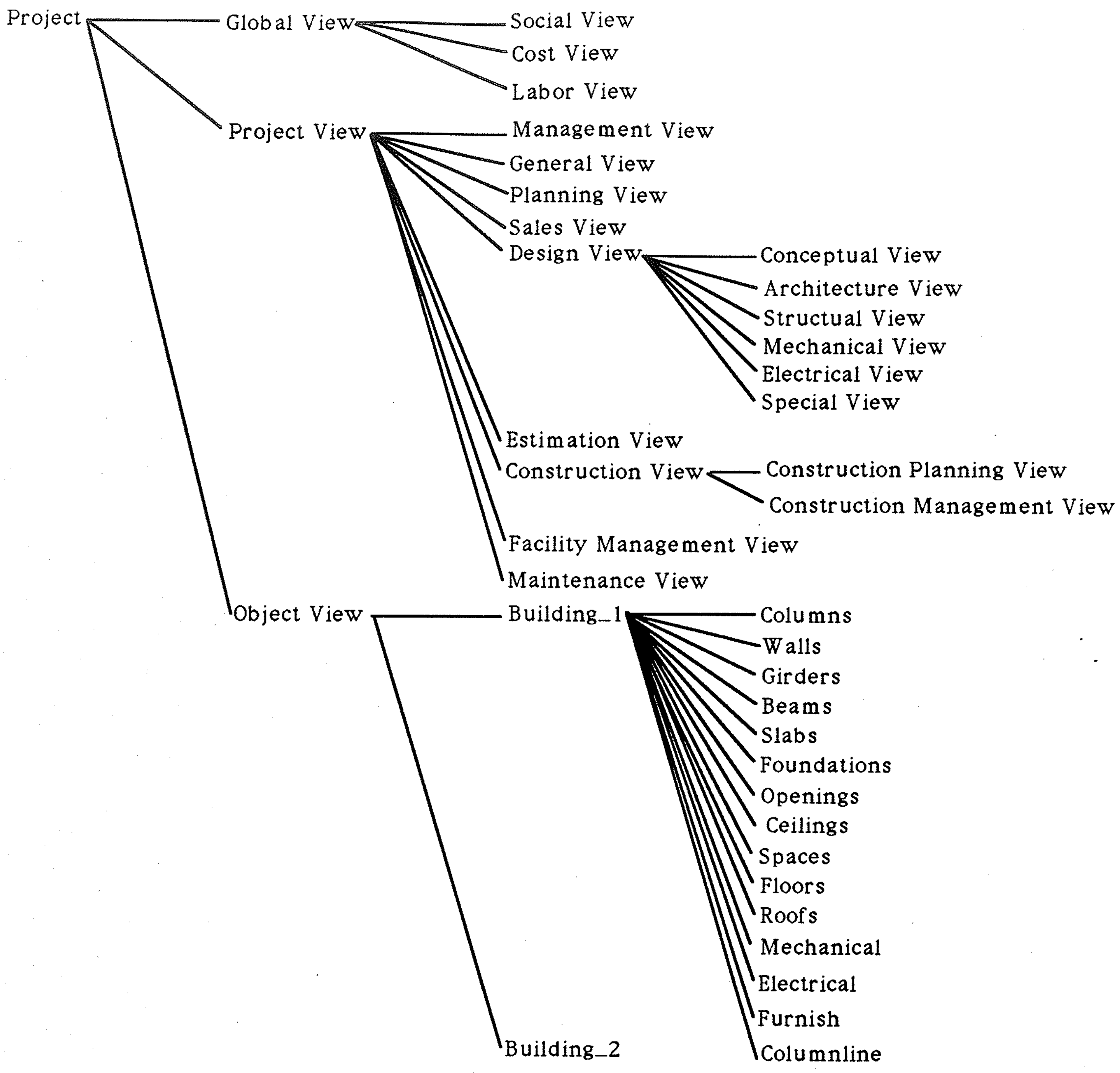


Figure-3.2.1 High Level View Hierarchy in PMAPM

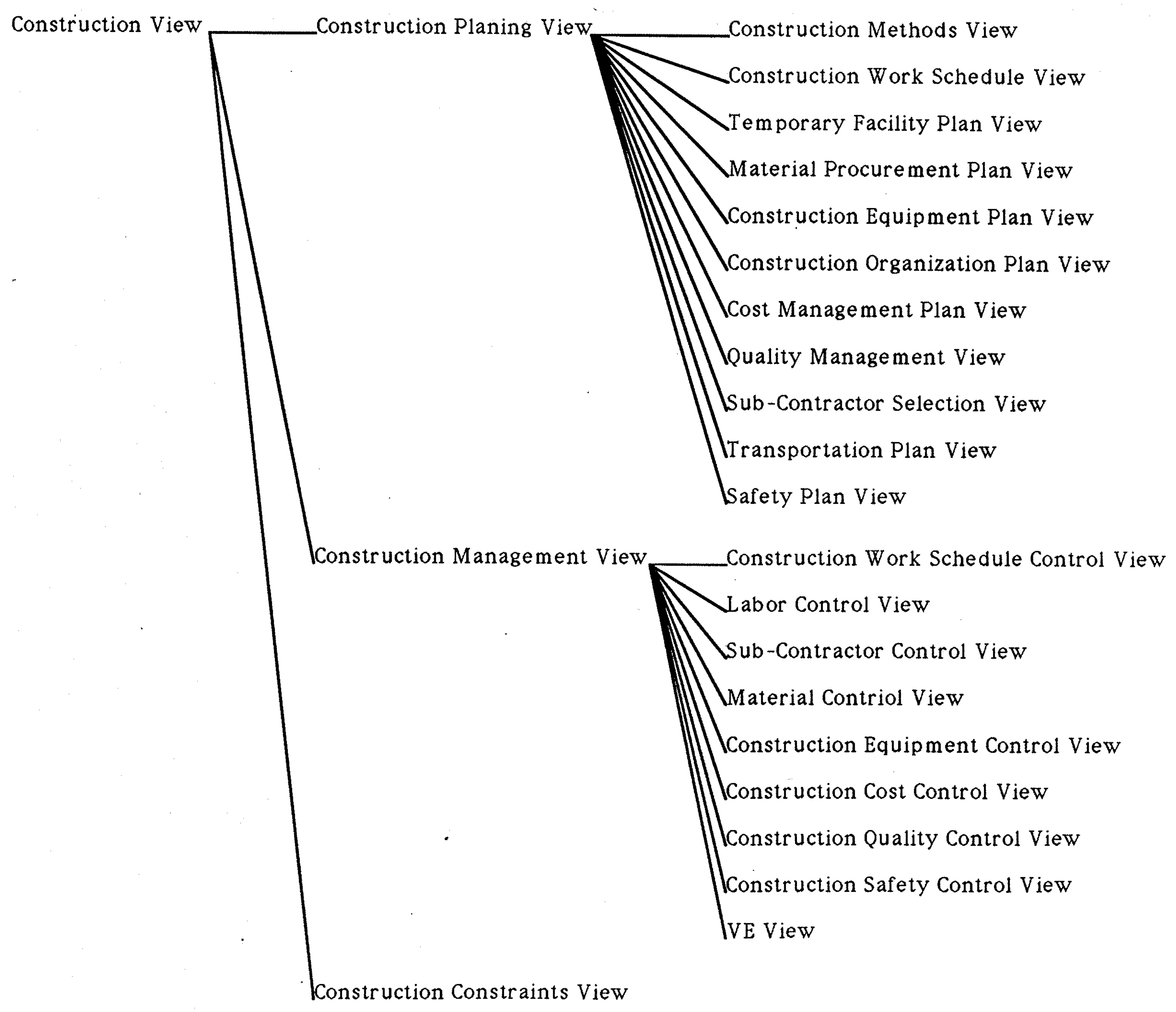
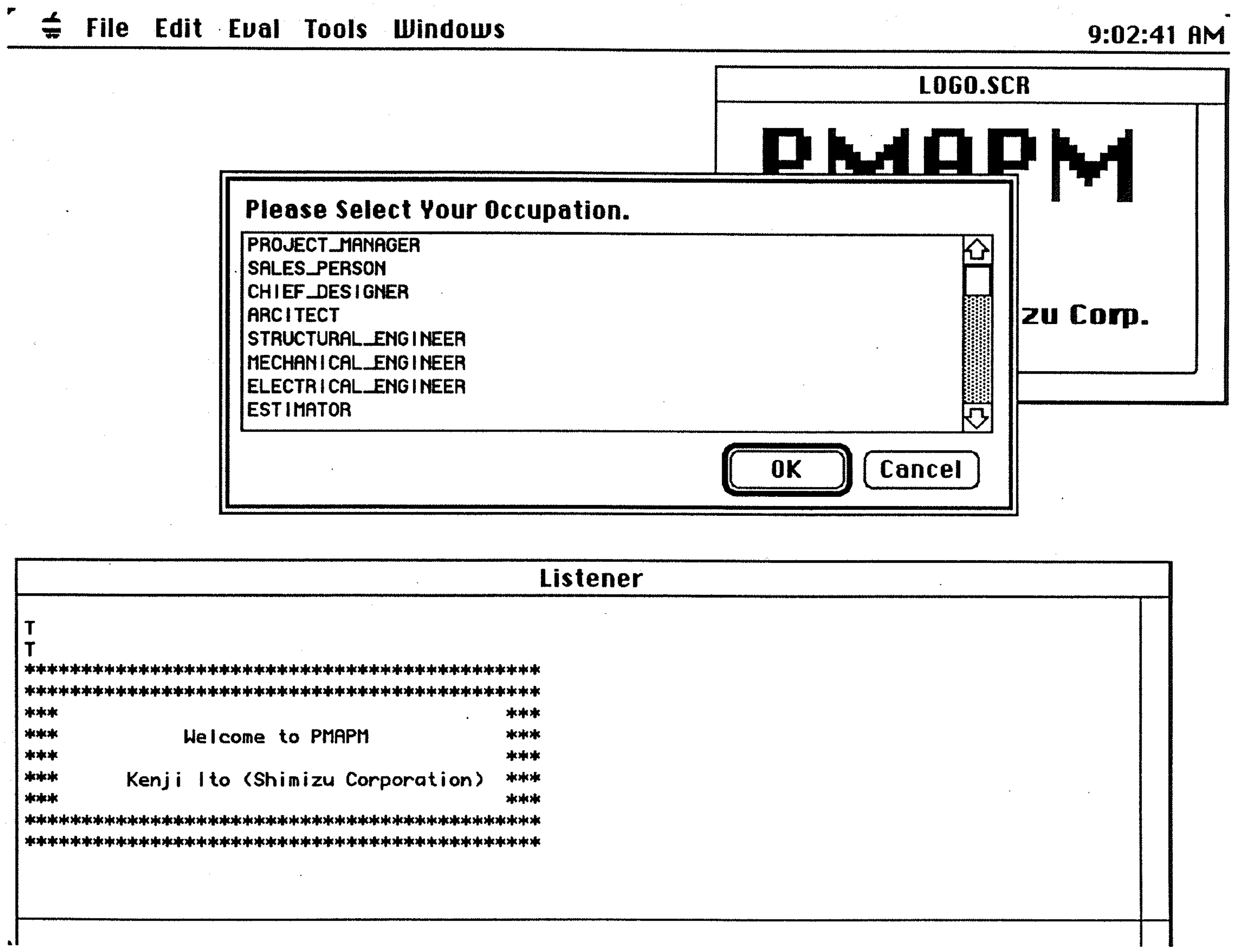

Construction View
Construction Planing View
Construction Methods View
Construction Work Schedule View
Temporary Facility Plan View
Material Procurement Plan View
Construction Equipment Plan View
Construction Organization Plan View
Cost Management Plan View
Quality Management View
Sub-Contractor Selection View
Transportation Plan View
Safety Plan View
Construction Management View
Construction Work Schedule Control View
Labor Control View
Sub-Contractor Control View
Material Contriol View
Construction Equipment Control View
Construction Cost Control View
Construction Quality Control View
Construction Safety Control View
VE View
Construction Constraints View

Figure-3.2.2 Example of Subviews



Please Select Your Occupation.

```
PROJECT_MANAGER
SALES_PERSON
CHIEF_DESIGNER
ARCITECT
STRUCTURAL_ENGINEER
MECHANICAL_ENGINEER
ELECTRICAL_ENGINEER
ESTIMATOR
```

```
T
T
*********************************************
*********************************************
***                                       ***
***          Welcome to PMAPM             ***
***                                       ***
***     Kenji Ito (Shimizu Corporation)   ***
***                                       ***
*********************************************
*********************************************
```

