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Information modelling in the construction industry: The information engineering approach

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Modelling of knowledge in the construction industry is a cumbersome task because of the large amount of data involved and the lack of automated information-modelling tools. Adoption of a method and an automated CASE (Computer-Aided Software Engineering) tool could eliminate many problems encountered in the development of information systems in the construction industry. In particular, this approach may help to assess the information requirements and define strategies for such information systems. The Information Engineering Method (IEM) is introduced to illustrate how the conceptual models may be improved by using this method. Additionally Texas Instruments' Information Engineering Facility (IEF™) CASE tool is described to illustrate the advantages of automating such a method. The introduction of conceptual modelling in the construction industry using data and process models should lead to a better structuring of information. This should result in the development of well defined and structured, not *ad hoc*, applications. This conceptual modelling approach using information engineering is currently being used at the University of Salford to study the potential development of an integrated database (design, procurement and management of construction) for the construction industry. The case study describes the information analysis phase of the procurement process included towards the end of this paper.

Keywords: Information modelling, information engineering, procurement, computer aided software engineering (CASE) tools.

Introduction

In contrast to other major industries such as defence, manufacturing and banking, the construction industry is very slow in adopting strategies, methodologies and techniques that help the management and proper modelling and handling of its information. In addition, the development of *ad hoc* applications to solve certain problems are very common in the industry. Many of these applications are designed and set up as physical databases and lack proper analysis using conceptual modelling. Information modelling in the construction industry has concentrated over the years on either the data or process aspect of information. It is, however, important to consider *both* the data and the process (activity) models and the interaction between them. Use of this approach could ensure the design and setting-up of the appropriate information systems. It is essential to study the relevance and potential of an engineering approach to the development of software applications entailing the different stages of analysis, design, construction and implementation.

The issue of information management and modelling has been highlighted by many researchers in the construction industry: Hendrickson *et al.* (1987), Augenbroe (1991), Bjork and Wix (1991), Esprit II (1991), Bjork (1992), and Poyet *et al.* (1992). Most of these researchers covered reviews of the various data

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0144–6193

and process models used, such as Entity Relationship Modelling, NIAM, IDEFIX and activity modelling, and addressed the problems facing information modelling, but failed to suggest possible solutions. This paper, however, introduces a method of information modelling to the construction industry that does not describe a particular data or process model. The approach adopted is that of the Information Engineering Method (IEM) which deals with information systems development at a high level of abstraction. This high level of abstraction is then refined until actual working models and computer systems are developed, constructed and implemented. The automation of this method is achieved by the IEF™ (Information Engineering Facility) CASE tool. Both the Information Engineering Method and Information Engineering Facility are currently being used by a research team at the University of Salford to develop a model of an integrated database for use in the construction industry.

Previous work

A literature search has shown that there is an abundance of articles and research on information modelling in the construction industry, e.g. Fereshetian and Eastman (1991) and Bjork (1992). However, most of the work was related to the development of *ad hoc* applications. In addition, there is a lack of knowledge among construction professionals about the establishment of an information strategy approach. Such an approach can help in defining a general framework for information structuring in the construction industry. Edgill and Kirkham (1990) have addressed this matter by adopting a systems method in the development of integrated databases for quantity surveyors. The Australian Construction Service (ACS) has used the information-modelling approach on a major tender document. It has evaluated the results and in the light of that experience is now carrying out major revisions to the document. Recent work carried out by Bjork (1992) has shown that the complete framework for computer-integrated construction needs to be fully addressed and established. Such a framework would entail the analysis of information requirements for the construction industry as a whole. Product modelling on its own is not enough to define the information requirements for a construction project.

The major approaches to information modelling in the construction industry were:

(a) data modelling;
(b) activity modelling;
(c) product modelling.

These aproaches will now be described.

Data modelling

Data modelling allows the identification and modelling of information for a certain domain (Bjork, 1992). The tools used are graphical schema languages (ERD, NIAM, IDEFIX) or data-definition languages. The former are widely used in the construction industry. An ERD (Entity Relationship Diagram) models the world in terms of entities, their attributes, and their relationships (additional information can be found in the section on the Data Modelling Tool). NIAM is a binary data modelling technique which makes no distinction between entities and attributes (Bjork and Wix, 1991; Rasdorf and Abudayyeh, 1992). IDEFIX is an enhanced entity relational modelling technique. NIAM and IDEFIX are being used by the developers of STEP. Express, which is a data-definition language, is also used by the STEP developers, Bjork and Wix (1991). A comparison of the various graphical information models can be found in Fereshetian and Eastman (1991). In this paper, the ERD is used as a tool for the data modelling of the information model described in the case study.

