CONCEPTUAL MODELLING OF BUILDINGS
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FROM RESEARCH TO PRACTICE

Matti Hannus

Cadex Oy, Atomitie 5 A, 00370 Helsinki, Finland
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ABSTRACT

The paper summarizes some research efforts in areas relating to product modelling and the implementation of results in commercial software developments.

A national industry standard for 2D CAD data exchange is described. The concept is based on an extremely compact neutral file format. A number of translator programs for commercial CAD/CAM-systems have been developed as well as software to interface CAD with management information systems of the manufacturing companies. Also a number of vertical application relating to data exchange have been developed.

A standard for product data definition for precast concrete elements has been developed. The specification has been implemented for data exchange between design and manufacturing and also for vertical CAD-systems.

A national research and development project focusing on product modelling of buildings and the implications of it for practical activities is described. Product modelling concepts are implemented in various other development efforts across the building industry.

Vertical CAD-systems for concrete and steel structures are described. These systems have been founded on the product modelling approach.

1. INTRODUCTION

The author represents a software house specializing on CAD data exchange and vertical CAD-systems for concrete and steel structures. In each of these areas the company has been actively involved in various research and development programs and has implemented many of the new ideas in commercial software.

Development in AEC-industry with it's scattered organizational structure is characterized by a stepwise evolution rather than revolution. Therefore intelligent 2D CAD data exchange is also emphasized as an important short term solution to exchange product data.

2. APPLICATION INDEPENDENT 2D CAD DATA EXCHANGE

Within the framework of a wider R&D project initiated by the precast concrete industry a national solution for intelligent 2D CAD data exchange was developed in 1985-6. The concept is based on a neutral file format called BEC and is supported by software of three categories: 1) translation programs for commercial CAD/CAM-systems, 2) programs for receival and manipulation of CAD data by the manufacturing industry and 3) vertical application programs.

The BEC data exchange system is based on general computer graphics and is independent of the technical application area.

The two fundamental ideas of BEC-format are proven compatibility and extremely compressed file size. These are also the main reasons for the development of a national solution instead of trying to adopt the IGES-standard. Due to small size BEC-files can easily be transmitted using telephone networks or PC-diskettes. Typically a BEC-file is about 50 % of the original system dependent binary file and about 3 % of corresponding IGES file. Compatibility has been achieved by a common set of access routines shared by all BEC-related programs and a strict validation procedure.

The logical data structure of BEC is based on the GKS-standard with some CAD-oriented enhancements: a limited set of graphical primitives, segments, symbols, layers, window/viewport-transformations and alphanumeric attributes.

Today BEC-format remains a de facto standard for CAD data exchange in Finland and has also been adopted to some extent in Sweden and Norway.

2.1 Translator programs

Based on the BEC-format translator programs were developed for several of the commonly used CAD/CAM-systems in AEC-applications in Scandinavia: Autocad, Dogs, HP-ME10, Intergraph, Medusa, Technovision and a number of locally developed CAD-systems. Some of these interfaces are developed by third parties.

2.2 Interface to manufacturing

A number of software packages were developed for the manufacturing companies which receive BEC-files from designers but may not need a CAD-system themselves. These programs provide functions like: graphical viewing and editing, plotting, extraction of alphanumeric data from graphics and interface to MIS.

2.3 Vertical applications

A number of vertical applications supporting BEC have been developed: parametric drafting packages for specialized design applications, CAD-systems for steel and concrete structures, data exchange by teletex, CAD-archiving on WORM disks, optical scanning, topographic surveying, graphical interfaces to traditional data base management systems etc.

2.4 Future enhancements

The focus of current developments is on a deeper integration of design and manufacturing with functions like: using BEC-file as the carrier of alphanumeric product data, postprocessing BEC-files into taylored receiver-defined documents for specific tasks in the manufacturing process, interfaces to analysis, detail design and numerical control, electronic distribution of drawings using laser printers, managing layers in integrated multidiscipline design projects etc.

3. PRODUCT MODELLING OF CONCRETE STRUCTURES

3.1 Standardized guidelines

The development of advanced CAD applications for precast concrete structures was encouraged by standardization efforts initiated by the industry.