Figure-3.2.3 Occupation Definition in PMAPM

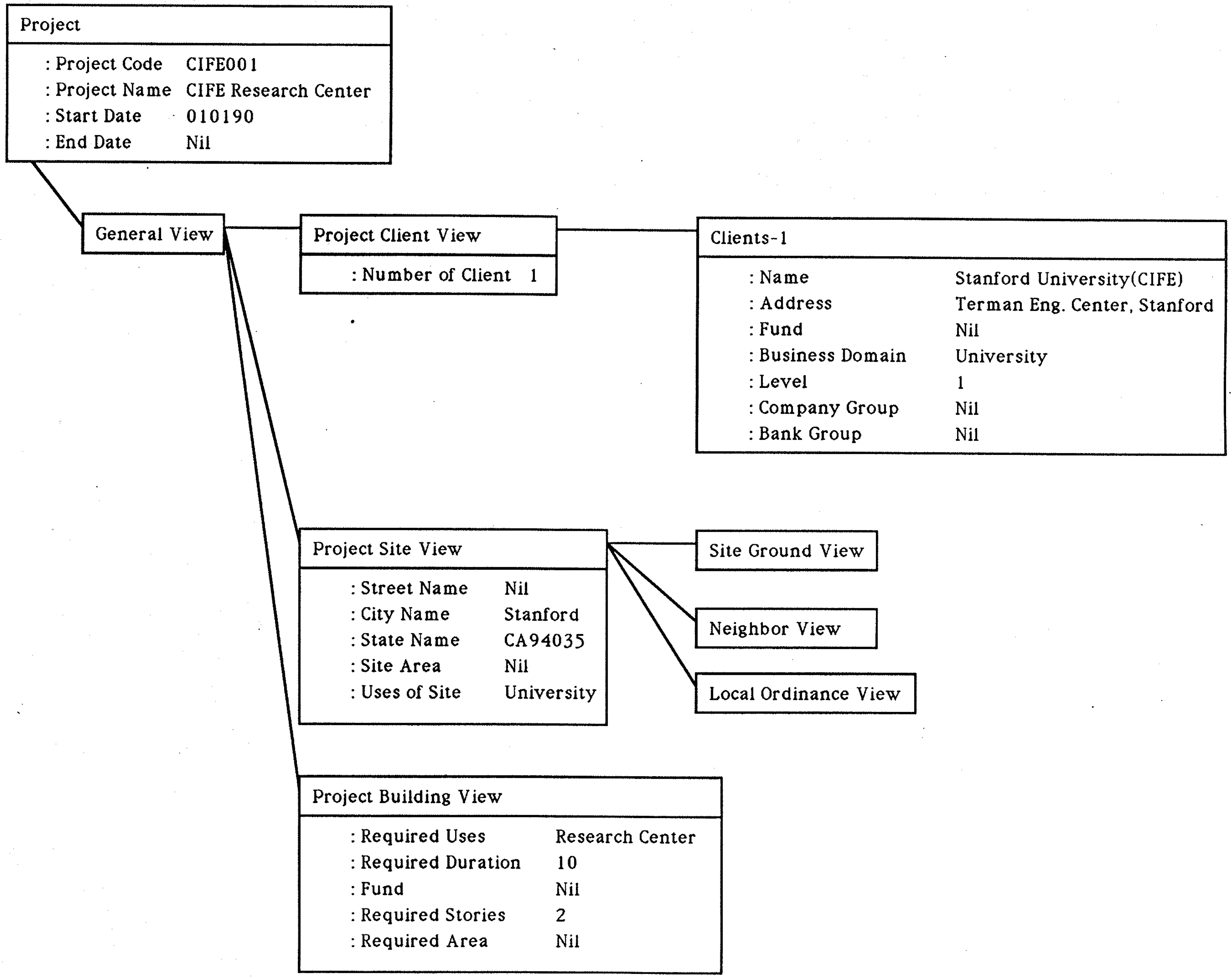


Figure-3.3.1 Initial Data stored into the General View

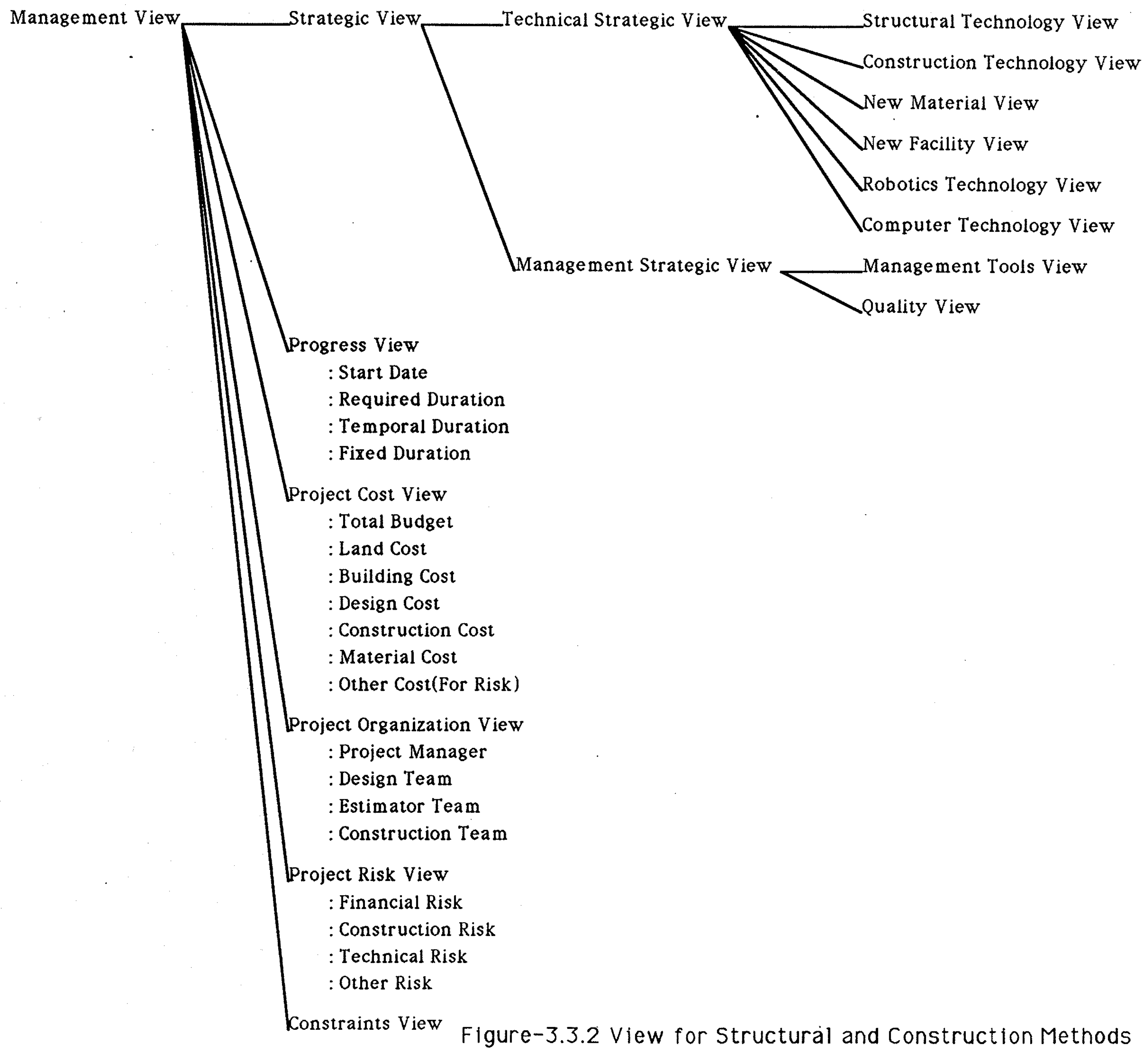


Figure-3.3.2 View for Structural and Construction Methods

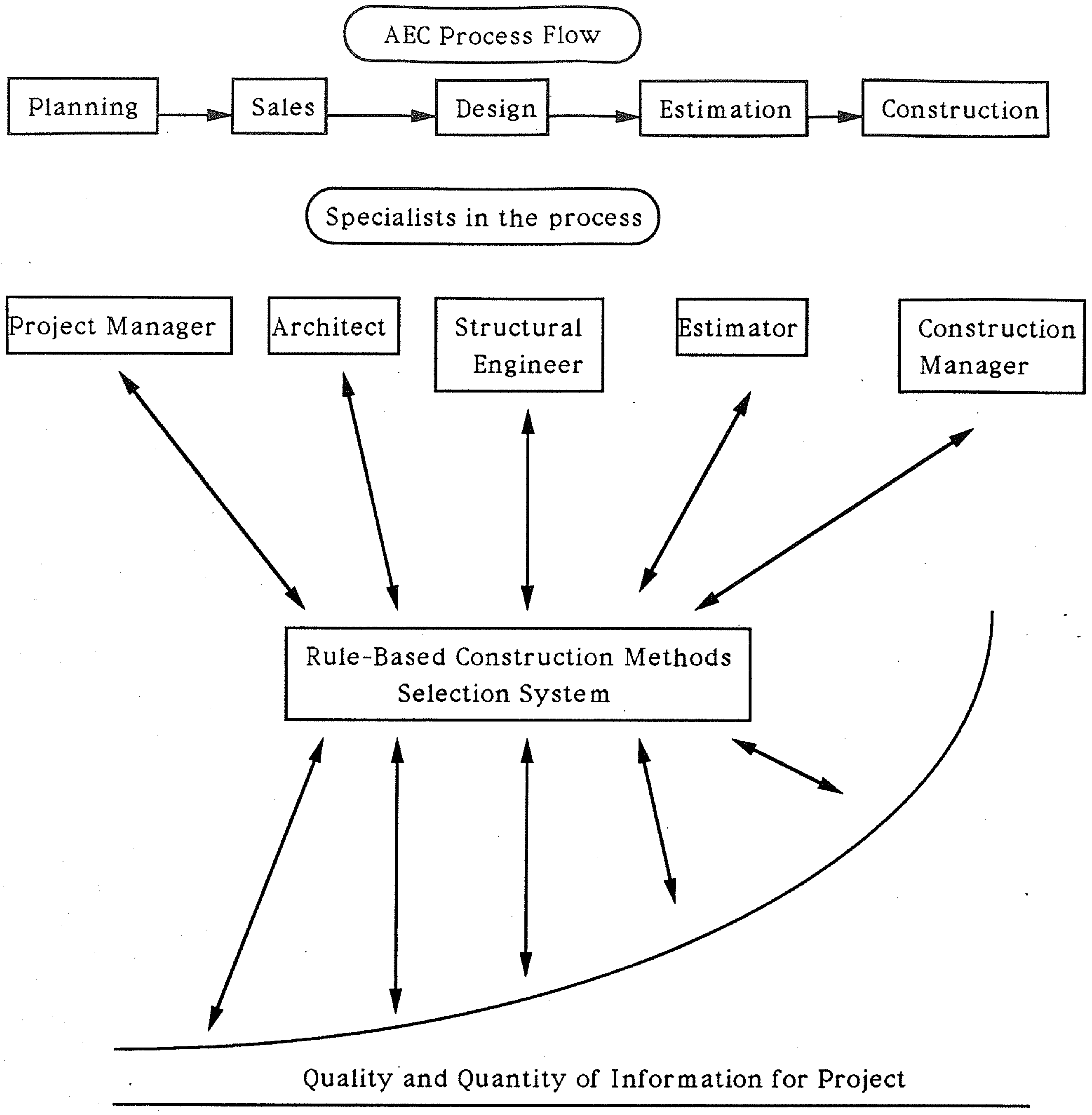


Figure-3.3.3 Example of Sharing the Function

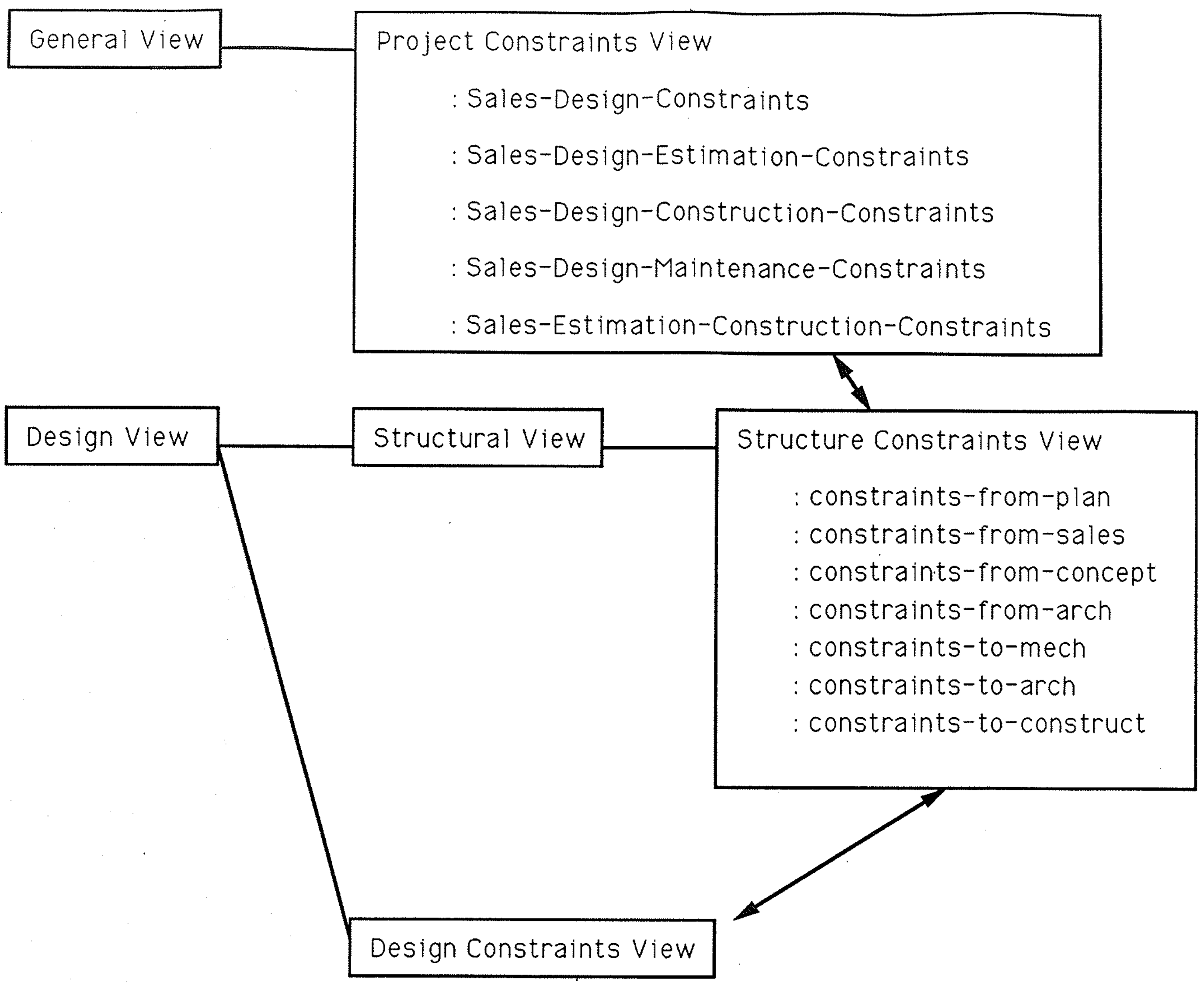

General View
Project Constraints View
: Sales-Design-Constraints
: Sales-Design-Estimation-Constraints
: Sales-Design-Construction-Constraints
: Sales-Design-Maintenance-Constraints
: Sales-Estimation-Construction-Constraints
Design View
Structural View
Structure Constraints View
: constraints-from-plan
: constraints-from-sales
: constraints-from-concept
: constraints-from-arch
: constraints-to-mech
: constraints-to-arch
: constraints-to-construct
Design Constraints View

Figure-3.3.4 Example of the constraints propagation.
Each slot of Structural-Constraints-View has method which access to the upper level constraints-view.

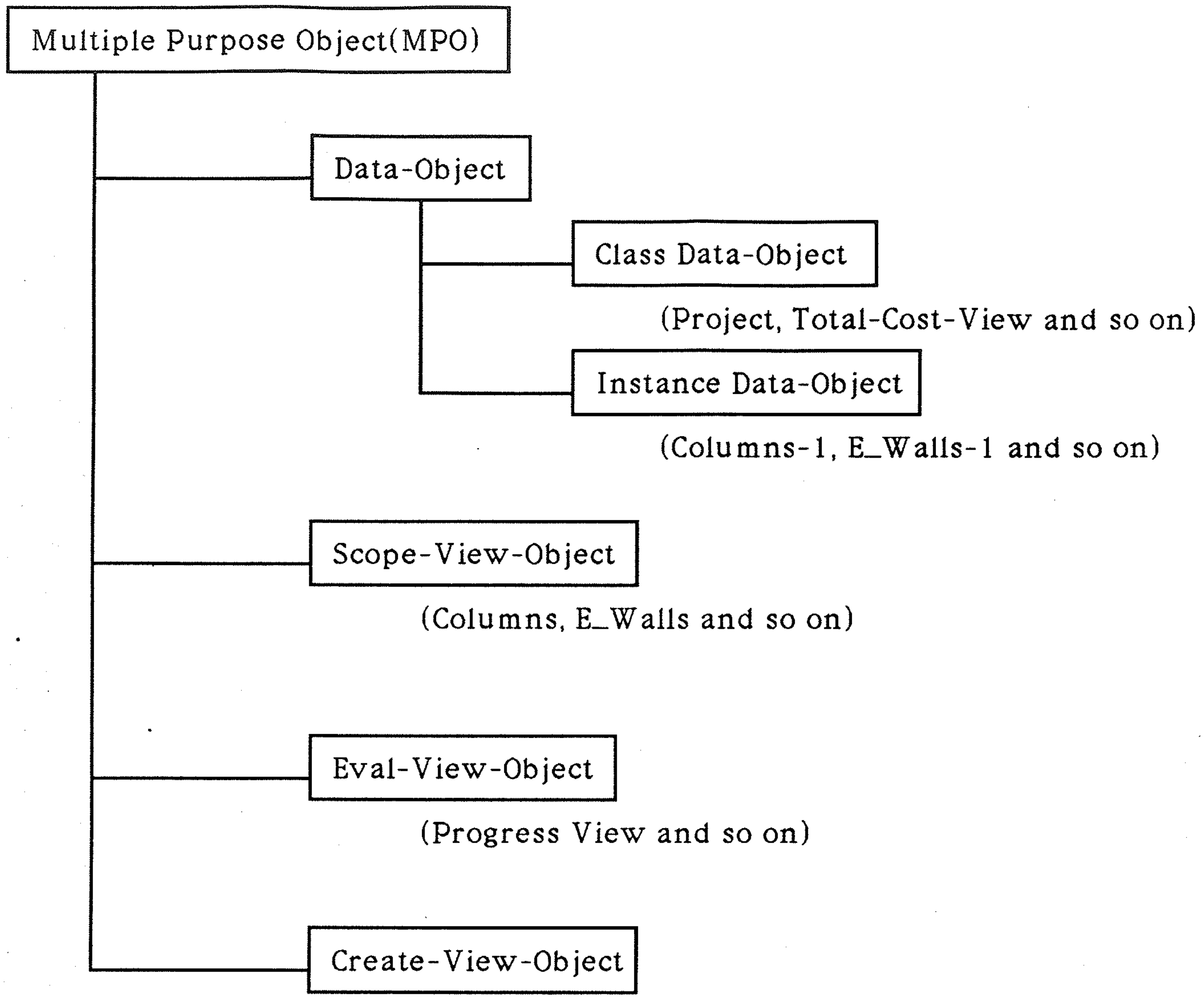

Multiple Purpose Object(MPO)
Data-Object
Class Data-Object
(Project, Total-Cost-View and so on)
Instance Data-Object
(Columns-1, E_Walls-1 and so on)
Scope-View-Object
(Columns, E_Walls and so on)
Eval-View-Object
(Progress View and so on)
Create-View-Object

Figure-3.4.1 MPO Hierarchy and Example of Object.

