UTILISING PRODUCT MODELS FOR INFORMATION SHARING IN AN INTEGRATED CAD ENVIRONMENT

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Abstract

Despite the extensive use of computing technology within the Architecture, Engineering and Construction (AEC) industry during the past few years, the crucial issue of information sharing amongst AEC participants still remains to be addressed. This results in poor building project co-ordination and affects productivity and final outcome.

Our objective at South Bank University is to develop integrated CAD systems that utilise conceptual building product models for efficient building-related data representation and exchange.

This paper presents our approach in defining a building product model of CAD-related design data (i.e. architectural, structural, etc.) that also identifies overlapping sections with non-design data (i.e. project planning, cost estimating, etc.) which are incorporated for producing enriched data specifications extracted from CAD drawings and used by various AEC disciplines. Different strategies for separating multiple-views of the resulting data are also discussed.

Finally, a prototype system (MicroLink) that runs under Intergraph's MicroStation PC CAD package is presented. The system operates on a partial set of entities of the overall product model and produces semantically-enhanced design data in a declarative form ready for use by knowledge-based systems for automatic construction activity generation.

Keywords: *CAD, CIC, object-oriented product model, information sharing, knowledge-base*

1 INTRODUCTION

The need for efficient information sharing within Architecture, Engineering and Construction (AEC) industry has been recognised as one of the key issues for increased productivity and improved efficiency in building design and construction [9,11,23]. The emergence of ISO-STEP and the use of product models as the means of conceptual description of building data and mechanisms for neutral exchange of the described data, can facilitate any integration effort. The development of intelligent software tools that are capable of automating the cumbersome tasks of describing, extracting, storing, retrieving and exchanging information between dissimilar applications, is the way forward for achieving integration within AEC.

The work presented in this paper is part of a major research project aimed at integrating design and construction. A framework for modelling construction data, based on a three-level decomposition, is illustrated. A building product model (IBPM) is under development and is believed to be the key element in an integrated AEC environment. A prototype system (MicroLink) that is being developed as an add-on to Integraph's MicroStation 3D CAD package and is capable of capturing semantics of CAD data is presented. The advantages of using Object-Oriented Data Base Management Systems (ODBMS) for persistent storage of building objects are discussed. Finally, the architecture of our integrated environment for design and construction is described.

2 A FRAMEWORK FOR MODELLING CONSTRUCTION DATA

Before any conceptual modelling effort, it is useful to establish a framework that allows the categorisation of data into different levels of abstraction. This is especially important when modelling construction data because of the number of different specialists involved and the particular views they have of the design data. It is proposed that the modelling process can be viewed from three different angles, each one representing a level of abstraction. Our "Three-Level Model" (Figure 1) is comprised of the discipline level, the view-point level and the data level.

2.1 DISCIPLINE LEVEL

At this level, the disciplines involved are identified and the different ways each one generates and uses data is examined. It is also useful to identify overlapping areas between the disciplines involved because this can lead to ways for establishing co-operation and inter-communication among separate data domains (i.e. architectural, structural, etc.).

2.2 VIEW-POINT LEVEL

It is evident from previous research that the problem of organising a product model is such a way where multiple views of the data can be extracted is a crucial one [1,18]. This is due to the fact that different specialists in AEC have different tasks to perform and therefore they have their own view of the design data. For example, an architect may only be interested in spaces and layout while a structural engineer in the building structure. Object-oriented design techniques offer a good example of achieving this by providing aggregation and inheritance hierarchies.

2.3 DATA LEVEL

An examination of the modelling task as outlined in the previous two higher levels will establish an area of interest from where data can be gathered and organised. At this level, objects, attributes and relationships are identified.