Activity modelling

Activity modelling is used to model processes such as design, procurement, estimating and planning, and data and materials flow between these processes. This modelling approach helps in identifying the various processes involved and the data they require. This can be represented in an interaction model which shows what data are required for a certain process. Ideally the data and process modelling should be carried out in parallel. Sanvido (1990) has developed an integrated building process model that shows the hierarchical structure of functions and sub-functions performed in the construction process. Also, some work has been done by MIDKEN (1991) to identify the different functions of the construction industry. Commonly used activity-modelling techniques are IDEF0 (used by the STEP developers) and SADT (Bjork, 1992) that are based on the traditional approach. However, some researchers (Hendrickson *et al.*, 1987) have adopted another approach using object-oriented methods (mainly frames) to integrate activities with product models. It is worth mentioning that process modelling simplifies the understanding of the construction process and the development of typical applications such as plan and cost estimates. However, process modelling cannot be used as a means to translate conceptual models into physical databases. In this paper, the activity-modelling approach adopted is described in the activity-hierarchy and process-dependency tools described in the case study.

Table 1 The information engineering stages

Stage	Output
Information Strategy Planning (ISP)	The establishment of a broad view of the information requirement of a business or industry
Business Area Analysis (BAA)	A detailed analysis of a particular segment of the industry or business called the Business Area
Business System Design (BSD)	The design of the computer system(s) necessary to carry out all or part of a Business Area
Technical Design (TD)	Determination of the organization and structure of the computer system(s) with respect to the hardware and the operating system.
Construction	The building (generation) of the computer system programs.
Transition	The installation of the system
Production	The working of the new system

Product modelling

Product modelling can be considered as a sub-set of data modelling and can be used to model the components found in a particular product and their relationships (a building is an example of a product). Much of the work on product modelling originated in Finland (Bjork, 1992). Product modelling is very useful for defining a product model, but fails to address the complete information requirements of the construction industry. The solution sought is thought to be the combination of product, contractual/procedural and production modelling which is currently being examined in a study at the University of Salford. Also, Bjork (1991) has acknowledged the importance of such combinations. The case study described towards the end of this paper covers contractual/procedural modelling within the context of building procurement.

Information engineering

Information engineering (Davids, 1992) is a method developed to simplify the development of information systems. The literature search suggests that this method, used by industries such as defence, manufacturing and banking, has not been used in the construction industry. A problem highlighted by Yates (1991), Young (1991) and Price Waterhouse (1992) is that companies have difficulty 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. Information engineering is considered 'business driven' and not technology driven. It not only addresses the corporate objectives of the company but provides the information infrastructure in which to build the management information systems which enable the project team to manage their project. It should not be confused with software engineering, which is concerned with building a technically correct system (Shooman, 1985; Texas Instruments, 1990; Davids, 1992) and can be considered as a sub-set of information engineering. One aim of this paper is to introduce this method and to make information analysts in the construction industry familiar with this approach to information modelling. Information engineering is divided into seven stages of abstraction that incorporate the various phases of planning, design and implementation. These stages and their outputs are shown in Table 1.

The need for a Computer-Aided Systems/Software Engineering (CASE) tool

The use of a method such as the Information Engineering Method (IEM) requires the collection, storing, collating and printing of large amounts of information concerning the models of the business that are being developed. It is not practicable to manipulate and check all this information manually. Consequently software has been developed which records this information on a database, called either a repository or an encyclopaedia, from which it can be interrogated, retrieved, checked,

Table 2 Information-modelling tools

IEF CASE tool	Function	Output
Activity hierarchy	The identification and representation of high-level functions performed by the business	Function Decomposition Diagram
Data modelling	Graphical representation of data	Entity Relationship Diagram
Activity dependency	The representation of relations between activities	Process Dependency Diagram
Matrix processor	Interaction analysis between data and activities	Different types of matrices

printed and plotted. The software to carry out this task is called a Computer-Aided Systems/Software Engineering (CASE) tool. This database is a vital part of the business as it contains a model of the business and the rules it uses to carry out its day-to-day activities. In areas such as computer-aided design, project management and word-processing the construction industry has long recognized the importance of automated applications tools. However, the usefulness of automated information modelling systems (CASE tools) has yet to be fully appreciated. Instead of using these CASE tools the IT practitioners in the construction industry still carry out these tedious tasks on a sheet of paper and then translate them into databases using commercial packages such as dBase or Oracle. This approach is considered as inefficient, particularly in an industry that involves a huge amount of data and processes.

