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An information engineering approach to modelling building design ☆

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Abstract

This paper highlights potential problems in the construction industry concerning the large quantities of information produced and the lack of an adequate information structure within which to coordinate this information. The Information Engineering Method (IEM) and Information Engineering Facility (IEF) CASE tool are described and put forward as a means of establishing an information structure at a strategic level thus providing a framework for the implementation of lower level applications systems.

The paper describes how the ICON (Integration/Information for Construction) project at Salford University is establishing and modelling the information requirements for the construction industry at the strategic level. The IEM and IEF are demonstrated using activity, data and interaction models with particular attention being paid to the function of building design within the broader context of design, procurement and the management of construction. Implications for future practice are also discussed.

Keywords: Information engineering; CASE tools; Modelling; Integration; Design

1. Introduction

The abundance and complexity of information in the construction industry along with a corresponding lack of management of this information has led to the industry becoming increasingly fragmented and uncompetitive. In addition the construction industry is very slow in adopting strategies, methodologies and techniques to help in the coordination and modelling of its data [1]. In order to improve this situation it is necessary to enhance the communication between the different disciplines involved in the construction industry and it is vital to establish an appropriate

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information structure to organise and maintain the data produced.

In the past, information modelling has tended to concentrate on either the data or process aspects of information independently of each other. The ICON project takes the view that it is crucial to consider both the data and the processes along with the interactions between them in order to establish the ways in which processes act on data and discover what changes are made to the data. Use of such an approach could ensure the design and implementation of appropriate information structures which will improve the integration of information within the construction industry.

The sharing of information brought about through the use of an integrated database system is seen as being of prime importance in this research. Data common to different disciplines can be stored in the database and shared across those different disciplines thus eliminating the need for data re-input. As long as data access and security is addressed as a management issue this will result in increased efficiency and accuracy when compared with traditional approaches. In addition, integration achieved in this way will facilitate efficient version control. The parties involved will always be working on the correct version of the information as the most up to date information will be able to be retrieved by authorised users.

This paper details the conceptual modelling of construction information, this is the initial stage of a process which will eventually lead to a fully integrated database system. Taking a strategic approach to the high level definition of an information framework will lead to well structured systems and databases which will facilitate the integration of construction information.

2. Previous work

A literature search has revealed extensive research in information modelling in the construction industry. Much of this work, however, has concentrated on the development of "ad hoc" applications, for example, knowledge-based interfaces linking multiple applications and multiple databases [2,3]. Some integrated systems have attempted to tackle problems encountered in information management but these are not brought together in a consistent way and there is no framework within which they can develop. Although the requirement for integrating information and improving communication has been highlighted by a number of researchers [4,5] there appears to be a general lack of knowledge regarding the establishment of an information strategy.

The value of establishing a framework for integrating information as opposed to developing adhoc applications lies partly in the ability for the incremental development of applications. It is not necessary for the full system to be established at one time, instead different parts of the system can be developed as and when necessary. Systems developed in this way conform to a common underlying model with the different areas remaining fully compatible. In addition data can be exchanged between all the applications developed within the framework thereby increasing efficiency and reducing data redundancy. The major approaches to information modelling in the construction industry were found to be data modelling, activity modelling and product modelling.

3. Information engineering

The approach taken in this paper, for the establishment of a strategic information framework, is that of the Information Engineering Method (IEM). IEM divides systems development into stages, initially causing information to be viewed at a high level of abstraction. With movement through the stages, data, activities and their interaction are viewed in increasing detail. This entire process is automated through the use of the Information Engineering Facility (IEF) Computer Aided Software Engineering (CASE) tool. It is unrealistic to expect a complete information system to be developed for the whole of the construction industry. This research therefore focuses on the three disciplines of design, procurement and the management of construction. In this paper particular attention is given to the conceptual modelling of the design activity as a provider of much of the information used in the later stages of the construction process.