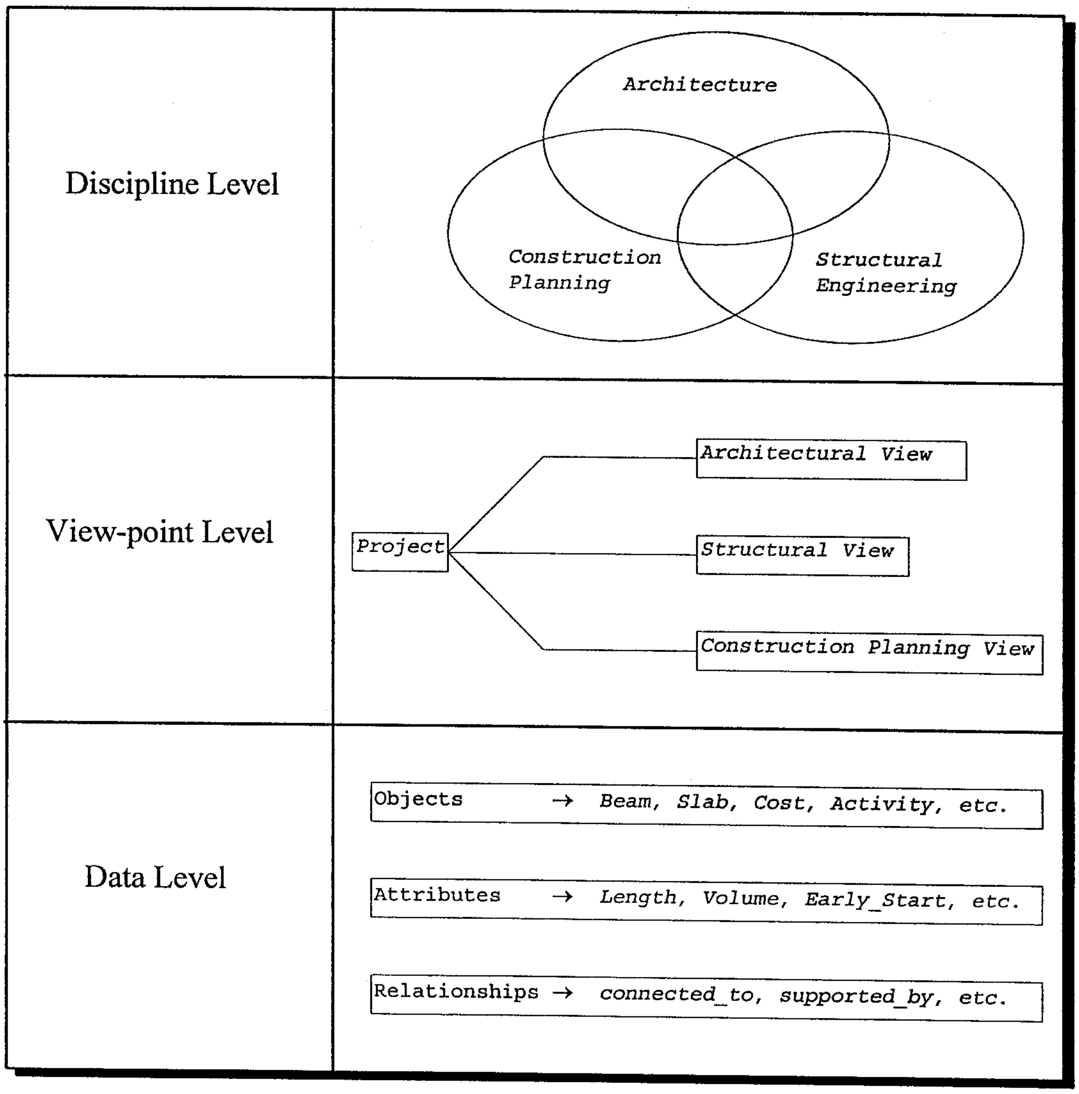

Figure 1. Three-Level Model for Modelling Construction Data

3 DEVELOPING PRODUCT MODELS FOR AEC

The use of product models as the means of sharing information between dissimilar applications is evident in research efforts [3,4,16]. A product model, as defined within the ISO-STEP framework, is an abstract description of facts, concepts and instructions about a product, or set of products [14]. This conceptual representation of a building as a product, can not only provide a clarified view of the data involved during the product's life-cycle but can also serve as a vehicle for integration. By making the right decisions, integration can be achieved on the conceptual level.

Conceptual building modelling has gained a degree of maturity during the last few years due to substantial international and national efforts in this area. The IRMA (Information Reference Model for Architecture, Engineering and Construction) project was aimed to serve as the core of a conceptual project model which can be used both as a framework for modelling and for implementing applications [17]. The IRMA model consists only of a limited set of high-level entities, namely product, activity, resource and contract, but served as a starting point for further debate regarding implementation and conceptual modelling issue during an on-line electronic forum amongst researchers in this area.

COMBINE (Computer Models for the Building Industry in Europe) commenced in 1990 and is concentrated in the short term on developing a means for designers in different disciplines to exchange data between a set of building performance evaluation tools, each capable of assessing with particular aspects of a building's performance. Although COMBINE only focuses on energy-related data, it fully adheres to ISO-STEP for data representation and exchange and therefore is a valuable paradigm of implementing integrated applications within STEP [3].

The RATAS project was initiated in 1987 and was developed at a national level in Finland [4]. Its purpose was to define necessary ingredients for CIC (Computer-Integrated Construction) and to implement the model through a series of prototypes. The RATAS building project model follows a more "traditional" (influenced by the entity-relationship model used in structured analysis) approach based on an abstraction hierarchy. It comprises five levels of decomposition namely building level, system level, subsystem level, part level and detail level.

In addition, ISO-STEP gives many definitions of generic entities in EXPRESS as parts of Integrated Generic Resources (Part 41: Fundamentals of Product Description and Support and Part 42: Geometrical and Topological Representation), Integrated Application Resources (Part 101: Draughting) and Application Protocols (Part 225: Structural Building Elements using Explicit Shape Representation). Currently, there is an international effort to create a number of IARs and APs for the building construction industry. A framework has already been established and seven new APs have been proposed. This will be a significant aid towards developing future product models for building construction.