Guidelines on the use of CAD was published as a printed manual containing recommendations for designers, fabricators and software developers. Examples of the recommendations are:
- visual layout, content and format of drawings,
- internal structure of CAD-drawings: layering, symbols, etc
- standardized formats of alphanumeric lists like: list of quantities, list of reinforcement bars, drawing headers, etc

A standard for product definition data was defined for the products based on precast concrete. Using the standardized representation it is possible to describe a whole building consisting of precast concrete elements up to very deep detail level like a single reinforcement bar, hole or steel component. This representation uses an alphanumeric file format which is easily processed by computer without human interpretation. Indirectly, this specification also defines a product model of buildings consisting of precast concrete components.

3.2 Commercial implementation

A suite of vertical application programs was specifically developed for the modelling and design of precast concrete structure. The fundamental idea of this package - called SystemCadex - is to provide information for the computer integrated manufacturing process rather that merely produce traditional design documentation. Therefore the product modelling approach was chosen.

Instead of focusing on the documentation of his design the user may concentrate on the design itself. The model of the building is stored in a database which contains a high level description of the real world objects and the relations between them. Documents like various lists and drawings are derived from the model. Any modification of the model will be automatically reflected in all derived documents.

3.3 Application modules

The system includes a number of modules for various subtasks. All of these modules have a CAD-like graphical user interface and work on a common data base. These modules may be used either as stand-alone applications or as an integrated system.

The overall layout of a building and the main geometric dimensions of the components can be modelled with a specific module of the system. Documents of the building can be extracted from the model with another module. Typical documents are plan drawings, sections, 3D-views and list of components.

The detail design and documentation of various components is carried out by specific modules for each component type: sandwich wall elements, slabs, columns and beams. Documents consist of drawings and bills of material.

Auxiliary modules include a plotting program and a graphical editor for the modification of the derived drawings. Since the drawing files are in BEC-format they can also be directly transferred to any commercial CAD-system having a BEC-interface.

4. PRODUCT MODELLING OF STEEL STRUCTURES

4.1 STEELCAD-system

STEELCAD is an interactive graphical product modelling system for the design of steel structures. The system includes functions for 3D-modelling of structures consisting of members like beams, columns, trusses and plates, definition of connections between the members and detailing of of members.

4.2 Product modelling approach

The entities of STEELCAD are described by a generic definition which is the basis for all functions of the system. No graphical entities (2D or 3D) are stored in the model. However, graphics is extensively used as a user interface to the product model. When needed, various graphical representations of the model are derived from the data base eg: simplified or detailed visualization on the screen, wire frame or surface model with hidden line removal and drawing graphics.

4.3 Data structure

The steel structure is composed of assemblies of parts. An assembly may consist of lower level assemblies. This hierarchical structure is freely controlled by the designer during run-time. An "assembly" here may be either a physical composition or a purely logical collection of of entities which the designer wishes to group together. In addition to this hierarchical structure, a network data structure is used to manage the connections between parts. The data base management system is specifically designed to manage the logical data structure with hierarchical assemblies and connections between entities with a fast responce time.

4.4 Connections

Parts may be connected to other parts by joints. A joint entity includes all relevant data of the connection of two or more members eg bolts and nuts, hole patterns and details of the connected parts. The joint is logically linked to the connected members in the data base so that consistency can be automatically maintained during all modifications by the user.

4.5 Output documents

The system is used to create a model of the steel structure in a data base. From the model various documents (drawings and lists) can be derived. Definitions of the documents (ie what is included in a document and how it shall be represented) can be stored in the model so that updated documents can be easily regenerated when desired.

4.6 European cooperation

Within the Eureka project EU130 "CIM for constructional steelwork" a product model for steel stuctures is being devoleped to cover most of the life cycle: conceptual design, estimating, analysis, design, detailing, manufacturing, quality assurance, erection and demolishing. The work will comply with the emerging ISO/STEP standard.