The benefits a CASE tool can offer to the development of information systems for the construction industry can be summarized as follows (Hewett and Durham, 1987):

- The cost and time of software development can be maintained according to the planned budget and timetable.
- The approach of planning, analysis, design and construction that is widely adopted and accepted by the construction industry can be used, as most methods and CASE tools are built around these aspects.
- The code-generation task is fully automated in some CASE tools. Construction-industry professionals, in collaboration with information-technology specialists, can carry out the planning, analysis and design tasks. The computer systems code, COBOL, C etc., will be automatically generated by the CASE tool and the need for programming will be significantly reduced.
- The cost of maintaining the software is kept to a minimum.

This paper adopts the IEF CASE tool that is used to automate the seven stages shown in Table 1. The following case study illustrates the usefulness of this automated tool during the analysis phase of an information model for the building procurement process.

Case study (building procurement)

The construction industry consists of a series of processes such as design, procurement, estimating and planning, which manipulate data such as briefs, schedules and cost plans. Therefore it is very important to adopt a method to define the information requirements of the various processes and data types. In addition, the use of an automated information-modelling tool helps the planning, analysis, design and implementation of the information systems. In this case study, the building-procurement process is used as an example to illustrate the usefulness of this approach as procurement (Turner, 1990) is a very important aspect of the construction process.

Procurement covers the collective action required to obtain the design, management and installation inputs for a construction project or some related aspect of the built environment (Yates, 1991). The procurement issue has been given equal importance to that of design and management of construction, for usually the success of a construction project can to a large extent depend on the selection of the appropriate procurement path. Building procurement is considered a business area of the construction industry where information is analysed. It is assumed that this area has been identified at the information-strategy planning (shown earlier in this paper in Table 1). The information analysis is taking place at the second level of the Information Engineering Method (Business Area Analysis). The IEF CASE tool automates these tasks as described in Table 2.

Procurement paths

Contacts with academics, professional workers and a literature search (Brandon *et al.*, 1988; Bennett and Grice, 1990; Edgill and Kirkham, 1990, Birrel, 1991; Yates, 1991) has confirmed that the different procurement paths used in the construction industry can be summarized as follows:

- Traditional
  - Sequential
  - Accelerated
- Design and build
  - Direct
  - Competitive
  - Design and construct
- Management
  - Management contracting
  - Construction management
- Design and manage
  - Contractor
  - Consultant

For a full description of these procurement paths, the reader can refer to Seeley (1984), Brandon *et al.* (1988) and Edgill and Kirkham (1990). These procurement paths have been used to capture the information that will be used in the modelling stage.

The activity hierarchy tool

The first step is to identify the very high level functions performed during the procurement process (Aqua Group, 1990). The output of this phase is a function-decomposition diagram. A function is an activity which represents what and why is carried, *not* who, when, where or how. It should not be confused with a list of the functions within a company. The activity hierarchy for the PROCUREMENT function is shown in Fig. 1. The PROCUREMENT function is considered to have five major sub-functions. In this case the order of the sub-functions corresponds to the order in which they would be followed in the procurement process. It should be understood that this is not always the case. The purpose of the activity hierarchies is to identify the functions and group them together. (The order in which which they are activated is shown in the Activity Dependency Diagram (see Fig. 8 for an example)). The small circles at the top right-hand corner indicate that each of these sub-functions can be broken down into further sub-functions (see Fig. 2). Activity or process modelling in the construction industry has recently been considered more seriously by information analysts such as Sanvido (1990). The use of a CASE tool to record activities performed by the construction industry simplifies and improves the process-modelling phase.