Another source of structured building data is classification systems (SfB) [8]. Although by no means aimed towards product modelling, they can be used as reference of building components and to check what is within the scope of a particular building subsystem (e.g. substructure, primary elements, etc.). Also British Standards BS 6100: "Building and Civil Engineering Terms" and BS 1192:5: "Guide for Structuring of Computer Graphic Information", can be used for building element definitions and structuring of graphic data respectively.

4 INTEGRATED BUILDING PRODUCT MODEL (IBPM)

There are mainly two approaches in developing product models. The first approach is concerned with the development of global models (also called reference models) that aim to provide information sharing for the whole AEC industry. Examples of such models are IRMA [17] and GARM [10]. The second approach focuses on the use of more specific models (or domain models) which are related to one or more AEC disciplines and suit the needs of particular applications. These models do not aim to represent data for the whole industry.

We chose to utilise the latter approach for developing our model (IBPM) since our project is mainly concerned with integrating CAD and project planning applications, but one of the key issue in developing the model was for it to be a) sharable and b) extendible. It can also be argued that domain models are more suitable for implementation than reference models.

A product model must be sharable because it will have to be used by more than one participants in an AEC project, where each participant has different view of the data and only concerned with part of the model.

A product model must be extendible so that more domains (disciplines) can be included in it if it decided that the scope of the model should be widened to serve more AEC participants.

In Figure 2, the top-level objects classes of IBPM are illustrated. Since our project is primarily concerned with design data of the building structure, the larger part of the model represents spatial elements and their inter-connections. The model is designed to provide three views of the design data, i.e. spatial view, separation view and structural view. While the spatial, separation and structural systems contain geometrical and topological data and also relationships between different elements (e.g., beam_1 is_supported_by column_1, etc), the project task system uses data from the three other systems in order to generate construction activities (or tasks) based on sequence and time (e.g. construct beam_1, construct column_1, etc.). Therefore, the model supports a forth view, the project task view.