5. NATIONAL R & D PROJECT ON PRODUCT MODELLING OF BUILDINGS

During 1987 a large number of organizations in the Finnish AEC-community sponsored a national co-operative study called RATAS. The goal of the project was to establish the foundation for integrated computer aided design process in the 1990's. The core of RATAS is a conceptual product model. Further developments of the RATAS model are taking place in a number of other projects whereby proposals from other countries and ISO/STEP will be studied more in detail.

5.1 Summary of RATAS product model

The RATAS model describes a building symbolically using objects. The term object is close to the term entity which is often used in other studies. Objects are typically physical "things" or functional units of a building. Other aspects of a building project can be modelled as objects in a similar manner: materials, contracts, tasks etc.

Objects are categorized into 5 abstraction levels; example:
Building / Structural system / Structural frame / Column / Console
Abstraction levels offer a means to organize data at increasing levels of detail. In many cases this division is also helpfull in defining a hierarchical product structure or in splitting responsibilities among persons or companies.

A class defines a set of properties or attributes which are associated with all objects belonging to the class. A class may also define the domains and default values of the attributes. An object may belong to several classes. A class may be subclass of another class and inherit attributes from the higher level class.

Each object assigns specific values to it's attributes. The attribute values may be explicite or can be derived from other data in the product model through methods.

Relations between objects are categorized into two main types: "consists of/is part of" hierarchy relation and "is connected to"- relation. Often the objects at different abstraction levels are related by a hierarchical relation.

Different users are interested in different aspects of the whole product model. This can be coped with the concept of viewpoint which defines a subset of the model and may use selected representations of the properties. Classes are the primary tool of viewpoint definition. Different attributes of objects are accessible through different viewpoints.

5.2 Implementation of RATAS model in practice

Implementations of RATAS model have been initiated in areas like:
- prototype product modeller using relational database,
- classification codes of building materials,
- organization of data in traditional CAD/CAM-systems,
- integrating alphanumeric databases with graphics,
- publishing electronic product data on PC-discettes,
- vertical CAD-systems for steel and concrete structures,
- modular fabrication of buildings,
- etc.

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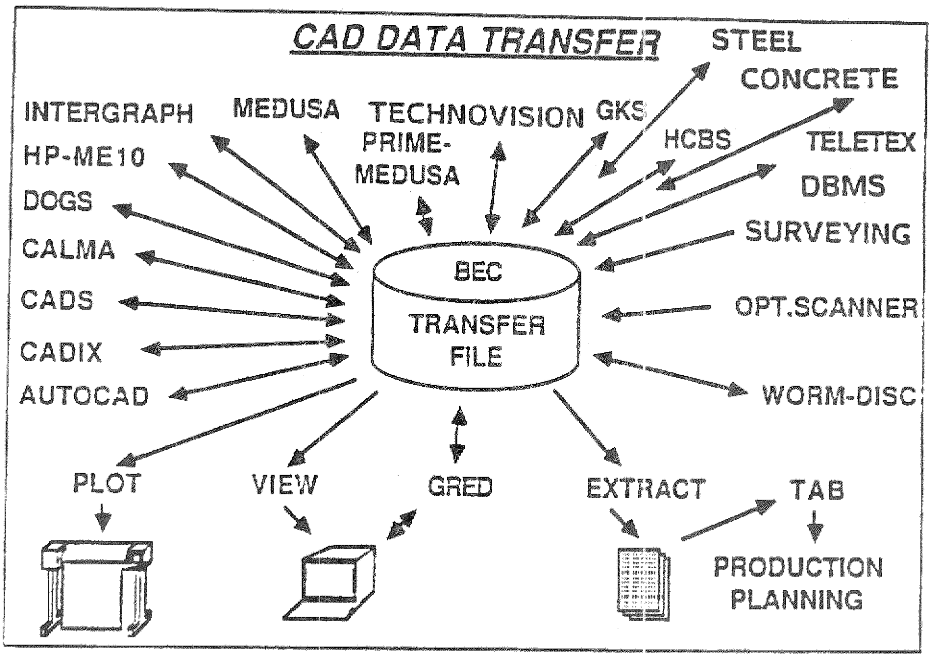

Figure 1. CAD data exchange - various CAD/CAM-systems, vertical applications and receival programs supporting the neutral BEC-format.