CIFECAD has the following information :

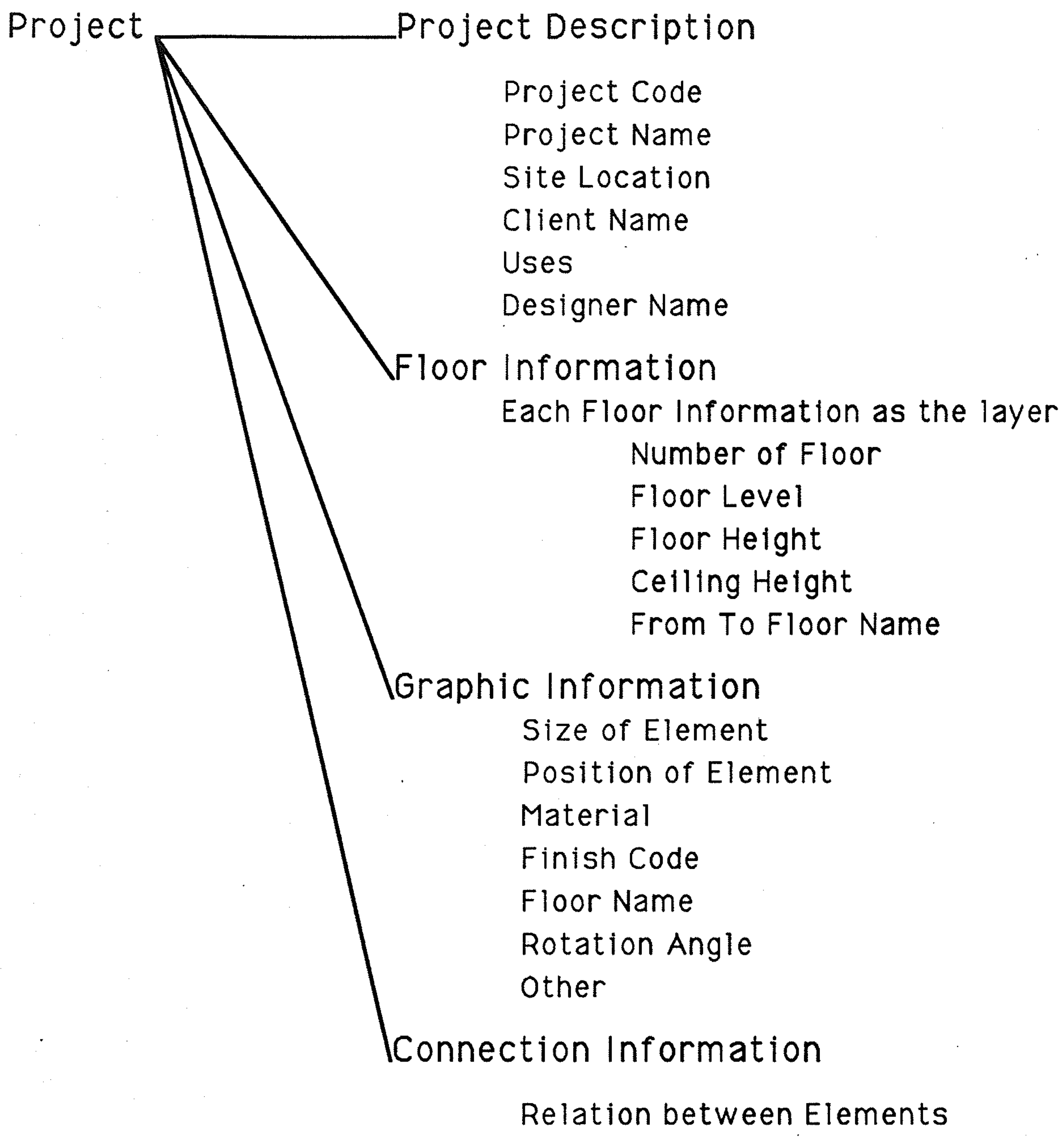


Figure-4.1.1 CIFECAD Data Hierarchy

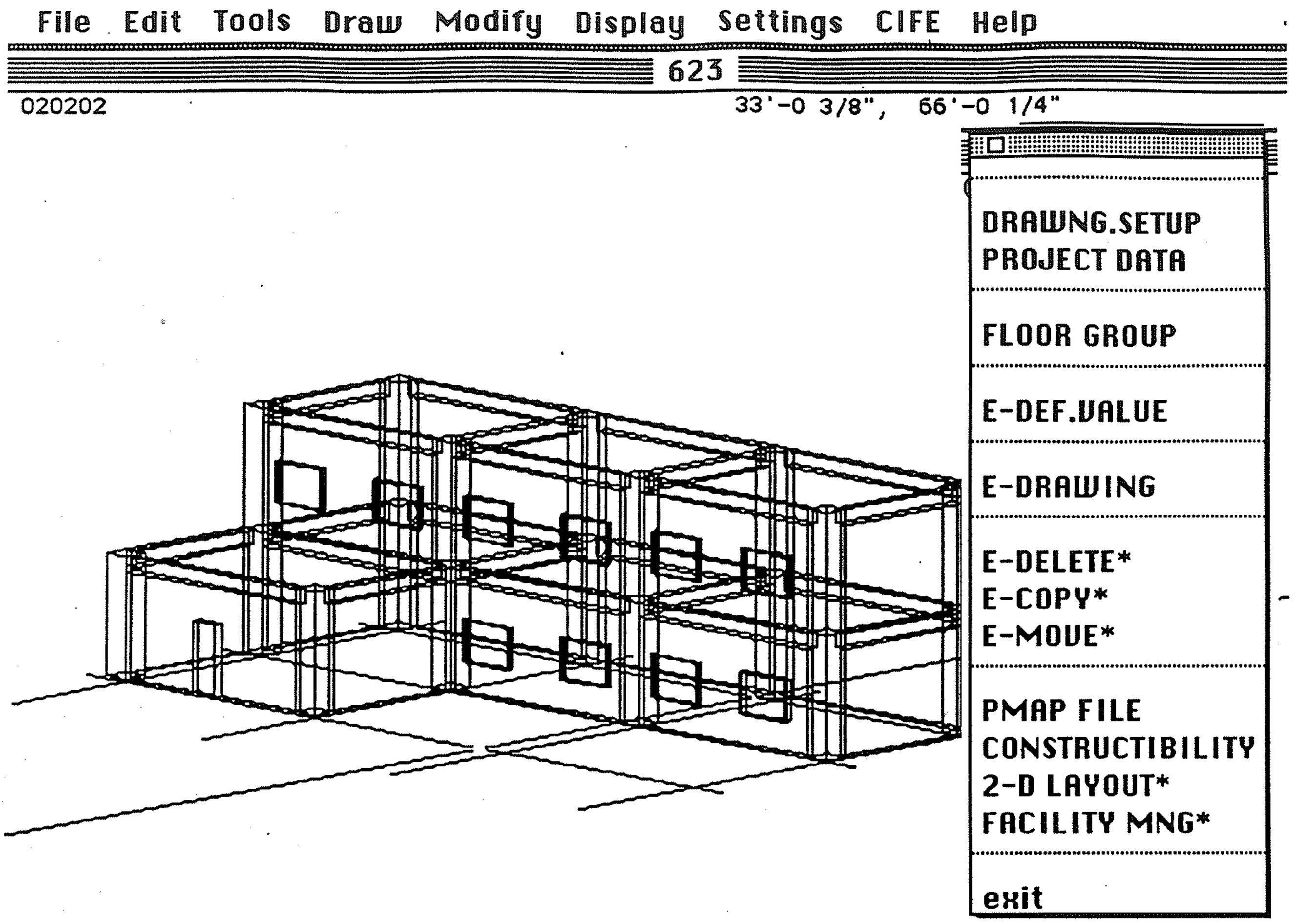


Figure-4.1.2 CIFECAD Interface

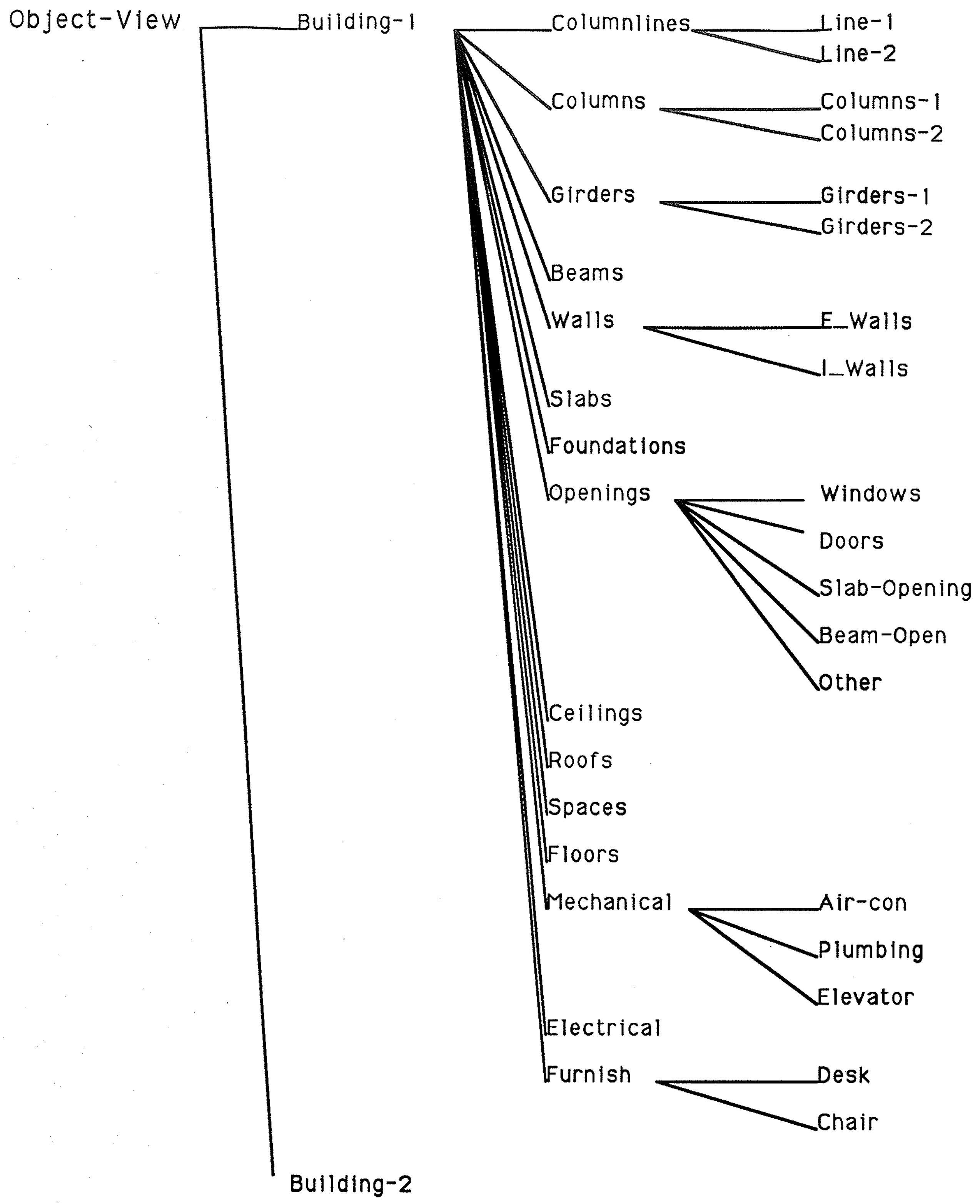


Figure-4.1.3 Object Hierarchy under Object-View

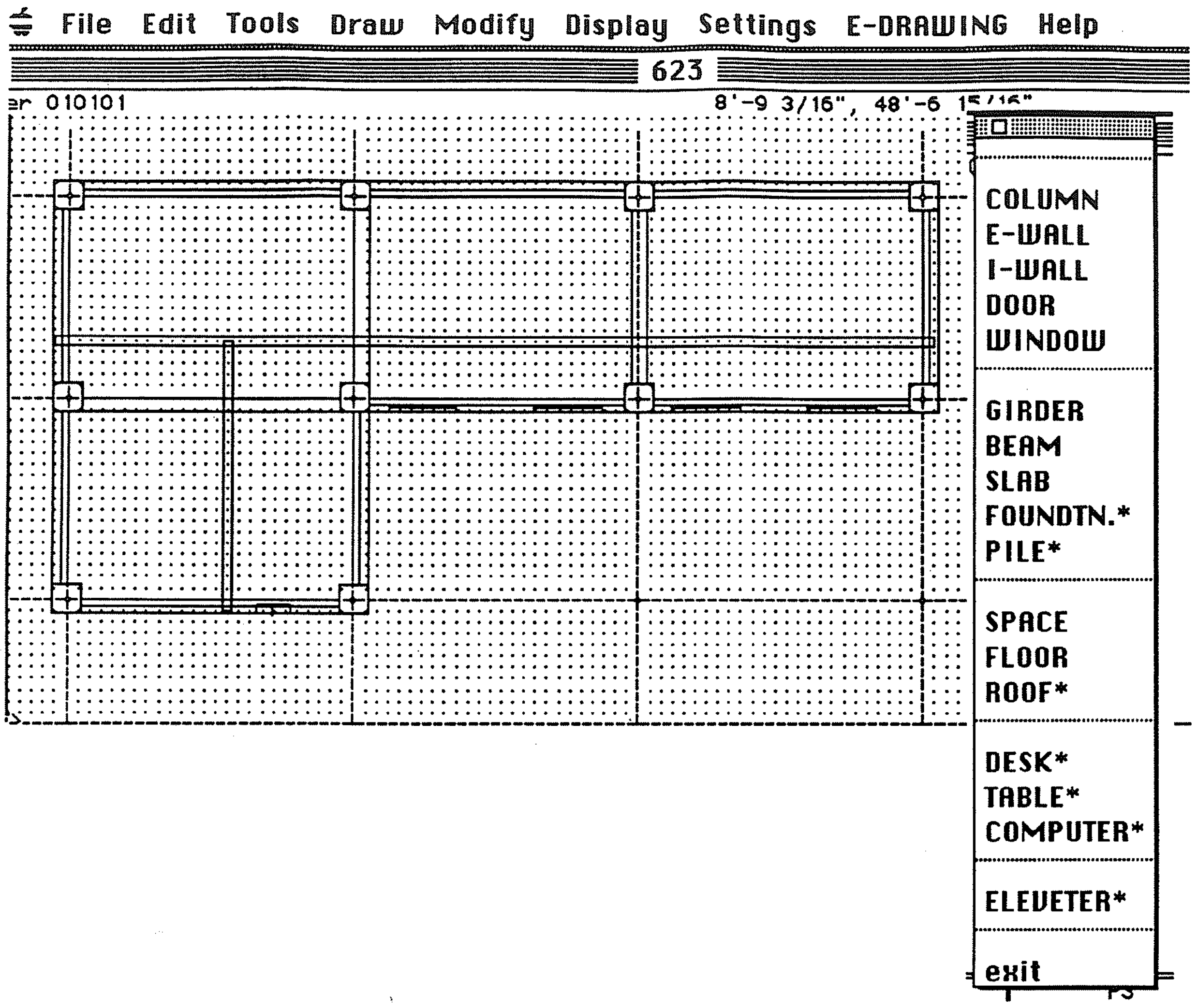
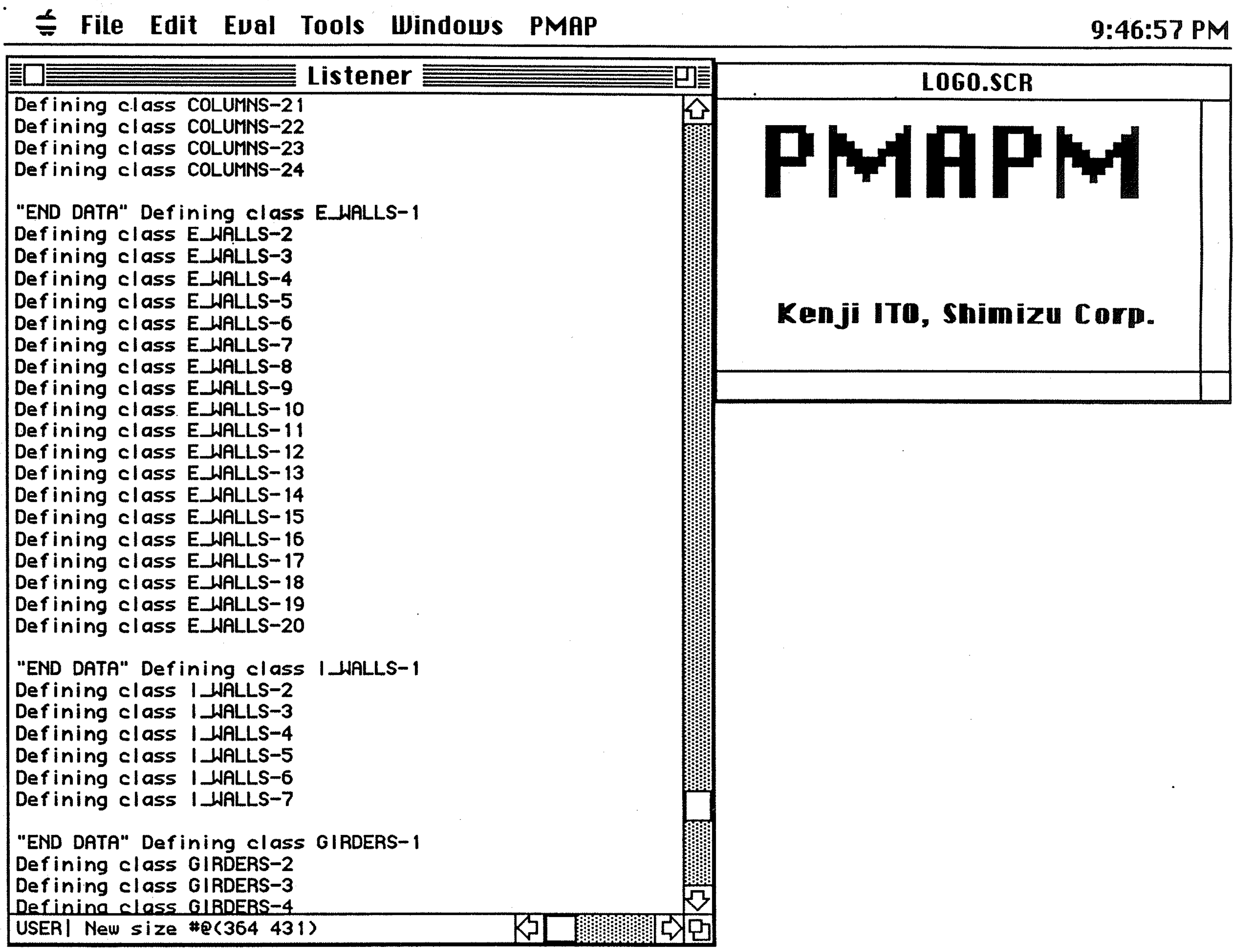


Figure-4.1.4 Drawing Example using CIFECAD



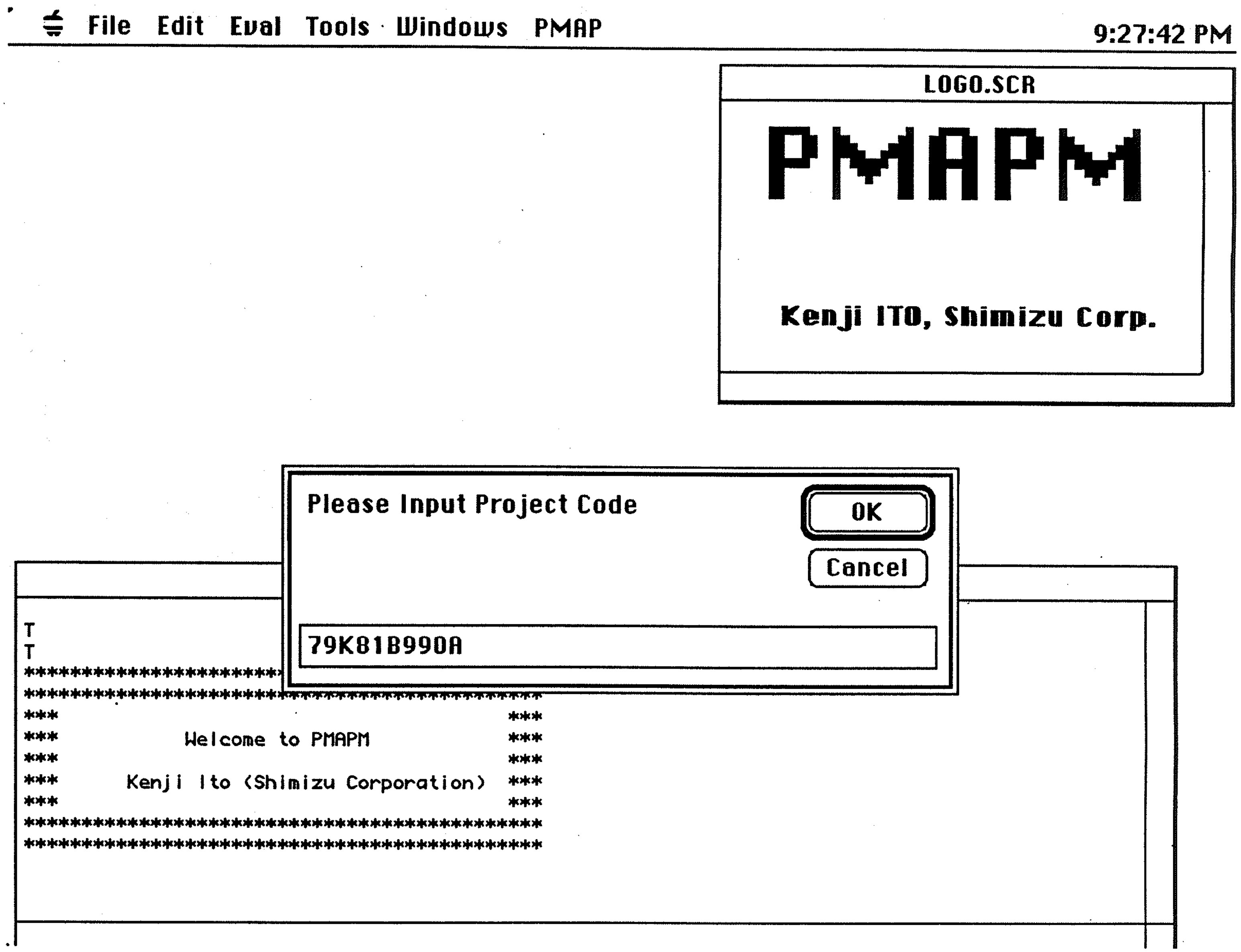
```
Defining class COLUMNS-21
Defining class COLUMNS-22
Defining class COLUMNS-23
Defining class COLUMNS-24

"END DATA" Defining class E_WALLS-1
Defining class E_WALLS-2
Defining class E_WALLS-3
Defining class E_WALLS-4
Defining class E_WALLS-5
Defining class E_WALLS-6
Defining class E_WALLS-7
Defining class E_WALLS-8
Defining class E_WALLS-9
Defining class E_WALLS-10
Defining class E_WALLS-11
Defining class E_WALLS-12
Defining class E_WALLS-13
Defining class E_WALLS-14
Defining class E_WALLS-15
Defining class E_WALLS-16
Defining class E_WALLS-17
Defining class E_WALLS-18
Defining class E_WALLS-19
Defining class E_WALLS-20

"END DATA" Defining class I_WALLS-1
Defining class I_WALLS-2
Defining class I_WALLS-3