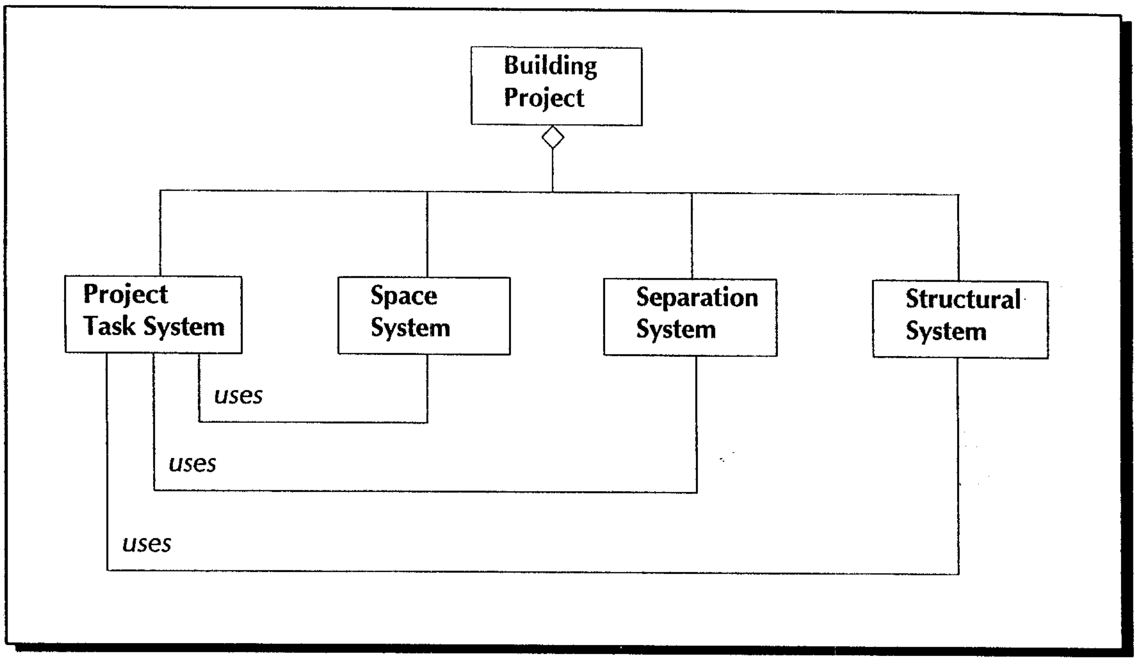

Figure 2. IBPM top-level object classes

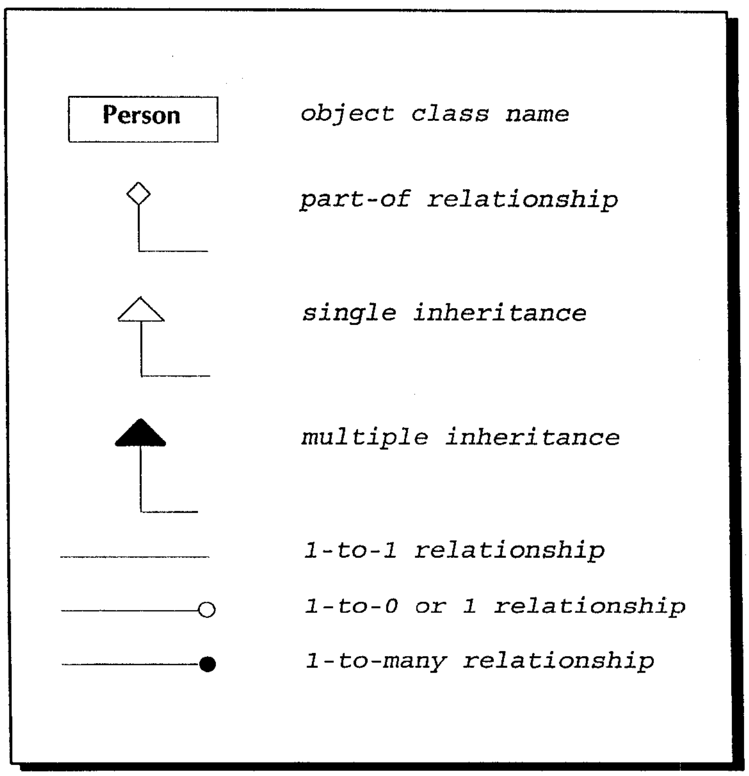

Figure 3. OMT Legend

4.1 MODELLING METHODOLOGIES

The methodology for modelling construction used in this project is OMT (Object Modelling Technique) [19]. It is an object-oriented modelling and design methodology that uses three king of models to describe a system: the object model, describing the objects in the system and their relationships; the dynamic model, describing the interactions among objects in the system; and the functional model, describing the data transformations of the system. Here only the object model was used which is the equivalent to product model.

Although this research aims to be compliant to ISO-STEP, it was felt that an object-oriented methodology like OMT is more complete in terms of supporting object-oriented concepts and techniques. OMT apart from "basic" support for inheritance, encapsulation, polymorphism, etc., utilises multiple inheritance, delegation, constraints and other advanced object-oriented techniques. The methodologies which are suggested by ISO-STEP namely NIAM, EXPRESS-G and IDEF1X have limitations. Also, it is necessary to use two different methodologies for describing a product model (one of the three mentioned) and process model (IDEF0). In OMT, the object model view of a system is the product model while the dynamic model view is the process model. The two models are designed to compliment each other. A legend of OMT (relevant to this paper) is described in Figure 3.

4.2 PROJECT TASK SYSTEM

In Figure 4, the four systems that comprise IBPM and the relationships amongst them are presented.

The Project Task System is used to describe information about the construction and use of the three other spatial systems. The system is structured around the Task (activity) class which represents project planning activities. The Construction Project Plan class contains information about the start and finish of the project, distinguishing between scheduled and actual finish and start times. It also describes total hours allocated to resources and project cost information. It also uses data from the Space system for tasks like furnishing, etc. A task is assigned to one or more resources represented as a resource group. It keeps information about time duration, preceding and succeeding task and float time. One or more tasks may be needed to construct a structural or a separation member.

4.3 SPACE SYSTEM

The Space System is concerned with describing all spaces in a building mainly from a functional point of view. A space is categorised as either a Room (kitchen, storeroom, office, etc.) or Circulation Space (corridor, lift well, etc.) but either types can be included to suit different applications. For each space, apart from description information, geometrical and topological information are also in scope. As is