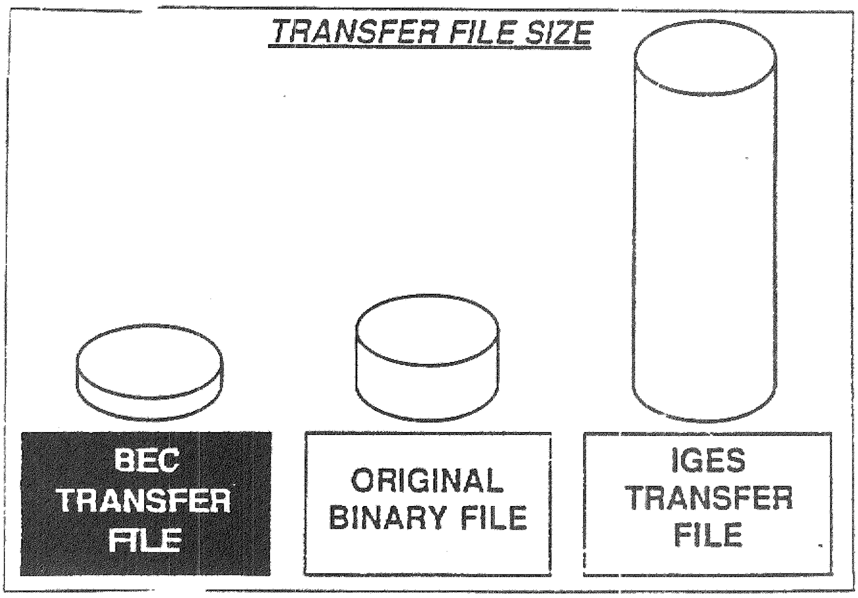

Figure 2. File size of neutral BEC-format.