Information Engineering Method (IEM) [15] is a methodology designed to simplify the development of information systems. These methods are fully explained by Martin [16]. Price Waterhouse [17], Yates [18] and Young [19] have all highlighted the difficulties found by companies in integrating Information Technology with their corporate strategy. This results in the development of information systems that are not aligned with the needs of the business. IEM forces analysts to align the information architecture with industrial goals, objectives and critical success factors. The Information Engineering Method applies techniques at the enterprise level rather than the project level. It progresses in a top down manner through seven stages (see Table 1). With progression through the stages data, activities and their interactions are viewed in increasing detail, ultimately resulting in the generation of actual information systems.

The Information Engineering Facility is the CASE tool which accompanies the Information Engineering Method, it automates the entire information systems life cycle. CASE tools are the software industry's equivalent of CAD tools. They employ graphical representations on screen to help automate the planning, analysis, design and generation of software. The diagrams are very effective for communication purposes as, using appropriate diagramming techniques, describing complex activities is easier through diagrams than text.

The core of a CASE tool is the central repository which is a comprehensive base of all the information needed to construct and document business systems. The repository is crucial due to the large amount of information generated when modelling which it is not practicable to manipulate and check manually. An important feature of CASE tools is that all the information stored in the repository is checked to ensure consistency and integrity. A further feature of CASE tools is that the information stored in the repository can be fed into the code generator of a CASE tool. This reduces the time and expense involved with programming and results in code with zero programming errors. The combination of the repository and the code generator enables high quality applications to be built quickly.

In areas such as Computer-Aided Design/Drafting, project management and word processing the importance of automated information modelling tools has been fully appreciated. However, automated information tools are not used. Instead of using CASE tools IT practitioners in the construction industry still carry out tasks such as the collection, collation and management of data using paper and translating them into databases using commercial packages such as dBase or Oracle. This approach is inefficient, especially in an industry such as construction which involves a huge amount of data and pro-

Table 1
The Information Engineering Method stages

Stage	Output
Information Strategy Planning	The establishment of a high level, strategic view of the information requirements of a business or industry.
Business Area Analysis	The development of a detailed conceptual model of a particular segment (Business Area) of the industry or business based on its information needs.
Business Systems Design	A detailed description of an application segment within a particular business system
Technical Design	The determination of the hardware, operating systems and Data Base Management Systems (DBMS) requirements.
Construction	Generation of the executable components of the system including programs, databases and screen formats.
Transition	The installation of the application systems
Production	Monitoring of the new system in operation, costs and benefits)

cesses. The ICON project has utilised both the IEM and the IEF CASE tool as a means of providing a high-level industrial framework for the construction industry. The approach will be demonstrated through the use of a case study of the building design activity.

4. Data modelling

In data modelling items of interest to the industry are identified and defined. The tools used are graphical schema languages (ERD, NIAM, IDEFIX) or data definition languages. An ERD (Entity Relationship Diagram) models the world in terms of entities, facts about them (attributes) and relationships between them. NIAM (Nijssen Information Analysis Modelling) is a data modelling technique which makes no distinction between entities and attributes [6,7]. IDEFIX is an enhanced entity relational modelling technique, NIAM and IDEFIX are being used by the developers of STEP. Fereshetian and Eastman [8] provide a comparison of the various graphical information models. The data definition language Express [6] adds a number of concepts which cannot be modelled in standard graphical tools such as rules and methods. In this paper the Entity Relationship Diagram is used as the technique for the data modelling section of the strategic information model.

5. Activity modelling

This involves the modelling of activities in a project and the data and material flows between them. Activity modelling simplifies the understanding of the construction process. Sanvido [9] has developed an integrated building process model that shows the hierarchical structure of functions and sub-functions performed in the construction project. Also, some work has been undertaken by Midken [10] to identify the different functions of the construction industry. Commonly used activity modelling techniques are IDEFO and SADT (Structured Analysis and Design Technique). In addition, work has also been carried out using object oriented methods [11] to integrate activities with product models. In the ICON project, activity modelling has been undertaken through the heirarchical decomposition of the construction activity into its component elements and through the use of process dependency diagrams to describe information flows between the activities.