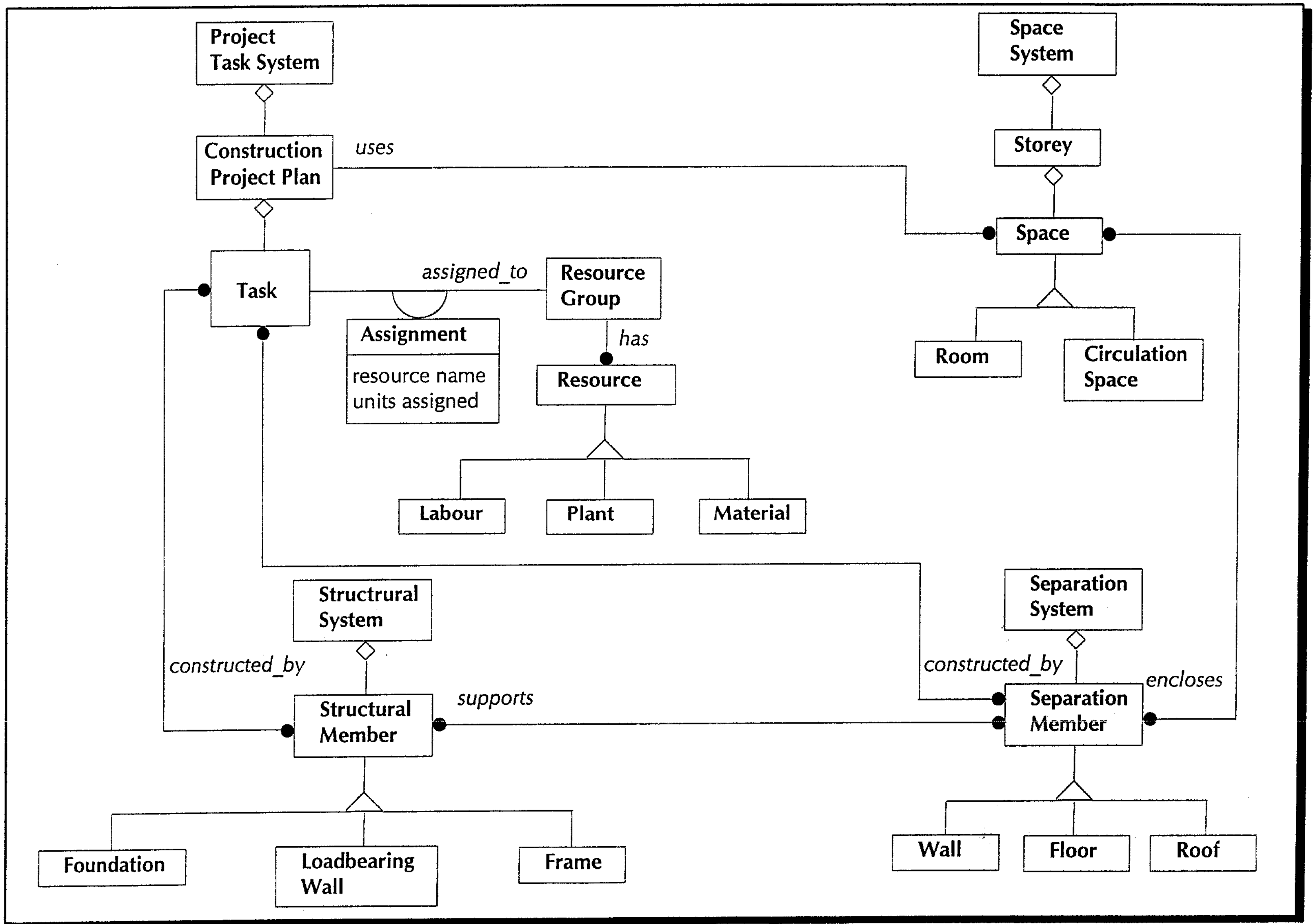

Figure 4. IBPM model

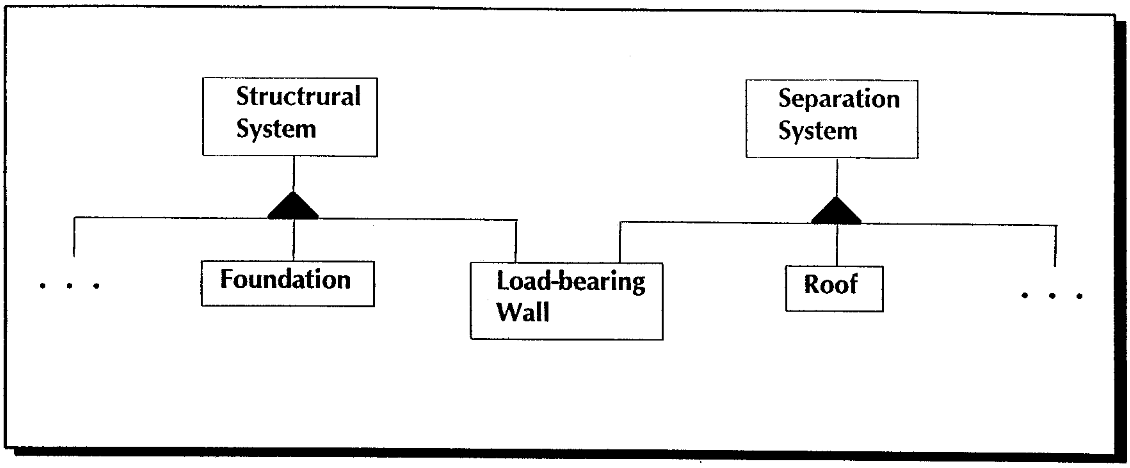

Figure 5. Load-bearing Wall inherits properties from both Structural System and Separation System (multiple inheritance)

depicted in Figure 4, Space has a number of separation (enclosure) elements where a particular separation element can enclose more then one spaces (many-to-many relationship).

4.4 SEPARATION SYSTEM

The Separation System is concerned with building objects which are used as vertical (walls) or horizontal (floors, roofs) separators. The function of separation members is to bound spaces. The case of Load-bearing Wall is of special importance. If a wall curries weight then is part of the Structural System (see next section). However, it can also be used as an enclosure element for a particular space in a building and hence is also part of the Separation System. Clearly, the class object Load-bearing Wall must inherit properties from both system. This is resolved by using multiple inheritance (Figure 5).

4.5 STRUCTURAL SYSTEM

The main purpose of the Structural System is to describe data that are related to load distribution. Elements that are in scope include Foundation, Load-bearing Wall and building Frame. For each one of them, different sub-types are included (omitted in here). The Structural Members provide support for the Separation Member as is shown in Figure 4. The system can easily be extended by adding more sub-types to Structural Member class if needed in particular applications.