Defining class I_WALLS-4
Defining class I_WALLS-5
Defining class I_WALLS-6
Defining class I_WALLS-7

"END DATA" Defining class GIRDERS-1
Defining class GIRDERS-2
Defining class GIRDERS-3
Defining class GIRDERS-4
USER| New size #@(364 431)
```

Figure-4.1.5 Object Creation using CAD Data



Please Input Project Code

79K81B990A

```
T
T
*********************************************
*********************************************
***                                       ***
***           Welcome to PMAPM            ***
***                                       ***
***     Kenji Ito (Shimizu Corporation)   ***
***                                       ***
*********************************************
*********************************************
```

Figure-5.1.1 Example of the textual Interface

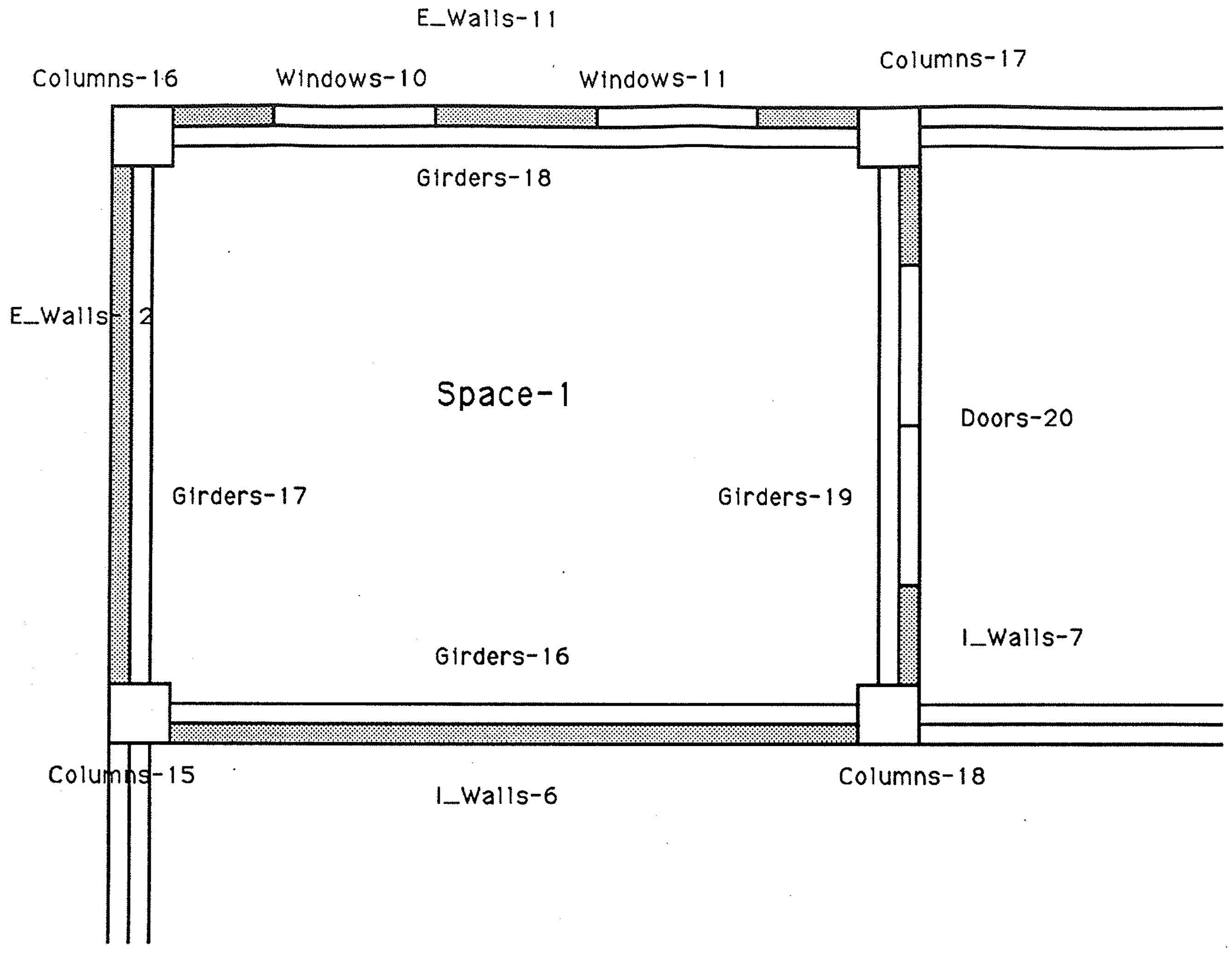


Figure-6.1.1 Shape of the Example Room

General Description of Building

Usage of Building		Office Building
Location		Palo Alto, California
Client		American Research Inc.
Structure	Under Ground	SRC
	Super Structure	RC
	Penthouse	RC
Number of Floor	Under Ground	1
	Super Structure	4
	Penthouse	1
Ground Condition		Good