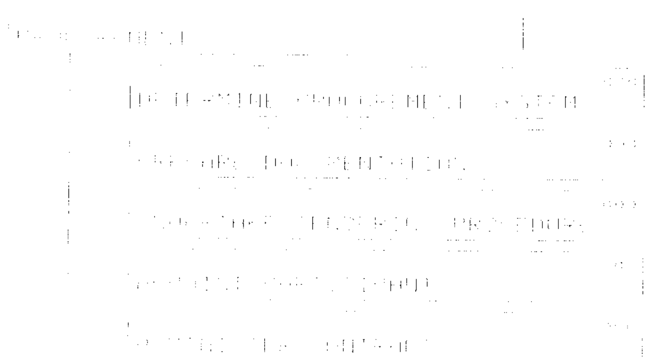

Figure 1 High-level functions of procurement. (All figures are produced from diagrams which appear on the screen of the IEF.)

The names of the functions in Fig. 1 do not describe in detail what is to be carried out. To document this aspect, the functions are described so that users will understand their purpose (see Fig. 3). The description is also accompanied by a listing of the superordinate and subordinate functions.

The decompositions of the other three functions could be seen by scrolling down through the screen. As was mentioned previously, the activity hierarchy does not indicate the order in which the functions are carried out. For example SUGGEST PROCUREMENT PATH has three subordinate functions. If ACCEPT PROCUREMENT PATH is followed then REJECT PROCUREMENT PATH and SUGGEST ALTERNATIVE would be ignored and vice versa. The order in which functions are activated would be shown on an Activity Dependency Diagram (see Fig. 8 for an example).

The data-modelling tool

An entity is a fundamental thing of relevance about which data may be kept. There are three categories of entities. Entities that store information on physical objects (like CLIENT and PROJECT, see Fig. 6) are called *tangible* entities. Entities used to capture data about less tangible concepts of interests to the enterprise are called *conceptual* entities. Examples include PROJECT FINAL ACCOUNT and PROJECT CONSTRAINTS. Finally, entities used to represent information about events that take place are called *active* entities. Examples include SITE MEETING and ACCEPTANCE. Identifying the entities is only part of the information required. The other part is finding the association between entities. This association is called a relationship and is defined as 'a reason of relevance to the enterprise for associating entities from one or two entities'. For example, Fig. 4 has entities CLIENT and CLIENT REQUIREMENT represented by the rectangles. The relationship between them is represented