5 GENERATION AND STORAGE OF CAD SEMANTICS

The problem of extracting spatial data from a CAD drawing which can then be used to construct an object-oriented product model is evident in many research efforts [6,12,16,]. However, the enhancement of CAD data with semantics is a necessity in order to develop intelligent integrated systems for AEC.

In linguistics, semantics is the study of meaning of language when used as a means of communication [21]. In information modelling, graphical representation methods such as conceptual graphs or semantic networks are used to explicitly represent semantics, which are relationships between two agents which may be people, things, events, etc. In the context of this research we endorse the same definition of semantics but we apply it to the description of relationships between building components.

Recent developments in artificial intelligence, in particular knowledge-based systems, have resulted in the realisation of techniques that facilitate the development of intelligent systems for decision support. However, the exploitation of these techniques in CAD-driven integrated systems is extremely difficult because of the incompleteness of the content of the data stored in CAD. Therefore, the aim of a semantic modeller is to enrich the data by using semantics and hence transform them into a declarative form, which can then be interpreted by knowledge-based systems (KBS).

The role of a KBS, within our application domain, is to use the semantically enhanced data in order to inference about project planning activities and also to determine precedence for the generated activities. It should also reason about allocation of resources (plant, labour, material, etc.). There is on-going parallel research in the School that is concerned with KBS support [22].

Previous research towards the integration of CAD with construction planning has attempted to develop CAD front-ends for capturing and extracting spatial data during design using different approaches. Ito et. al. [16] developed CIFECAD as a front-end to AutoCAD for data capture during building design. While the system demonstrates the generation of attributes and relationships from CAD drawings, it does not allow user intervention to resolve conflicts in exceptional cases and it does not provide a satisfactory solution towards data exchange between dissimilar applications. Cherneff et. al. [6] developed BUILDER which automates element identification. The relationships of elements are partly automated for straight forward relationships such as "part_of" and partly user-driven by prompting for the appropriate relationship. Seren et. al. [20] developed OOCAD which extracts attribute data for all defined building elements but depends on the user to identify