General Description of Floor

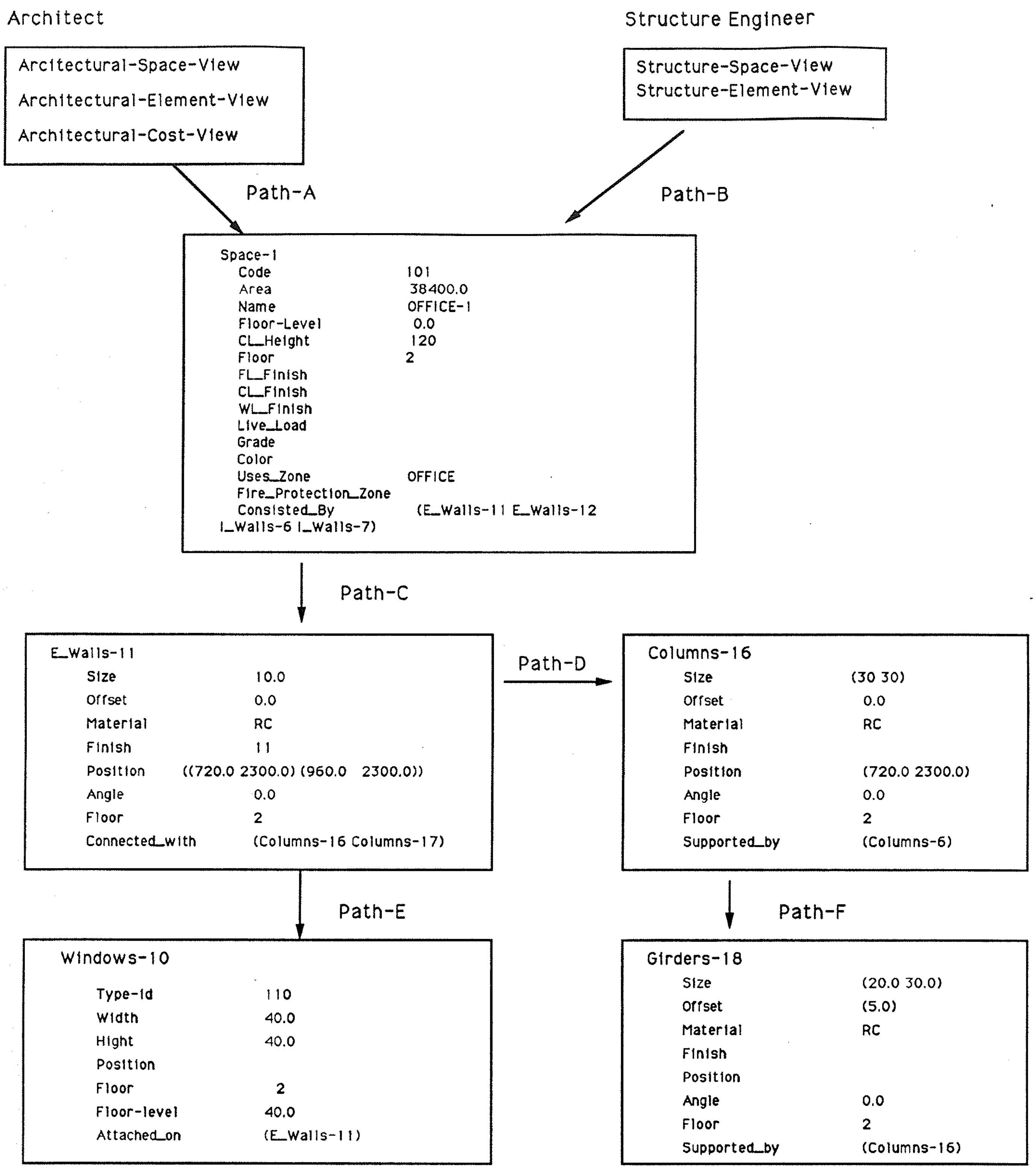
Floor Name	2
Usage of Floor	Office
Area of Floor	1400 square ft.
Structure	RC

General Description of Room

Consists_of	2 Exterior Walls	Material RC, Thickness 10.0
	2 Interior Walls	Material RC, Thickness 8.0
	4 Columns	Material RC, Size 30.0x30.0
	4 Girders	Material RC, Size 20.0x30.0
	1 Slab	Material RC, Thickness 12.0
	2 Windows	Width 40.0, Height 40.0
	1 Door	Width 120.0, Height 80.0

(Unit inch)

Figure-6.1.2 Description of the Example



Space-1

Code	101
Area	38400.0
Name	OFFICE-1
Floor-Level	0.0
CL_Height	120
Floor	2
FL_Finish	
CL_Finish	
WL_Finish	
Live_Load	
Grade	
Color	
Uses_Zone	OFFICE
Fire_Protection_Zone	
Consisted_By	(E_Walls-11 E_Walls-12 I_Walls-6 I_Walls-7)

E_Walls-11

Size	10.0
Offset	0.0
Material	RC
Finish	11
Position	((720.0 2300.0) (960.0 2300.0))
Angle	0.0
Floor	2
Connected_with	(Columns-16 Columns-17)

Columns-16

Size	(30 30)
Offset	0.0
Material	RC
Finish	
Position	(720.0 2300.0)
Angle	0.0
Floor	2
Supported_by	(Columns-6)

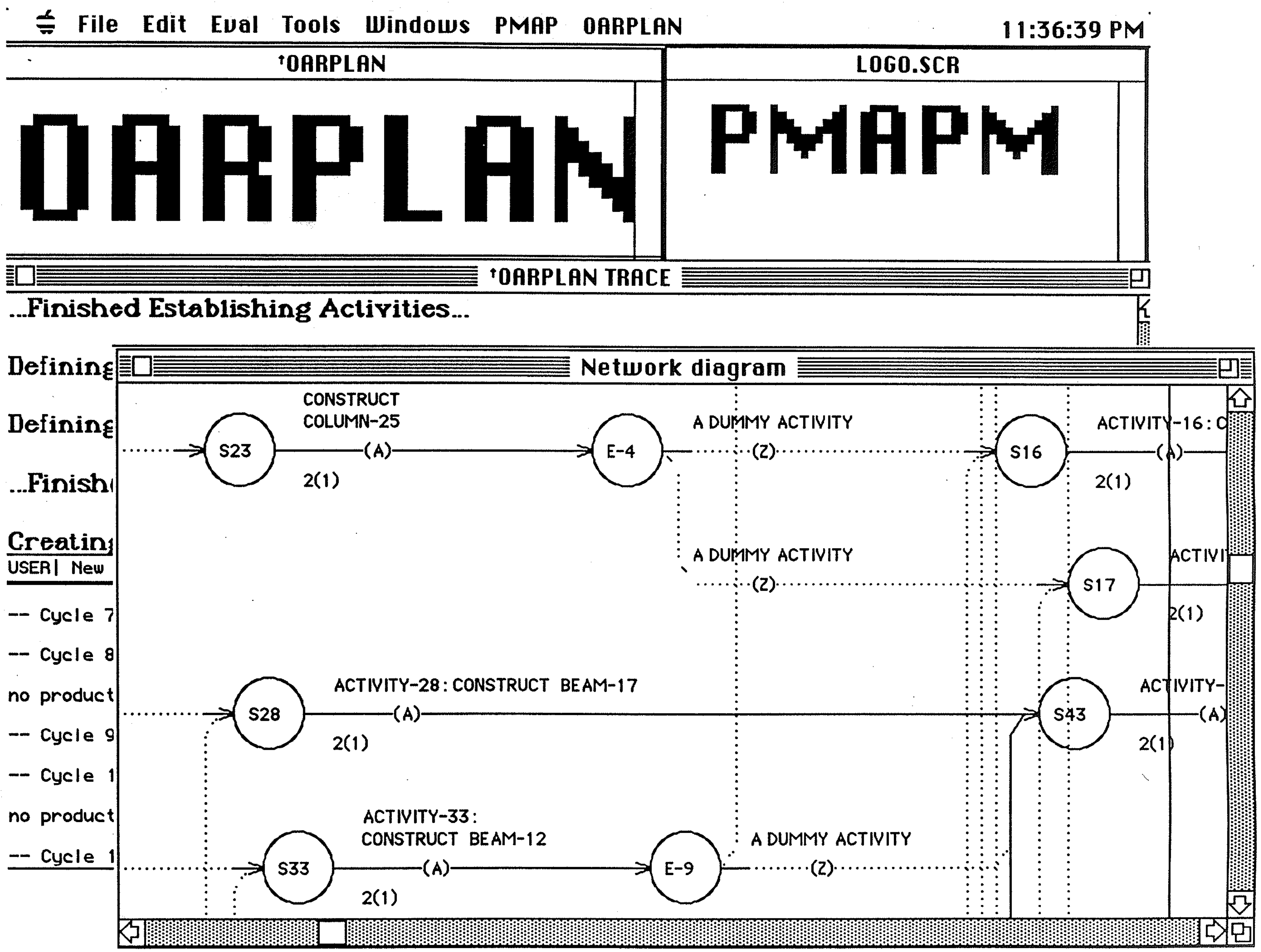
Windows-10

Type-id	110
Width	40.0
Hight	40.0
Position	
Floor	2
Floor-level	40.0
Attached_on	(E_Walls-11)

Girders-18

Size	(20.0 30.0)
Offset	(5.0)
Material	RC
Finish	
Position	
Angle	0.0
Floor	2
Supported_by	(Columns-16)

Figure-6.1.3 Example of the Data Search Path for every View



...Finished Establishing Activities...

Defining

Defining

...Finish

Creatin

USER| New

-- Cycle 7

-- Cycle 8

no product

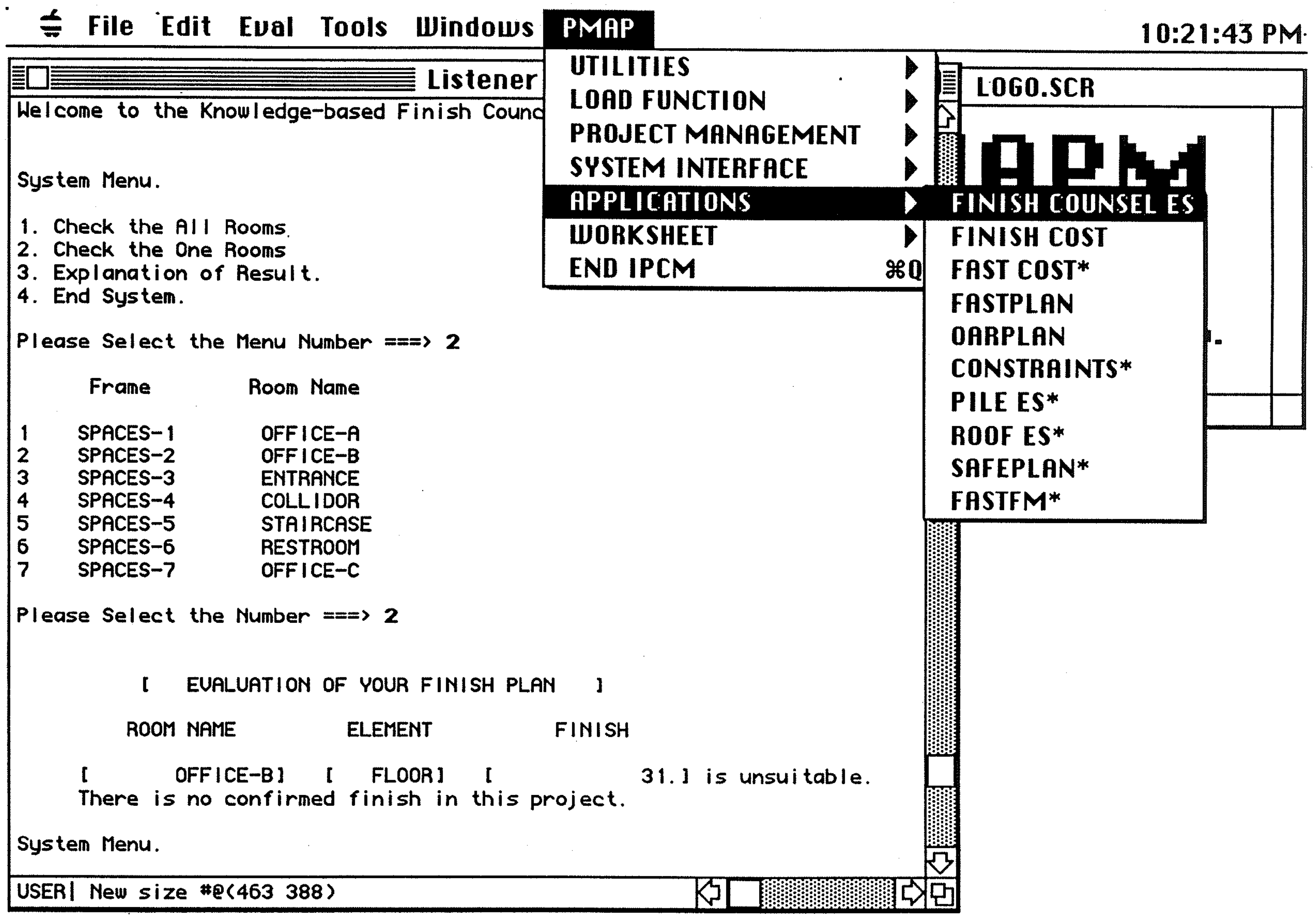
-- Cycle 9

-- Cycle 1

no product

-- Cycle 1

Figure-7.1.1 OARPLAN Operation Screen



```
Welcome to the Knowledge-based Finish Counc


System Menu.

1. Check the All Rooms
2. Check the One Rooms
3. Explanation of Result.
4. End System.

Please Select the Menu Number ===> 2

      Frame          Room Name

1    SPACES-1        OFFICE-A
2    SPACES-2        OFFICE-B
3    SPACES-3        ENTRANCE
4    SPACES-4        COLLIDOR
5    SPACES-5        STAIRCASE
6    SPACES-6        RESTROOM
7    SPACES-7        OFFICE-C

Please Select the Number ===> 2


         [   EVALUATION OF YOUR FINISH PLAN   ]

         ROOM NAME          ELEMENT          FINISH

     [       OFFICE-B]   [   FLOOR]   [            31.] is unsuitable.
     There is no confirmed finish in this project.

System Menu.
USER| New size #@(463 388)
```