6. Product modelling

This is used to model the components found in the building and the relationships between them. Much of the work on product modelling has been carried out by VTT in Finland [12,13]. Product modelling lacks the ability to address the differing information requirements of the various disciplines involved in the construction industry at a detailed level and may result in compromises having to be made. Bjork [14] has stated how the research emphasis is shifting in the area of product modelling from global solutions to local models.

7. Building design case study

The activity of design within the construction project is a complex interaction of activities and information which results in the production of a series of design representations. Whether or not design is undertaken using a Computer-Aided Design/Drafting tool, it is a layered process involving inputs from many sources including architects, structural engineers and technical experts. In addition, design evolves through an iterative process from the sketch-design stage through to the production of detailed documentation. Design thus involves constant communication between the various agents involved in the design activity.

It is necessary, in order to build an accurate information framework for the construction industry, to analyze the many and varied information sources and interactions involved in the design activity. This analysis was performed through the gathering of information from books and research papers and from interviewing academics and practising members of the professions involved. The analysis was documented using the toolkits available within the IEF CASE tool. This resulted in the production of a series of models which are being validated by a group of professionals from the construction industry.

7.1. The data modelling tool

This tool allows the definition of the logical data model. The data model is comprised of items of interest to the construction industry (entities), facts about them (attributes) and relationships between them. There are three categories of entity (Fig. 1): entities that store information about physical objects (for example, Surveyor Site) are called *tangible* entities; entities used to capture data about less tangible objects of interest to the industry (for example, Legal constraint) are called *conceptual* entities; entities used to store information about events that take place (for example Feasibility study, Soil analysis) are called *active* entities.

7.2. The activity hierarchy tool

This tool facilitates the decomposition of the high level design activities into more detail. Analyzing activities separately of data helps to understand the activities within the area being studied and the nature of the information required and produced by these activities. It is an extremely important aspect of modelling since the activity hierarchy model lays the foundation for subsequent systems design and implementation.

An activity hierarchy defines the activities carried out during the design phase of a construction project, it is concerned with WHAT is done, not by whom, when, where, or how. It is to be remembered therefore that the decomposition does not imply any temporal characteristics, although it may appear that this is the case. This is a mistake commonly made when viewing such a decomposition.

The activity model (Fig. 2) shows the very high level activities carried out during building design. The complete activity of designing a building is