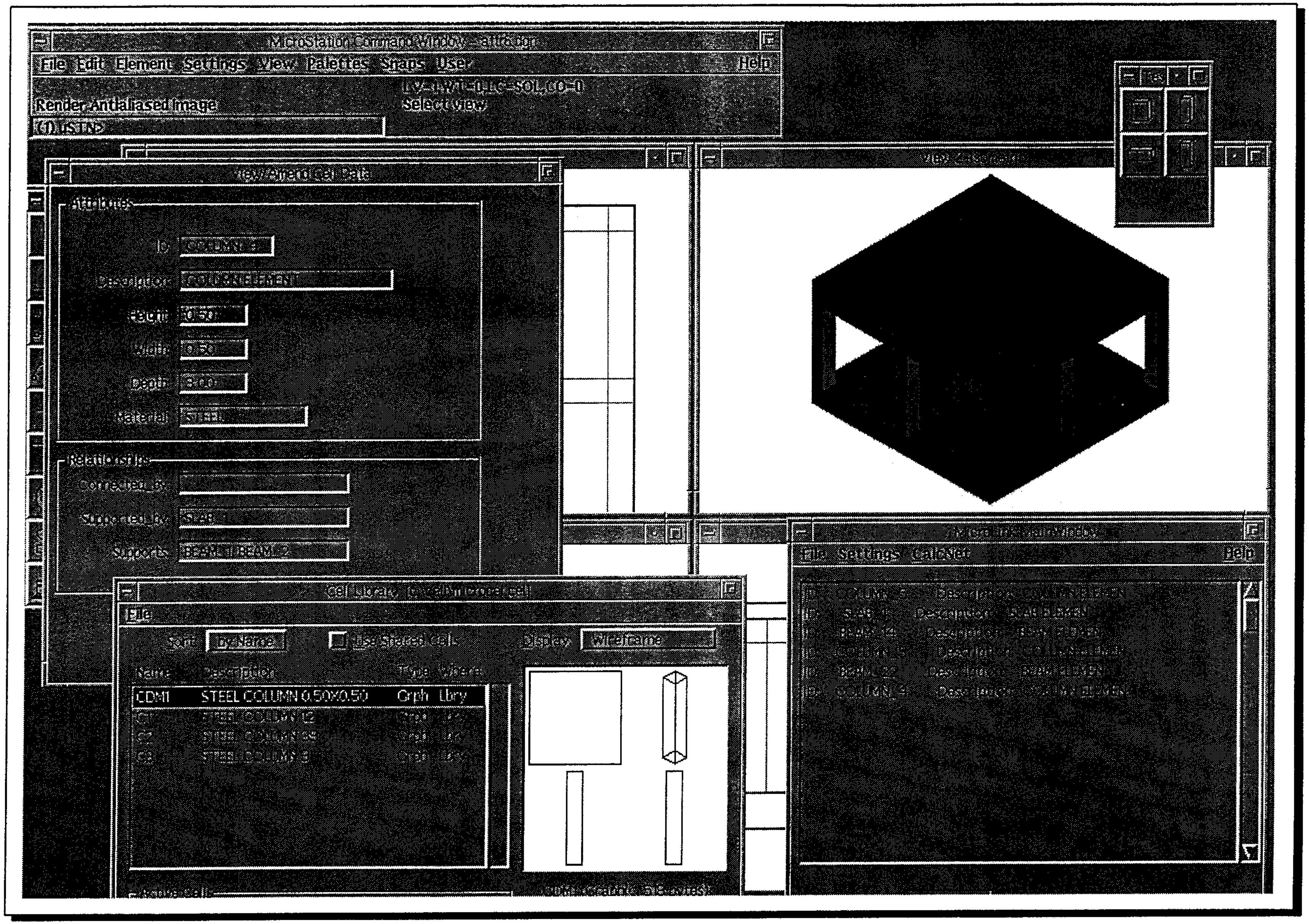

Figure 6. MicroLink prototype working session

relationships between two elements. The system is capable of storing data in neutral format.

From the above is evident that significant work still needs to be undertaken in the area of semantic data capture and representation in order to developed intelligent integrated systems coupled with KBS support that could be utilised in solving practical problems for the industry.

5.1 METHODS FOR IDENTIFYING ELEMENTS AND RELATIONSHIPS

A new approach was sought for identifying building elements and relationships. It is believed that the way forward is to automate the process as much as possible but also to give the user control over the data generated. Two methods for achieving this are proposed and are currently under implementation in a prototype system.

5.1.1 Pre-identification method

The pre-identification method, allows the relationships between objects to be automatically identified by capturing design intent. The system is capable of using the designer's intention and based on the stage of the design process it can infer the appropriate relationship. The "pre" affix refers to the fact that the relationship is established before the element is written in the design file.

5.1.2 Post-identification method

The post-identification method, provides a flexible way for the user to resolve conflicts with the system logic by interactively specifying a different relationship that overrides the one that was generated by this system. This is necessary due to the large number of different situations that can arise during building design. It is also an essential feature by the user's point of view since it gives control over the automatically generated data. The "post" affix here emphasises that the element in question is retrieved from the design file.

5.2 MICROLINK PROTOTYPE

The MicroLink prototype is being developed to act as an intelligent tool for capturing and storing semantically enhanced CAD data. The system works seamlessly as part of Integraph's MicroStation 3D CAD package under Windows NT in an Intel Pentium-P60 machine. MicroStation was chosen because it offers a robust and complete ANSI C development environment and is compliant to OSF/Motif style for graphical user interface (GUI) development [23]. The "pre-identification" method is currently used to automatically establish relationships between elements. The "post-identification" method is under development.

In Figure 6, a screen capture of a working session with MicroLink is illustrated. MicroStation provides four views of the drawing, top, left, right and isometric. In the isometric view, a 3D rendered image of a building frame is depicted. By clicking on the appropriate icon of an icon tool palette (upper right corner), the user can choose the element he/she wishes to place in the drawing. Each icon has attached to it a cell (symbol) library (bottom left corner) that can contain any number of different types of the same element (column cell library, slab cell library, etc.). Different users have the freedom to use their own specific element libraries. As elements are placed in the drawing, the system automatically generates attributes and relationships for each element. The user is able at any time to inspect the generated data and make any amendments, if necessary, by utilising a dialog box (upper left corner). The system functionality is controlled through the MainWindow dialog box (lower right corner). At present, a user attribute linkage is generated for each element to hold all extracted data and is save in the design file with the geometrical data. This facility is used temporarily since it is intended to use an ODBMS (ObjectStore) as the central data repository.

5.3 ODBMS

ODBMS provide the benefit of coupling together all advanced features that can be found in "traditional" database systems such as data modelling, persistence, recovery, query language, etc., with object-oriented capabilities such as abstraction, identity, encapsulation, inheritance, etc. [1]. The result is a powerful object-oriented environment where large quantities of complex data can be modelled, managed and shared efficiently.

In particular, CAD/CAE projects involve a number of designers who work in collaborative in order to design a complex structure. This is the case in building design where large volumes of data are generated and need to shared dynamically. ODBMS are far superior for use in such applications to relational data base management systems (RDBMS) because they result in more powerful and realistic data models and offer facilities for inheritance and schema evolution which are essential for model extensibility.

Moreover, the relational data model [7] cannot capture and control much of the semantics of complex applications [5]. ODBMS, due to their object-oriented nature, are able to maintain the combined data structure and behaviour of semantic data models. This is crucial to the objectives of this research project where the generation and storage of semantics is essential.

The choice of ObjectStore for use in this research was largely due to the availability of the product for PC platforms and because it supports most advanced features of ODBMS. Another important factor is the use of Visual C++ as the programming language for ObjectStore due to its suitability for engineering applications and the portability it provides.