Figure-7.1.2 Example of FINISHES

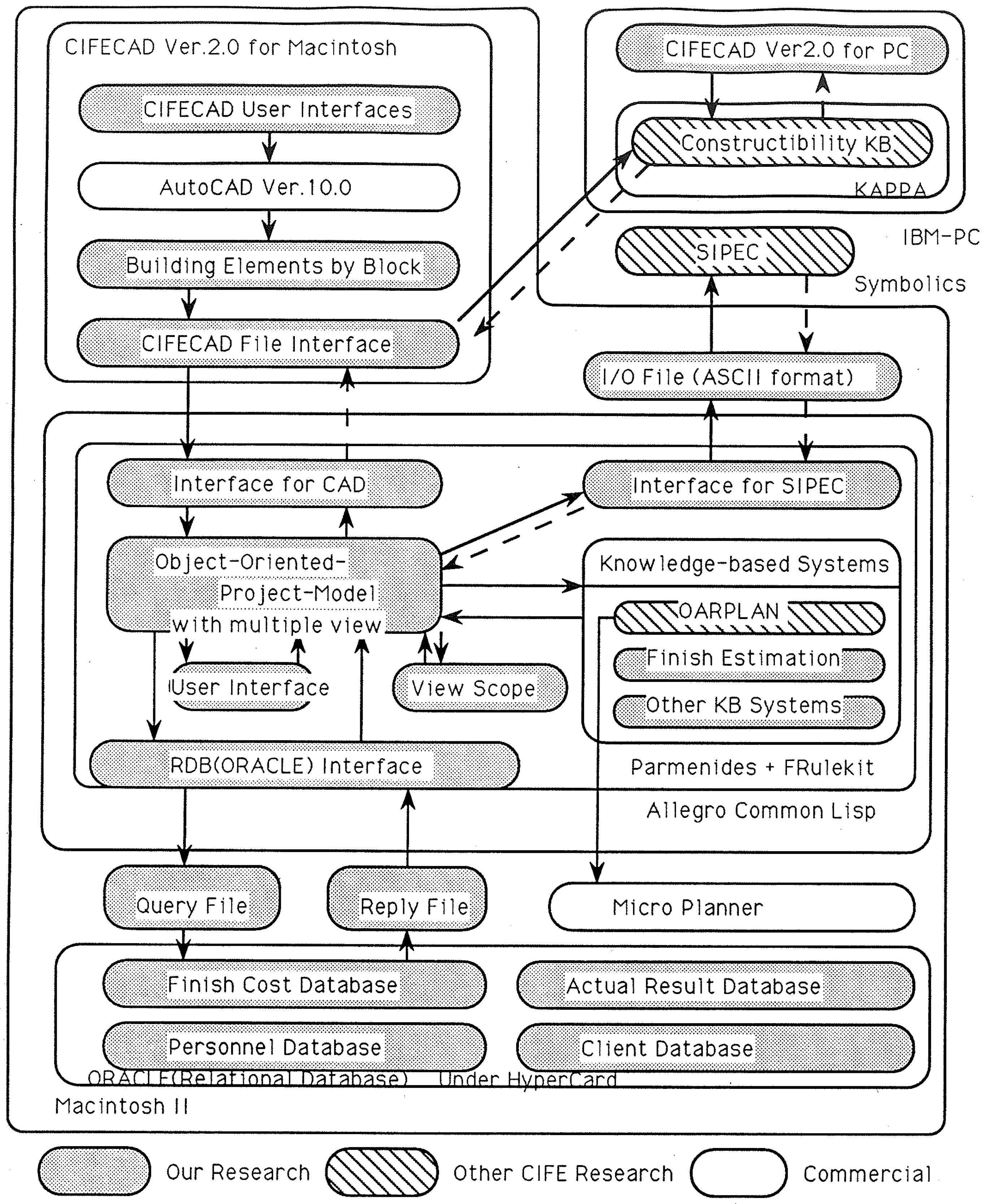
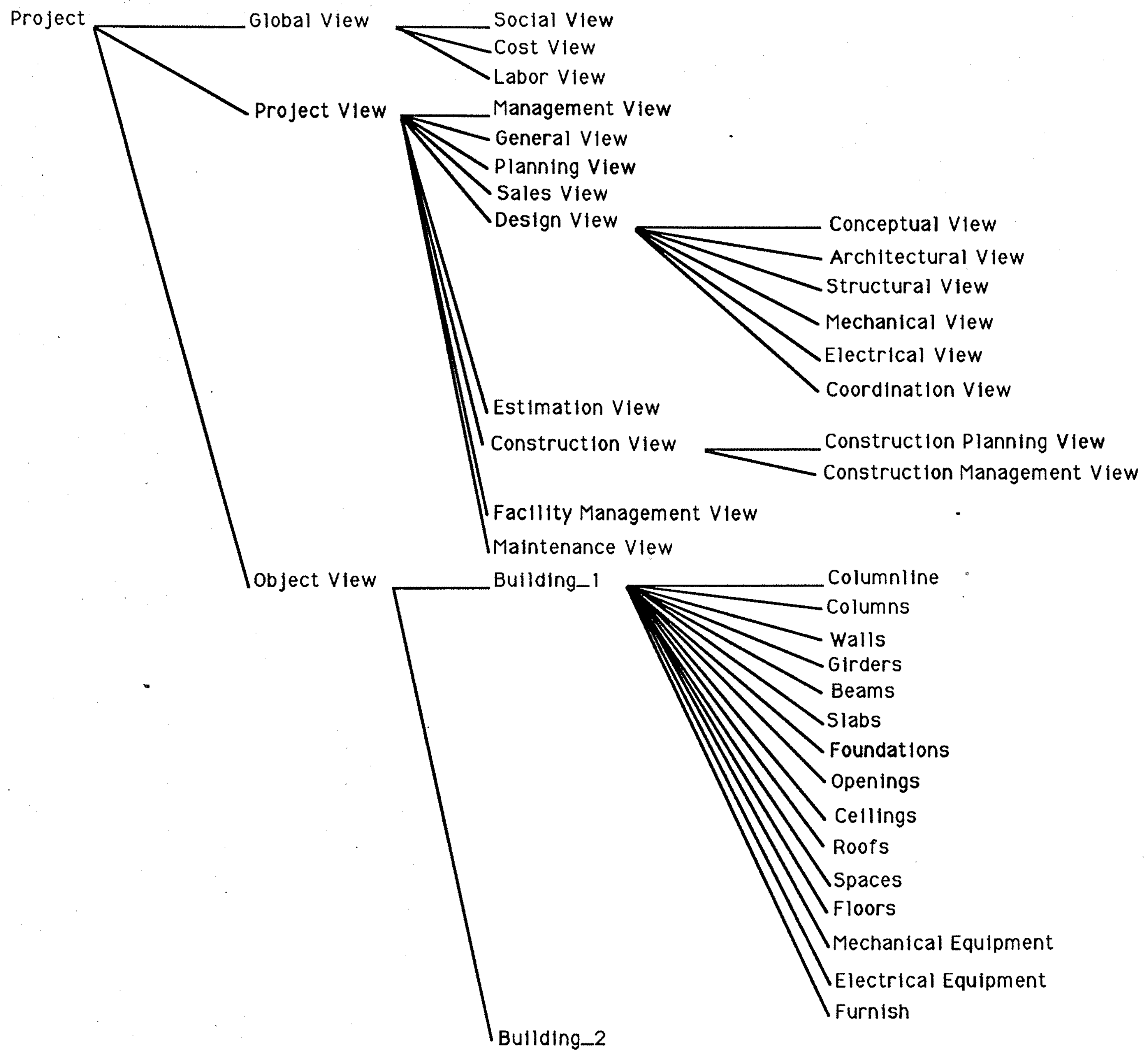


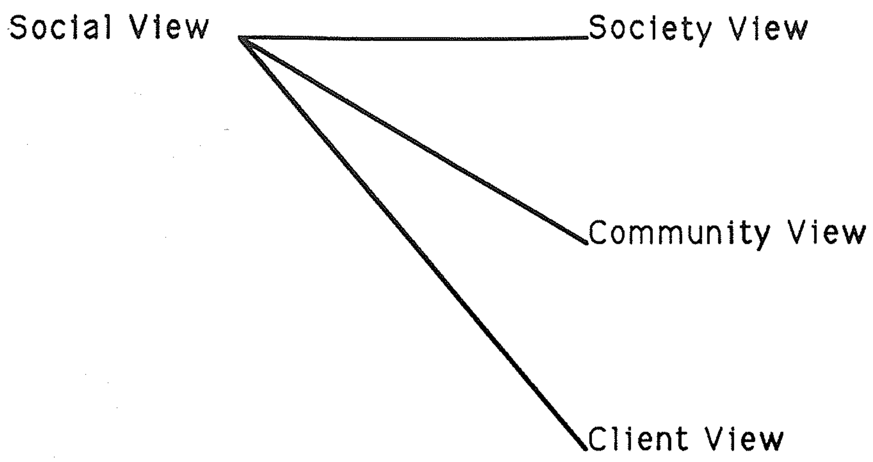
Figure-8.1.1 Current System Image

Appendix-A: PMAPM Object Hierarchy:

In PMAPM, we define many kinds of object, collectively termed multiple purpose objects (MPO). We cannot exhaustively define all the view objects shared by all the participants in an A/E/C project. Some view-objects described in this Appendix only have object-name, and some have objects and slot names (but no values). However, we believe that these examples of object information will provide some useful ideas to other researchers who are interested in object oriented project or product models, or object-oriented databases for CAD systems. The basic hierarchies of PMAPM are summarized in the following figures and the examples of various descriptions of views and objects are given in Appendix B.

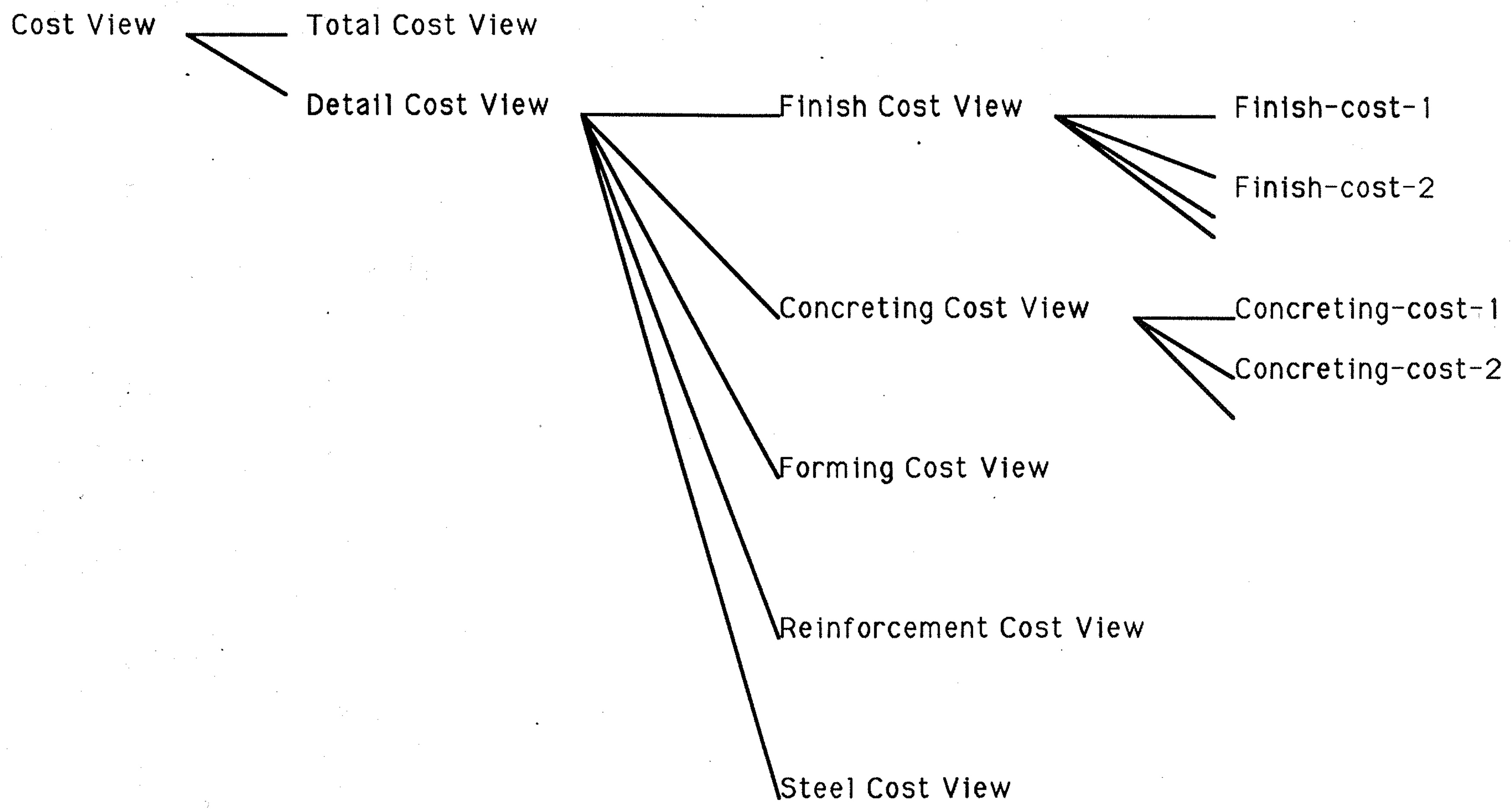


A-1 Global Hierarchy of PMAPM

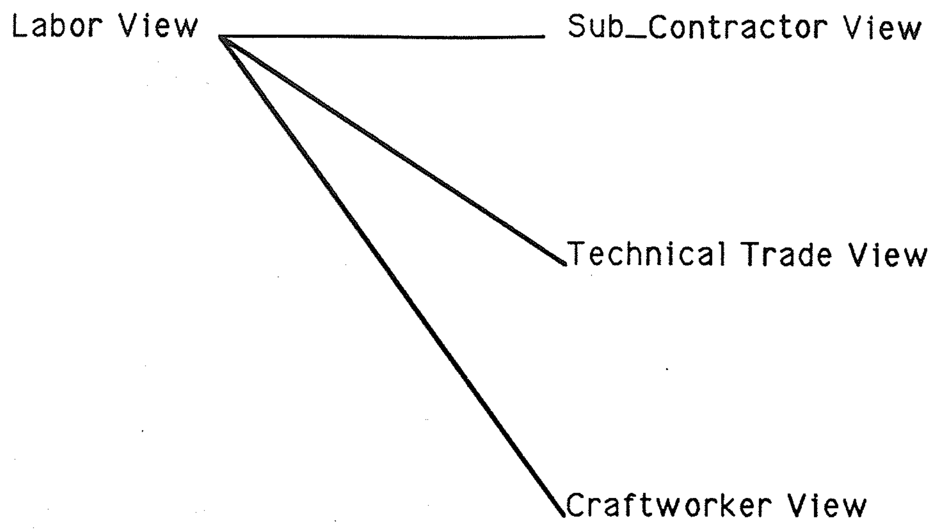


A-2 Hierarchy of Social View

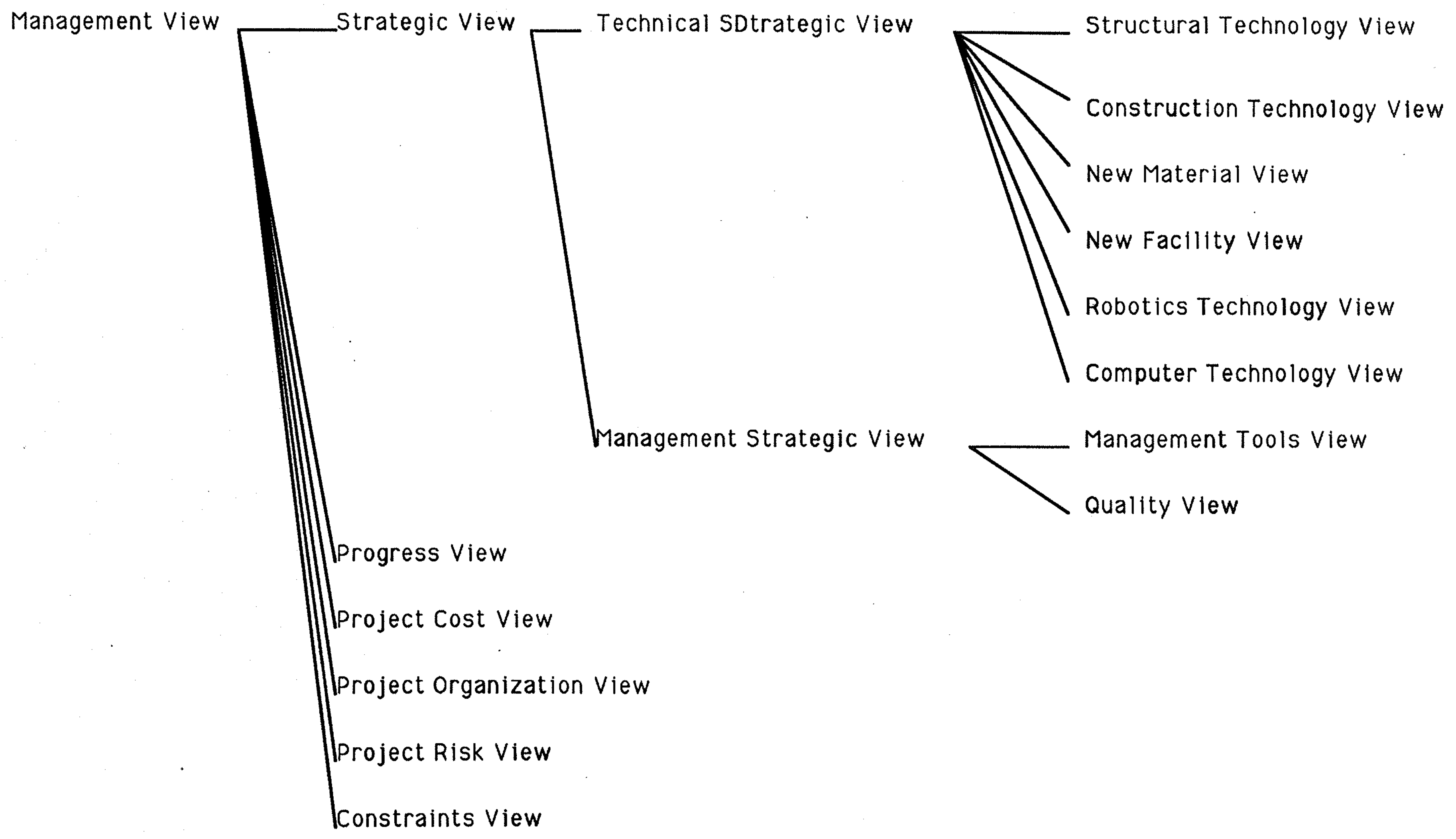
Thees views describe the trends of social needs to the Facility and General Contracter