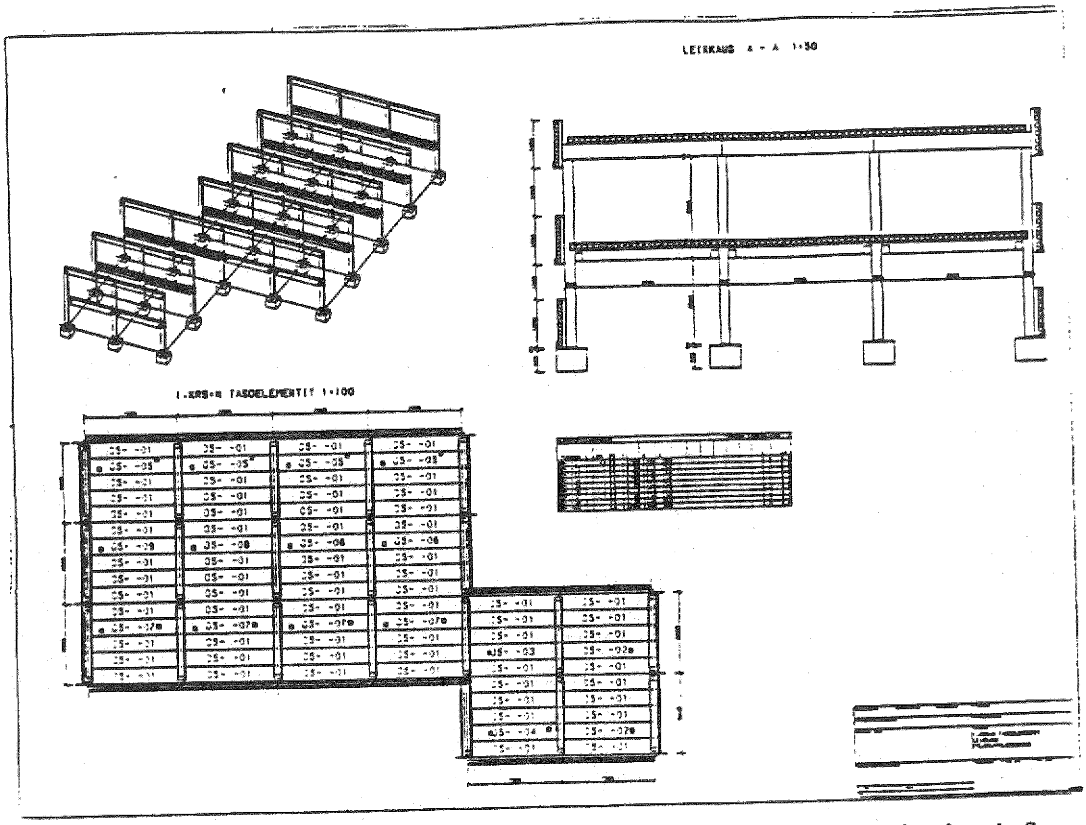

Figure 3. Typical drawing of a precast concrete structure derived from the product model data base created with SystemCadex.

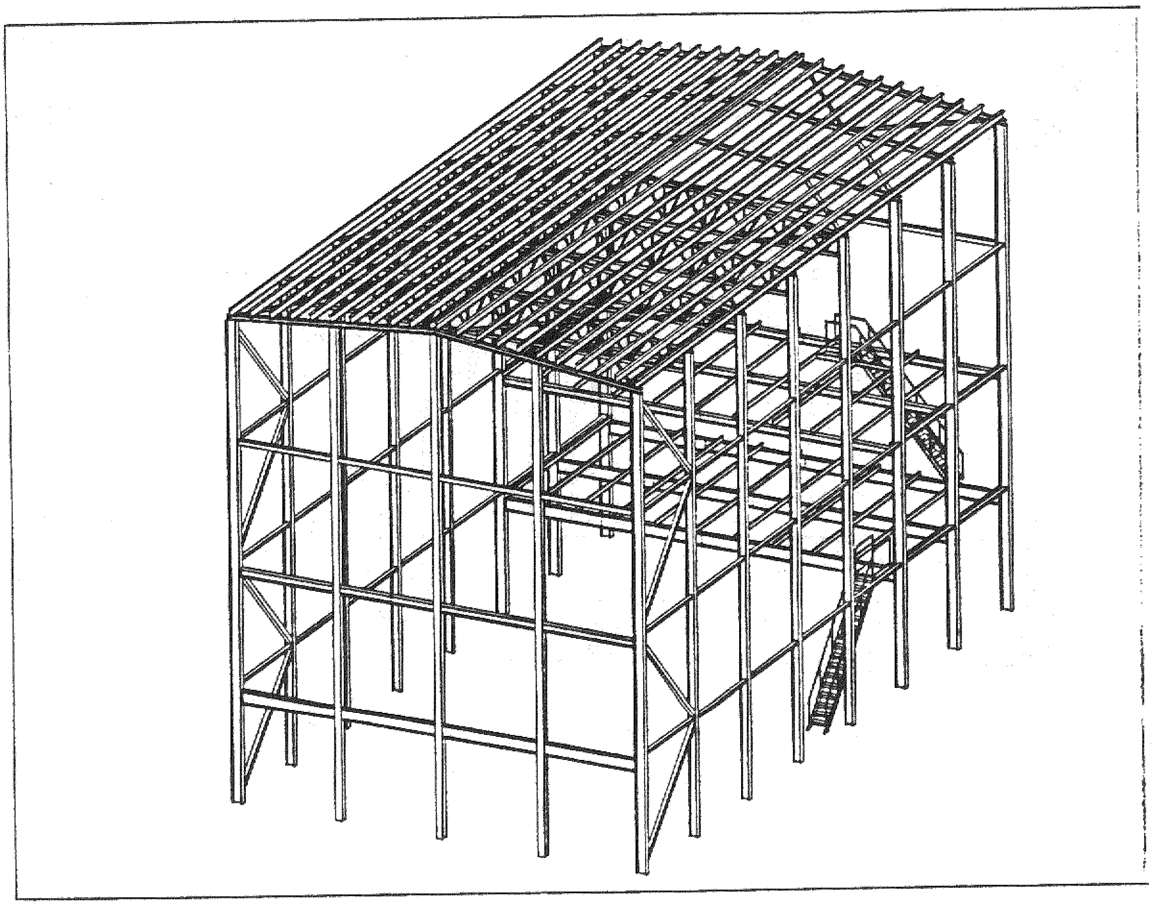

Figure 4. Visualization of a structure modelled with STEELCAD system.