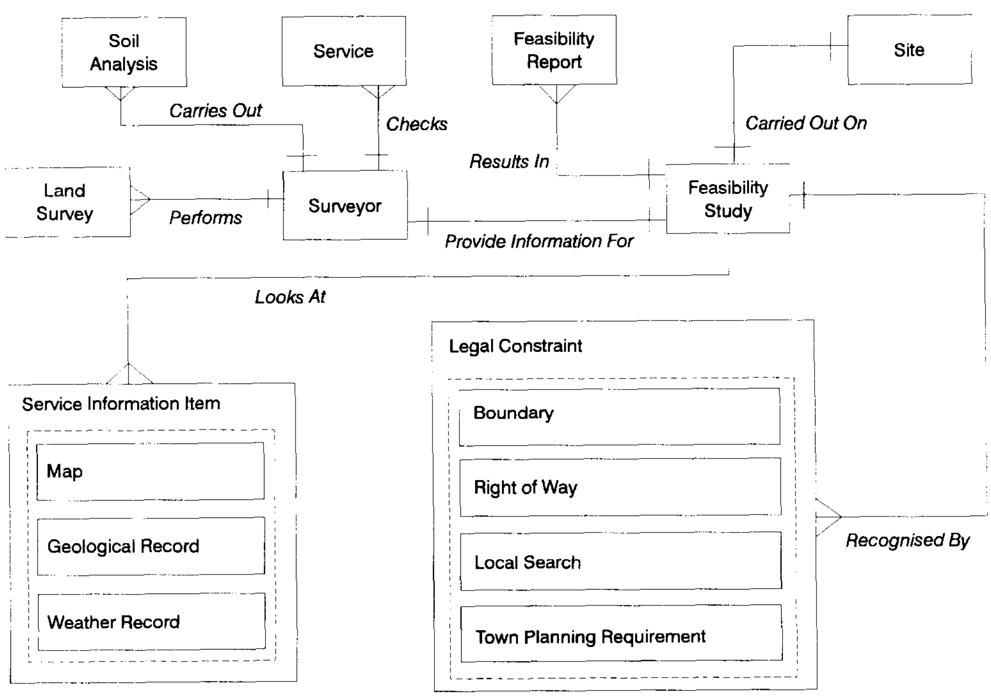

Fig. 1. Undertake feasibility study entity relationship diagram.

considered to have 8 major sub-functions. The three small circles in the top right-hand corner indicate that each of these sub-functions can be broken into further sub-functions (Fig. 3). The names of the functions do not describe what is to be carried out. In order to record this, the function is accompanied by a description which gives by a listing of the function's superordinate and subordinate activities.

Much of the work carried out in design is largely external to the process of actually "designing". These areas of work are undertaken, and modelled, in a fairly mechanical way and include activities such as determining client's requirements, undertaking a feasibility study and liaising with statutory bodies. Breaking down the actual "designing" activity into more detail proved problematic since each activity should define a discrete area. This is very difficult to undertake accurately due to the number of interdependencies existing within design. Although a breakdown was achieved, it is to be remembered that architectural, structural and the various aspects of technical design are not entirely separate activities but are heavily intertwined, with changes occurring in any one discipline having consequences for other disciplines. For example, an architect changing the dimensions of a wall may lead to the structural engineer having to recalculate loads on columns, beams and foundations, an HVAC engineer having to reconsider dimensions for a heating system and an electrical engineer having to redesign the wiring system. Alongside the difficulty in separating the different areas of design there is also the fact that design is an iterative process. This led to the establishment of the very loosely defined activities "Spatial Design", "Technical Design" and "Structural De-

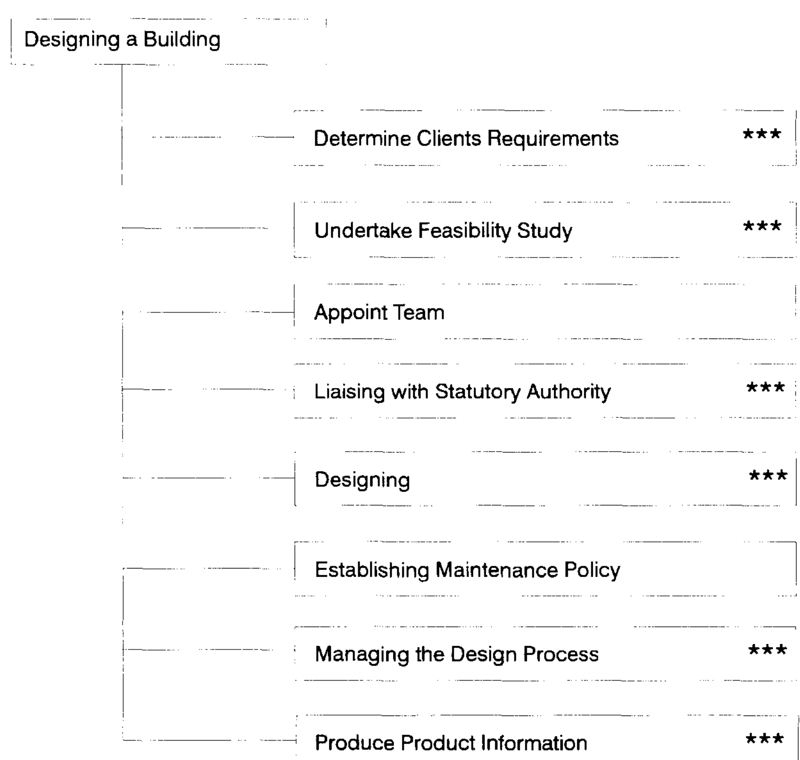

Fig. 2. High level activity hierarchy diagram for designing a building.

sign" which will each include the various stages of design from sketch through to working drawings.