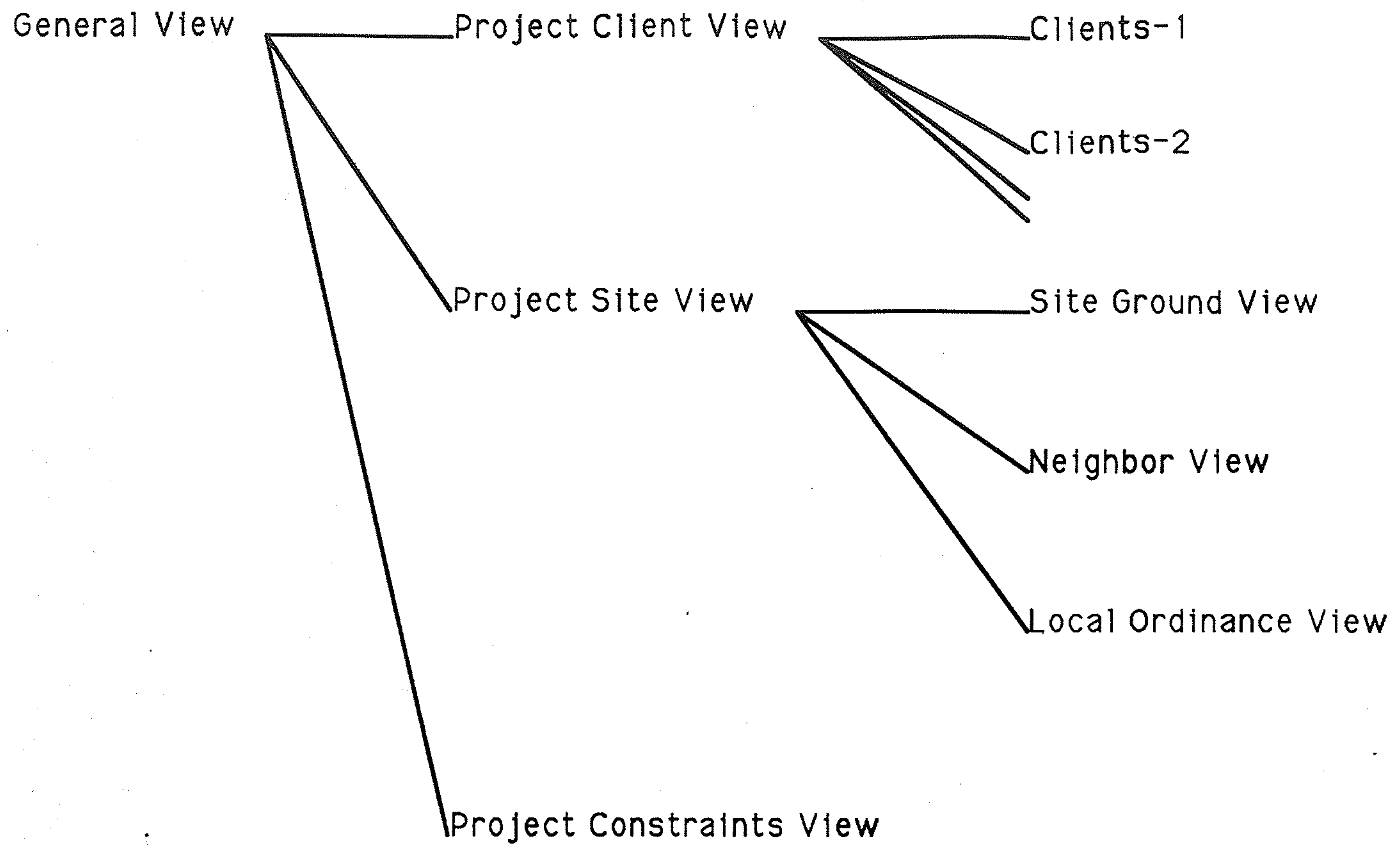
A-3 Hierarchy of Cost View



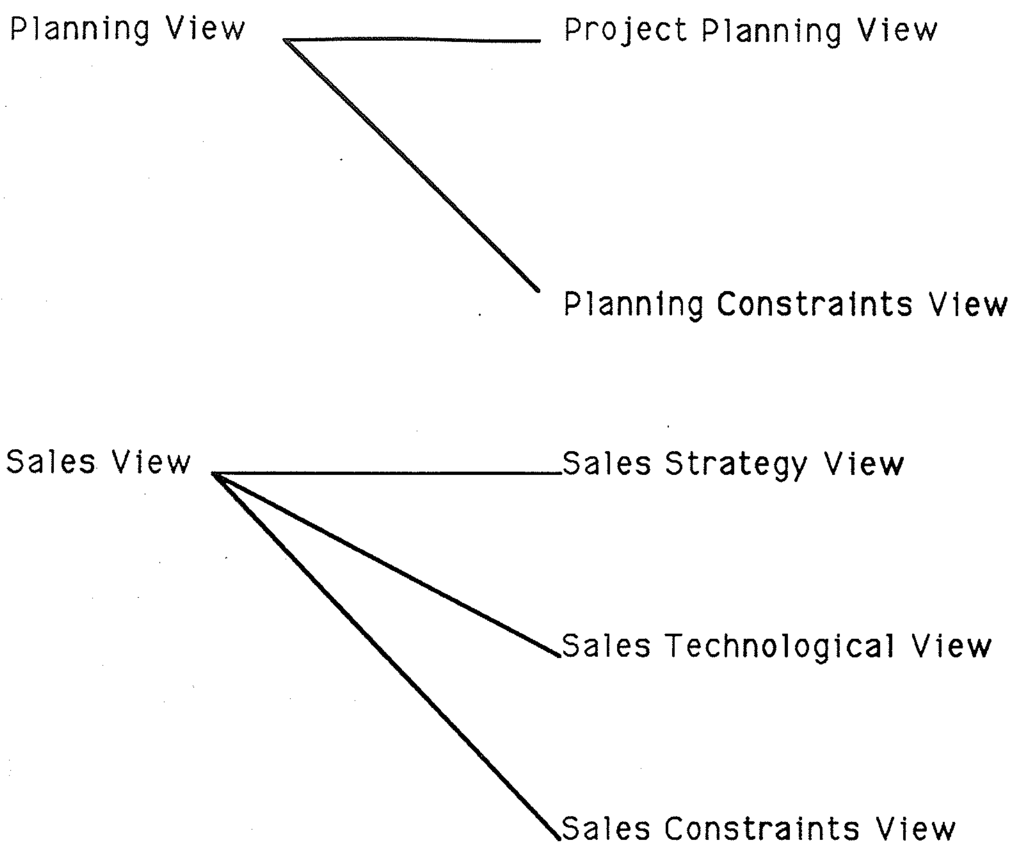
A-4 Hierarchy of Labor View



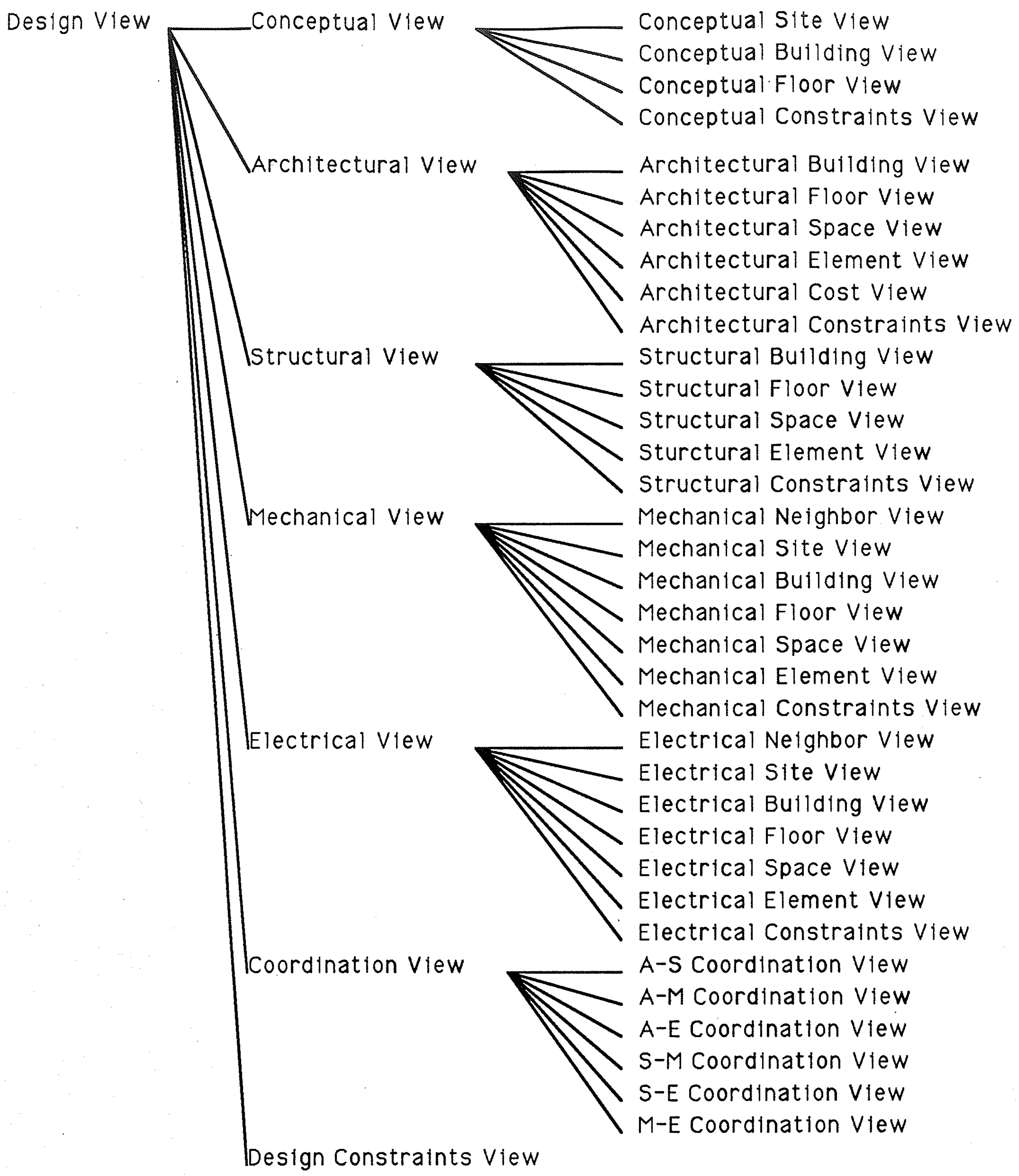
A-5 Hierarchy of Management View



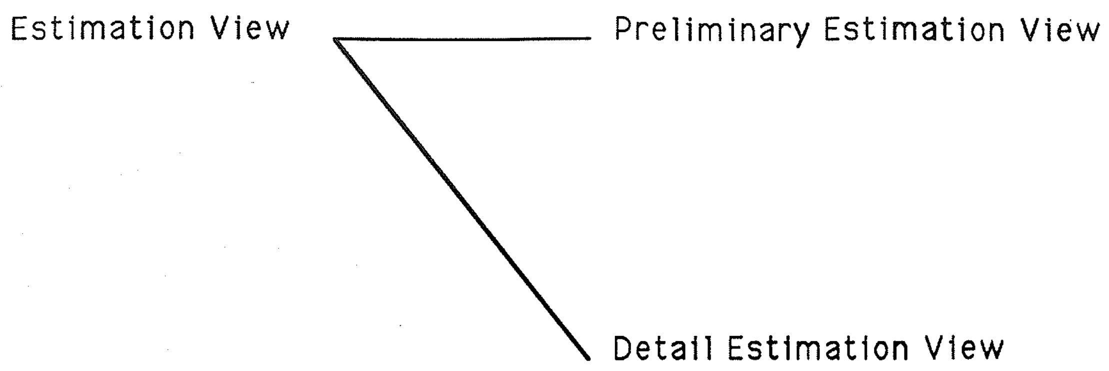
A-6 Hierarchy of General View



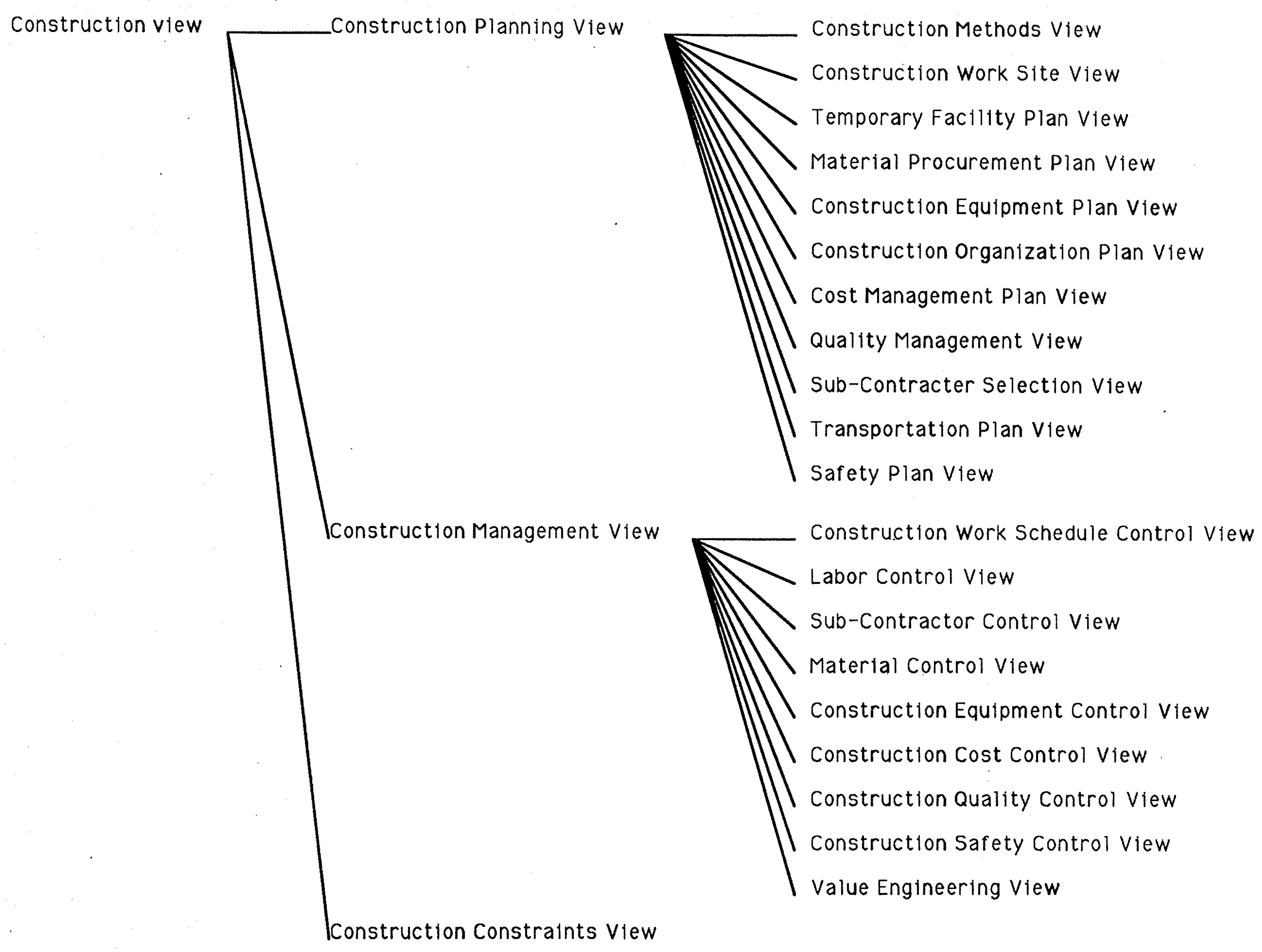
A-7 Hierarchy of Planning View and Sales View