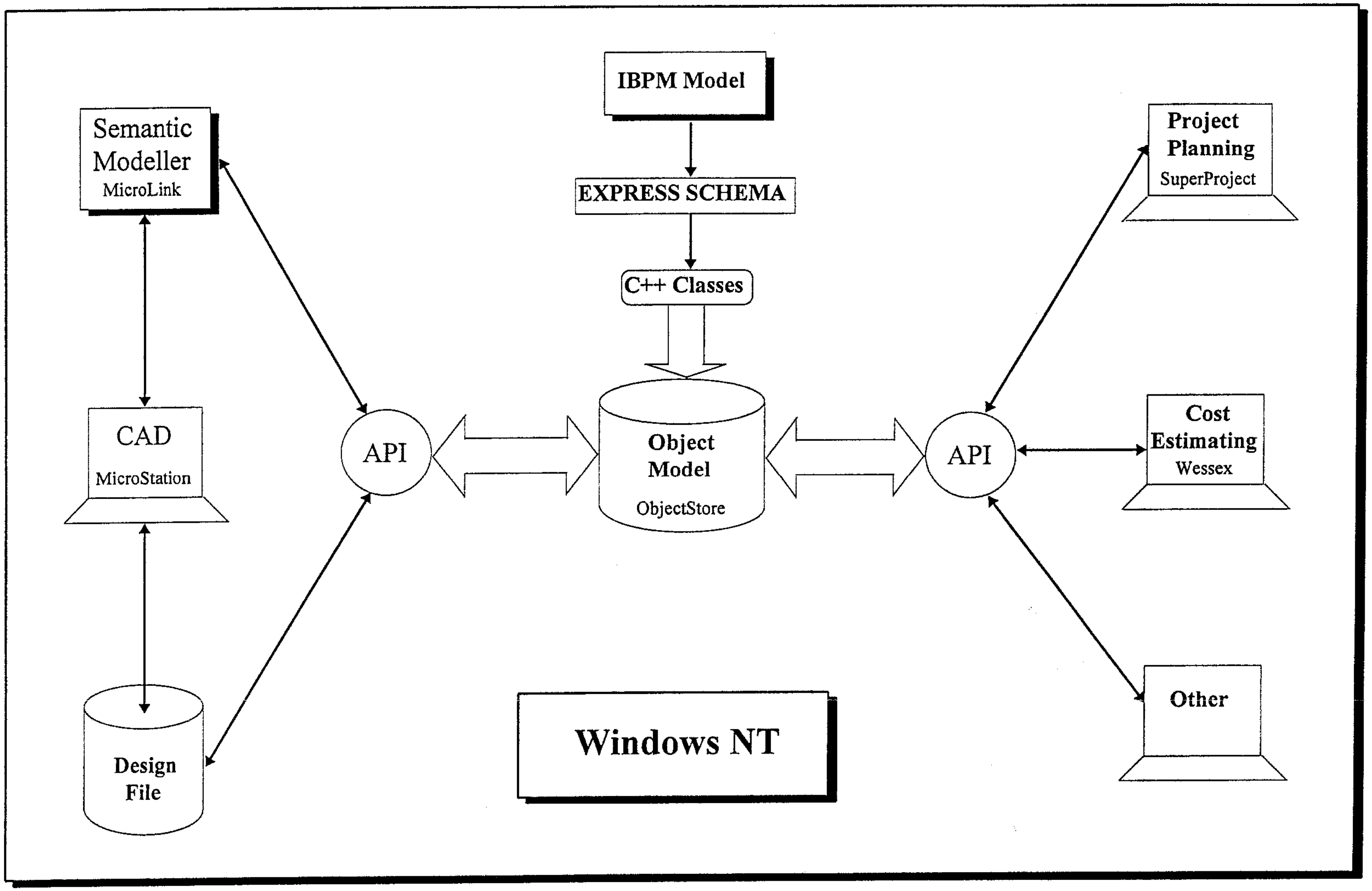

Figure 7. System Architecture

6 SYSTEM ARCHITECTURE

The proposed system architecture is presented in Figure 7. The IBPM model is translated into EXPRESS schema [15]. This is usually done by a CASE tool. Then the EXPRESS schema is mapped into C++ classes so that it can be entered into ObjectStore.

The CAD data, which include semantics provided by the semantic modeller and geometrical and topological data taken from the design file, are used to instantiate the relevant objects classes in ObjectStore. They access ObjectStore via an application interface (API) which takes care of the translation of the data into STEP instances. The link is bi-directional so that CAD can store or retrieve data from the object database. Other applications can have access to the data via their own APIs. They can also make their own data available to different applications by storing them into the object database.

7 CONCLUSION

This paper describes on-going research in the area of integrated AEC systems. A framework for modelling construction data into three different levels of abstraction was presented. Previous research efforts for developing product models for construction were discussed. IBPM, a product model that incorporates multiple views of the design data was presented. A prototype system (MicroLink) which is aimed at extracting semantically enhanced CAD data is under development. The suitability of ODBMS for CAD/CAE applications was argued. Lastly, the future system architecture was illustrated and the information sharing that takes place was discussed.

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