7.3. The activity dependency tool

This tool verifies that the activity hierarchy established using the activity hierarchy tool is correct. In addition it facilitates the documentation of the sequence in which activities occur thus helping in the identification of dependencies between different processes and the description of information flows.

The output of this tool is a process dependency diagram. The symbols include arrows which show events, either internal or external to the activity, which trigger the execution of a process which affects the activity being described. External objects are used to show either the source of information to be used by the activity or the destination of information produced by the activity.

7.4. The matrix processor

Up to this point activity and data models, although produced simultaneously, are largely independent of each other: there is minimal checking of the interaction between them. At this stage it is necessary to carry out an interaction analysis by cross referencing activities and entities using the IEF Matrix Processor. This matrix records the expected effects of functions on entity types. An example of a matrix is displayed in Fig. 4. Activities may have one of four effects on data: they either create, read, update or delete it. For example, the function of establishing maintenance policy reads the entities production information item and building specification and creates a maintenance plan item. Priorities are such that if a function can create or delete an entity type it can also update and read it, similarly if an activity can update an entity type it can also read it.

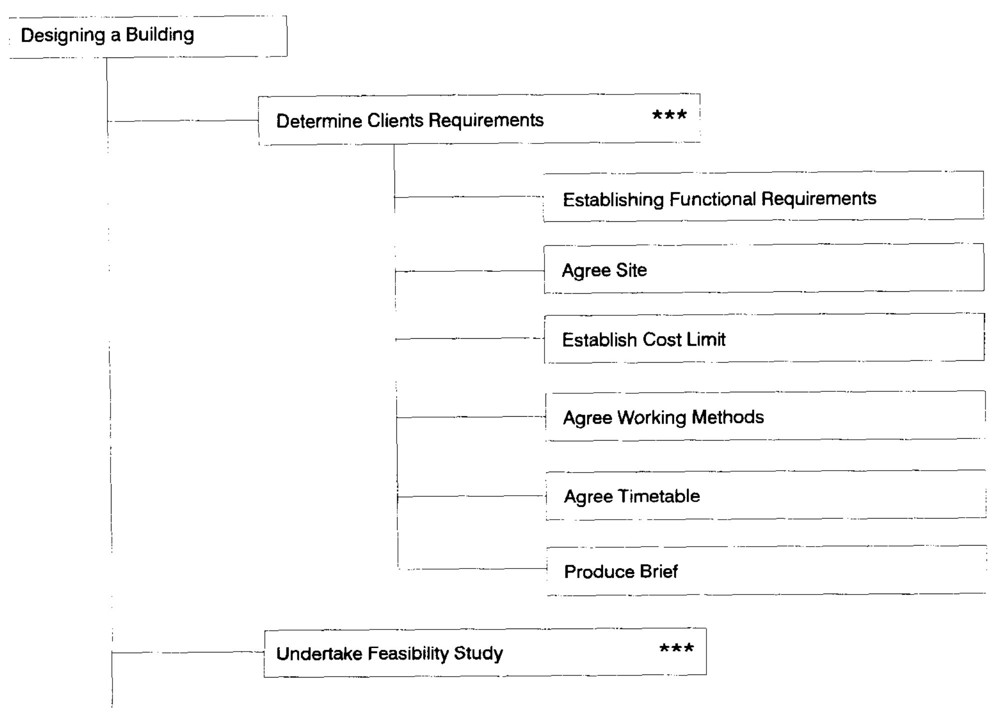

Fig. 3. Detailed level activity hierarchy diagram for designing a building.

Once the matrix has been populated, an automatic clustering and affinity analysis can be carried out. This process groups related facts into clusters based on their involvement with one another. These clusters form the basis for potential sub-divisions which can be implemented as separate systems. Systems developed in this way will be integrated yet developed a stage at a time.