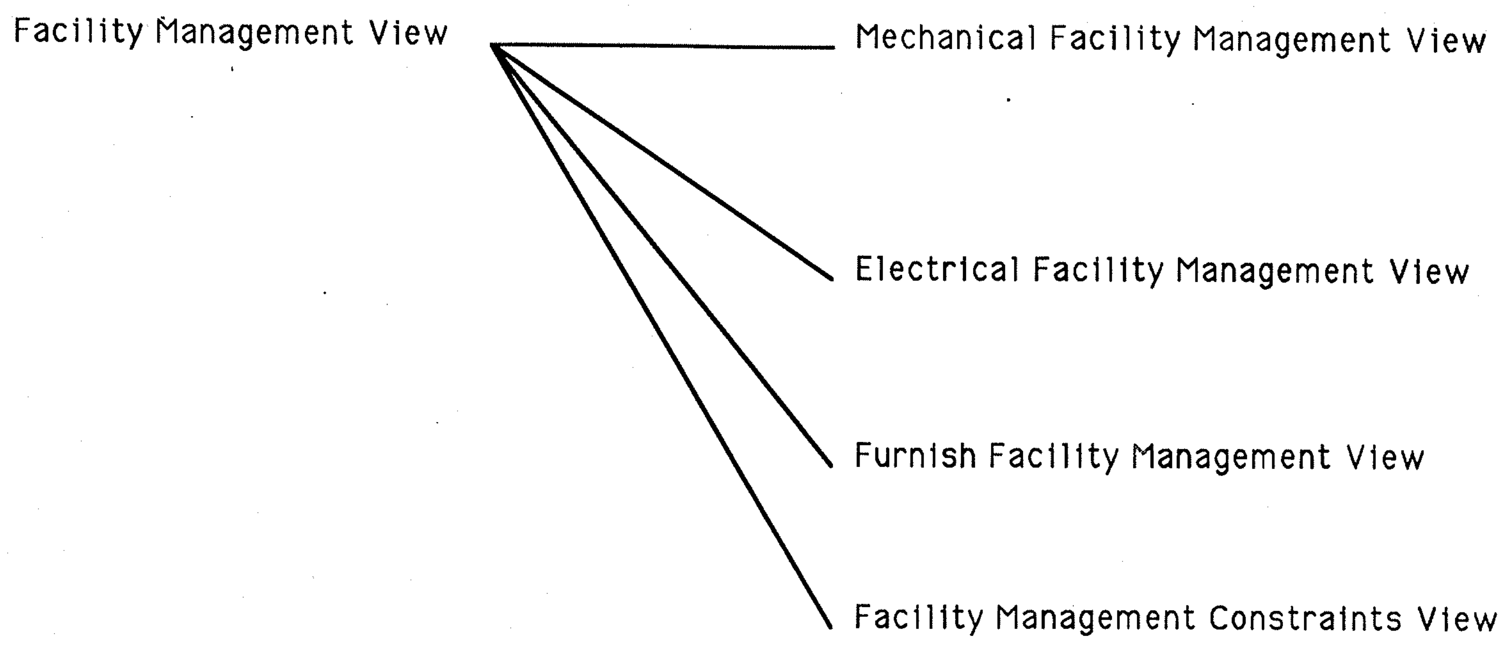
A-8 Hierarchy of Design View



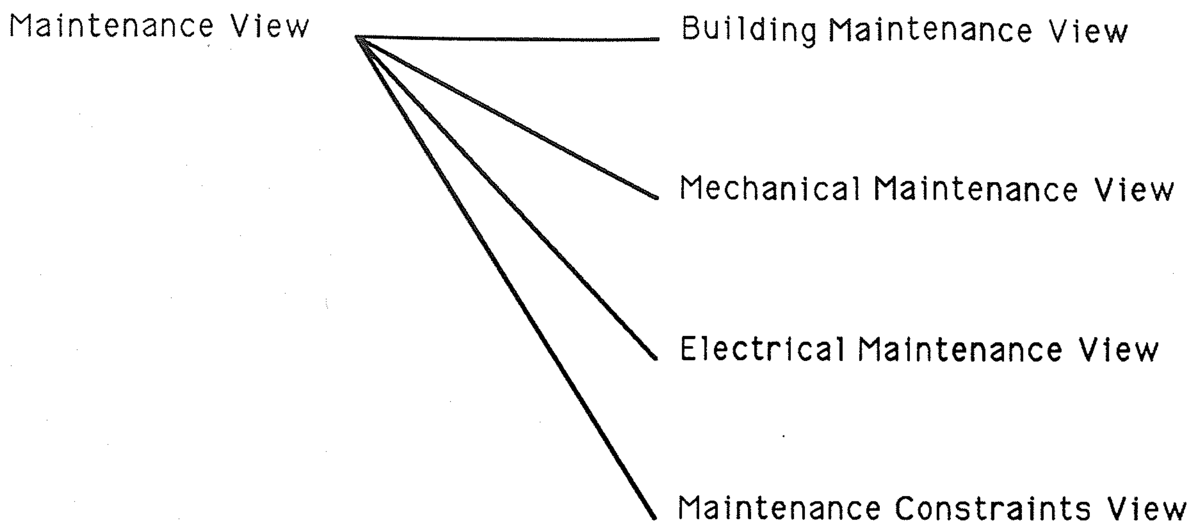
A-9 Hierarchy of Estimation View


Construction view
Construction Planning View
Construction Methods View
Construction Work Site View
Temporary Facility Plan View
Material Procurement Plan View
Construction Equipment Plan View
Construction Organization Plan View
Cost Management Plan View
Quality Management View
Sub-Contracter Selection View
Transportation Plan View
Safety Plan View
Construction Management View
Construction Work Schedule Control View
Labor Control View
Sub-Contractor Control View
Material Control View
Construction Equipment Control View
Construction Cost Control View
Construction Quality Control View
Construction Safety Control View
Value Engineering View
Construction Constraints View

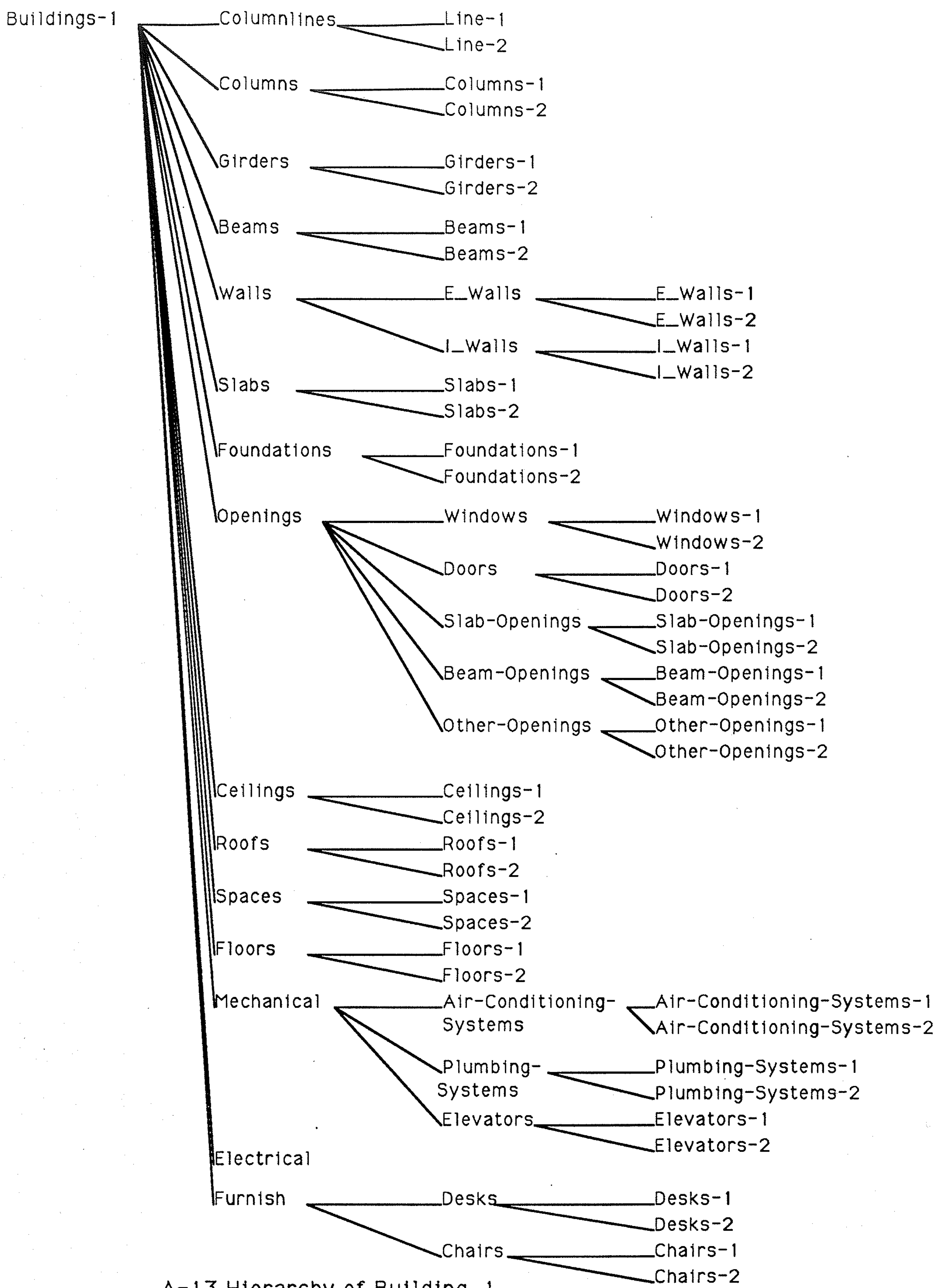
A-10 Hierarchy of Construction View


Facility Management View
Mechanical Facility Management View
Electrical Facility Management View
Furnish Facility Management View
Facility Management Constraints View

A-11 Hierarchy of Facility Management View


Maintenance View
Building Maintenance View
Mechanical Maintenance View
Electrical Maintenance View
Maintenance Constraints View

A-12 Hierarchy of Maintenance View



A-13 Hierarchy of Building_1

Appendix-B Detail Object Description

In this section, we list some examples of object definition and the description of various functional and physical objects.

Example of the Functional object definition

Project	**(Class Object)**
Project_name	Strings
Project_code	Strings
Start_date	Strings
End_date	Strings
Total Cost View	**(Class Object)**
Concreting Cost	List
Forming Cost	List
Reinforcement Cost	List
Steel Cost	List
Progress View	**(Instance Object)**
Start-date	List
Required-Duration	List
Temporal-Duration	Demon (Rule)
Fixed-Duration	Demon (Rule)
Dummy	List
Project Cost View	**(Instance Object)**
Total-budget	List
Land-cost	List
Building-cost	List
Design-cost	List
Construction-cost	List
Material-cost	List
Other-cost	List
Project Organization View	**(Class Object)**
Project-Manager	Strings
Design-team	Demon(Function)
Estimator-team	Demon(Function)
Construction-team	Demon(Function)
Project Risk View	**(Instance Object)**
Financial-risk	List
Construction-risk	List
Technical-risk	List
Other-risk	List

Constraints View	**(Class Object)**
Requirement-of-usage	List
Init-physical-constraints	List
Init-functional-constraints	List
Init-legal-constraints	Demon(Rule)
preset-constraints	Demon(Rule)
postset-constraints	Demon(Rule)
unconfirmed-constraints	Demon(Rule)
constraints-propagate-1	Demon(Rule)
Project Client View	**(Class Object)**
Number-of-client	List
Clients-1	**(Instance Object)**
Client-name	Strings
Client-Address	Strings
Client-business	List
Fund	List
Company-group	List
Bank-group	List
Company-level	List
Client-note	List
Project Site View	**(Class Object)**
Street-name	Strings
City-name	Strings
State-name	Strings
Site-ground	List
Soil-condition	Demon(Function)
Neighbor-information	List
Site-note	List
Design View	**(Class Object)**
Project-leader	Strings
Architectural Space View	**(Class Object)**
Space-volume	Demon(Function)
Finish-check	Demon(Rule)
Usage-check	Demon(Function)
Color-check	Demon(Rule)

Example of the Physical object definition

Columns	**(Class Object)**
Size	List
Offset	List
Material	List
Finish	List

Number-of-column	List(Demon)
Columns-1	**(Instance Object)**
ID	List
Size	List(Inherit)
Offset	List(Inherit)
Material	List(Inherit)
Finish	List(Inherit)
Position	List
Angle	List
Floor	List
Support	List
Supported_by	List
E_Walls	**(Class Object)**
Size	List
Offset	List
Material	List
Finish	List
Number-of-ewall	List(Demon)
E_Walls-1	**(Instance Object)**
ID	List
Size	List(Inherit)
Offset	List(Inherit)
Material	List(Inherit)
Finish	List(Inherit)
Position	List
Angle	List
Floor	List
Connected_with	List
Windows	**(Class Object)**
Width	List
Height	List
Floor_level	List
Number-of-window	List(Demon)
Windows-1	**(Instance Object)**
ID	List
Type_id	List
Width	List(Inherit)
Height	List(Inherit)
Position	List
Floor	List
Floor_Level	List(Inherit)

Attached_on	List
Spaces	**(Class Object)**
Floor_level	List
Ceiling_height	List
Floor_finish	List(Demon)
Ceiling_finish	List(Demon)
Wall_finish	List(Demon)
Number-of-space	List(Demon)
Spaces-1	**(Instance Object)**
ID	List
Room_code	List
Area	List
Room_name	List
Floor	List
Floor_Level	List(Inherit)
Ceiling_height	List(Inherit)
Floor_finish	List(Inherit)
Ceiling_finish	List(Inherit)
Wall_finish	List(Inherit)
Live_load	List(Demon)
Grade	List
Color	List(Demon)
Usage_zone	List
Fire_protection_zone	List
Consisted_by	List