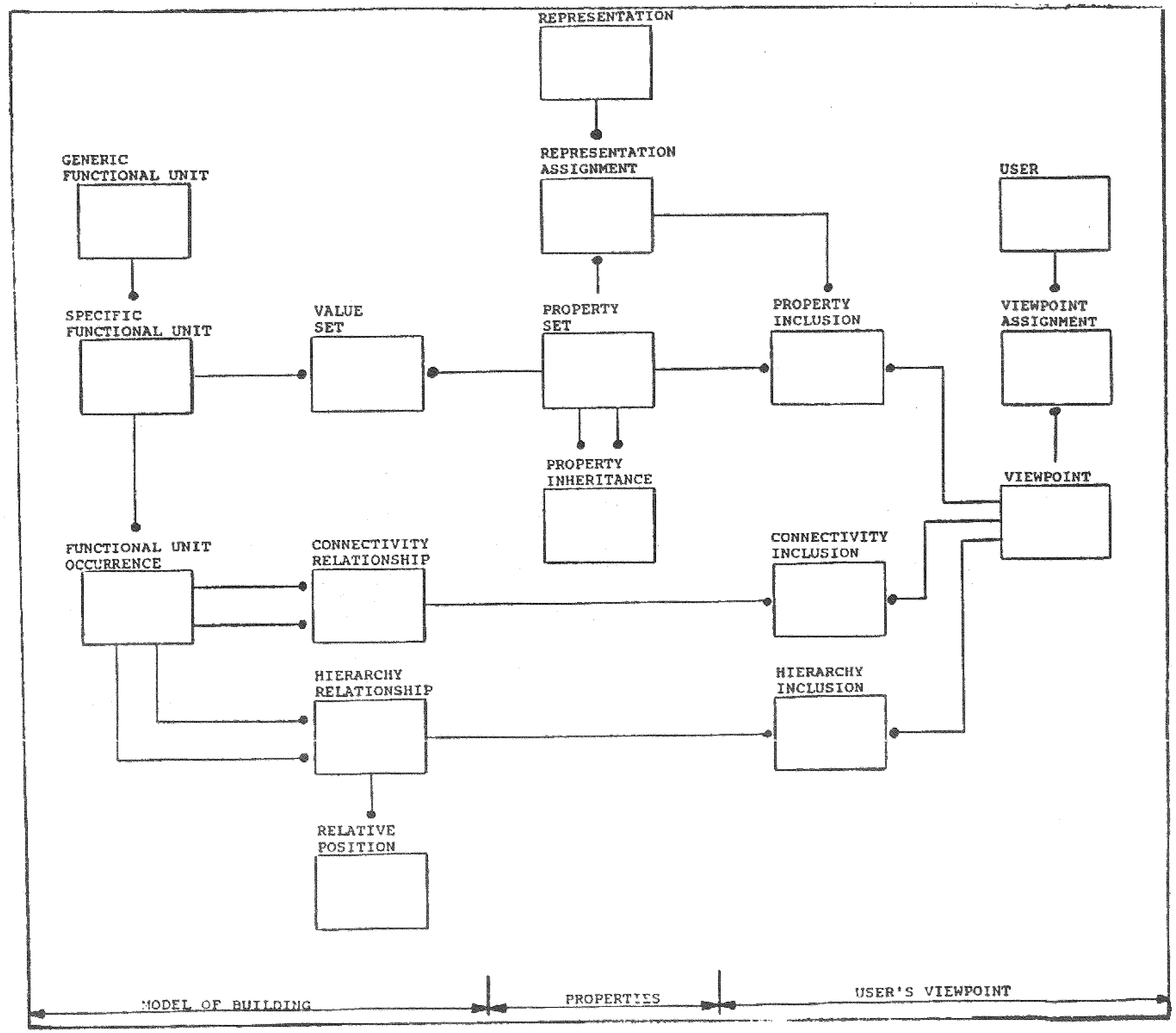

Figure 5. A draft attempt to describe the RATAS product model using IDEF1X-notations. (The model was originally defined using an ad-hoc methodology.)