7.5. Consistency checking

The consistency checking feature on the IEF toolkit allows the checking of the entire model or any part of it for completeness and consistency. The facility checks the model against a set of predefined rules, it does not validate that the right model is built but it does highlight missing and conflicting items.

7.6. The way forward: object oriented methods

This paper demonstrates the strength of the Information Engineering Methodology as a means of establishing a *strategic* information framework for the construction industry. It was found, however that certain areas of design were difficult to model accurately, for example the simple breakdown of design into spatial, structural and technical design — the modelling tool imposed too rigid a structure which prevented the richness and complexity of design to be represented accurately. In addition, in the use of the IEM when modelling at a lower level of abstraction there is the need to make compromises when attempting to incorporate the differing information needs of the various users of information.

In order to solve this problem, the ICON project intends to embrace object oriented methods utilising the object oriented CASE tool PTech and the object oriented database ONTOS in order to allow the individual perspectives of different disciplines to be incorporated within a single information model (Fig. 5). In particular, the techniques applied will allow objects to be classified and aggregated in the most suitable way for the requirements of each particular task or pro-

Business Function	Entity Type: Structural Design	Maintenance Plan	Building Feasibility	Building Project Condition	Legal Requirement	Statutory Authority	Etc.
Managing Document Changes	U	U			R		
Assembling Documents	R	R			R		
Producing Final Documentation	R	R			R	R	
Communicating Documents & Changes	R	R		R	R		
Preparing Tender Documentation	R	R		R	U		
Submitting Offer	R	R		R			
Suggest Procurement System			R	R	R		
Managing Business Areas					R		
Coordinating Management Function							
Establish Client Requirements	U	U			R	R	
Performing Feasibility Study	U	U	C		R		
Carry Out Structural Design	C	U	U		R		
Carry Out Technical Design	U	U	U		R		
Etc.							

Fig. 4. Simple CRUD matrix for designing a building.

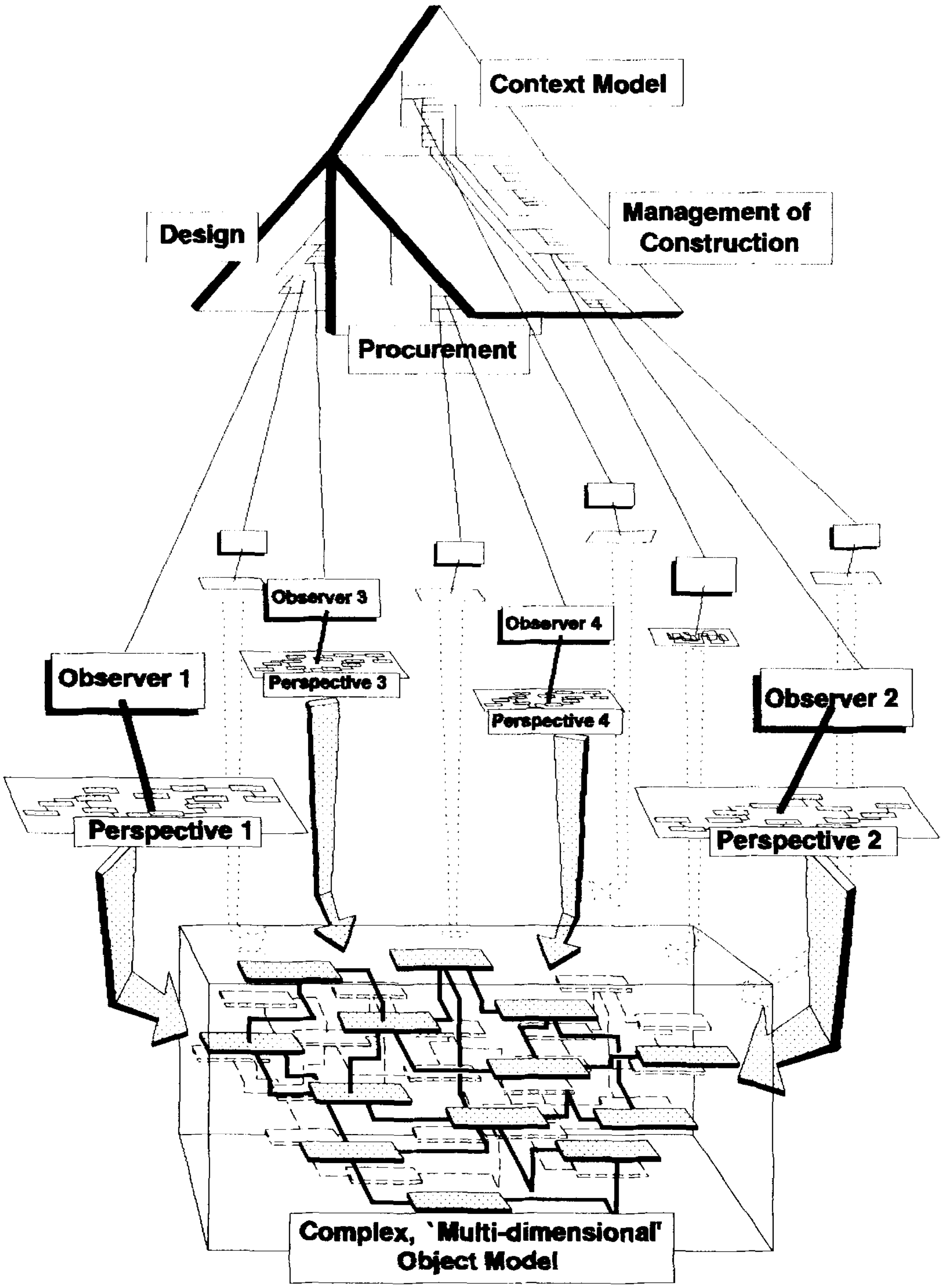

Fig. 5. Individual perspectives within a single model.

cess whilst still conforming to a common underlying information model.

8. The practical implications

This paper presented an approach used by the ICON group in the development of a framework for an integrated database for design and construction. In this approach, the IEM method and its associated CASE tool (IEF) have been used to establish a framework for an integrated database where the design aspect can fit. This framework will be taken further in the next stage of this project by incorporating some object oriented features to enhance the modelling phase. Once developed, the system will be used to model an existing church. The results of this task will be a set of AutoCAD and Superproject demonstrators which will demonstrate how commercial packages can interface with the integrated database.

The work presented in this paper covers an area of significant importance to the construction industry. As proper information modelling has become vital for the survival of this industry, it is essential to undertake this task within a framework. This modelling allows the establishment of sound and reliable information models for the building design process as well as other processes. This work is still however at its infancy. This field will be developing in the next few years. Information modelling will need to be performed properly before implementing physical databases. The models presented can make a starting point for the development of building design information models.

The work presented is of developmental nature which makes it difficult to be assessed. It is the mapping of the conceptual models into physical databases which makes the assessment exercise easier. This will be the subject of further research and another publication. The demonstrators mentioned before will be developed once the physical database is generated.

The ICON project once developed it will have many implications to the industry. First, information sharing between the various disciplines will be facilitated. Second, the design models as well as other models will fit within an integrated environment. Finally, the methodology developed by the project helps to establish a context for the information to be shared between the various disciplines.

9. Conclusions

This paper has stressed the importance of establishing a well defined information framework for the construction industry. Such a framework will provide a solid base for the development of information systems which will allow the coordination and management of the large quantities of information generated during a construction project. This, in turn, should aid communication between the different disciplines involved. The result of such an exercise should be an improvement in the productivity and competitiveness of the construction industry. The case study of building design demonstrates that such a framework can be defined at a very high (strategic) level and that the use of an automated information modelling tool such as the Information Engineering Facility is a very useful and efficient instrument with which to build such a framework.

Finally this paper concludes that although IEM and IEF are extremely useful for structuring information at the strategic level and providing a high level information framework, a move to object oriented methods and techniques would prove beneficial at the more detailed level in order to reflect the complexities of the construction industry as a whole and design in particular.

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