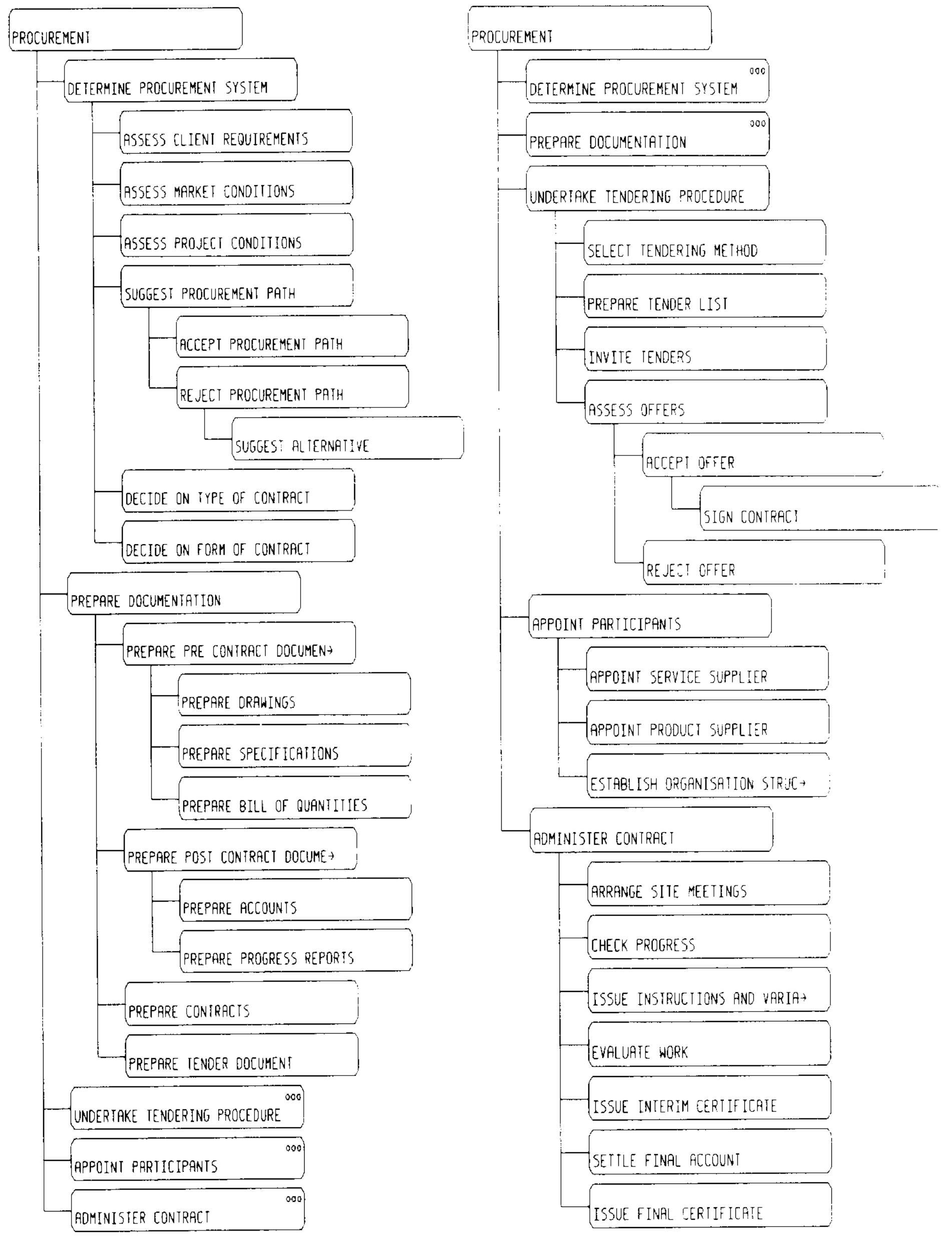

Figure 2 Decomposition of the high-level functions of procurement

by a line. The relationship is named in both directions to give it a unique identification. This would read CLIENT *DEFINES* CLIENT REQUIREMENT and CLIENT REQUIREMENT *IS DEFINED BY* CLIENT. A CLIENT REQUIREMENT *IS DEFINED BY* only one CLIENT, the bar next to the CLIENT entity signifies one. However a CLIENT *DEFINES* one or many (the 'crow's foot' symbol next to the CLIENT REQUIREMENT entity) CLIENT REQUIREMENT at any one time.

These diagrams are called Entity Relationship Diagrams (ERD) and capture the information and the relationships between the information and model the rules to which the enterprise operates. For example the rules of the enterprise modelled in Fig. 4 state that **every** CLIENT REQUIREMENT must have a CLIENT and that a CLIENT can be involved with zero, one or many CLIENT REQUIREMENTs. That is we consider as a CLIENT somebody with whom we worked with in the past but presently who has no active CLIENT REQUIREMENTs. This is very important as it means that the CLIENT will still be in the information system even though not active. In other words the CLIENT details are available so that contact can be maintained.

Identification and modelling of these data types and

Model : PROCURE
Subset: (complete model)

29 Oct 1992 09:56
Page 1

Activity Definition

NameDETERMINE_PROCUREMENT_SYSTEM

Description:The "determine procurement system" process is used to determine a procurement path for a certain project. The factors which can affect this process are: market and project conditions and the client requirements.

Type: Function

Subordinate of:PROCUREMENT

Subordinates:ASSESS_CLIENT_REQUIREMENTS
ASSESS_MARKET_CONDITIONS
ASSESS_PROJECT_CONDITIONS
SUGGEST_PROCUREMENT_PATH
DECIDE_ON_TYPE_OF_CONTRACT
DECIDE_ON_FORM_OF_CONTRACT

NamePREPARE_DOCUMENTATION

Description:This process identifies the various documents required to run a construction project: drawings, specifications, contracts, etc.

Type:Function

Subordinate of: PROCUREMENT

Subordinates:PREPARE_PRE_CONTRACT_DOCUMENTATION
PREPARE_POST_CONTRACT_DOCUMENTATION
PREPARE_CONTRACTS
PREPARE_TENDER_DOCUMENT

Figure 3 Activity descriptions of the high-level functions of procurement

their interrelationships can be very tedious if carried out manually as the diagram would have many entities and associated relationships, typically in the hundreds. The production of this data model is fully automated within the IEF CASE tool and the user can interact with the screen of the tool to define entity types, relationships between these entity types and attributes. Attributes describe the data content of the entity. For example in the ERD of Fig. 5 the PROJECT entity would have attributes such as START DATE, COMPLETION DATE, PRICE, etc. The plus sign (+) in the top left-hand corner of the box indicates (see PROCUREMENT PATH and SUPPLIER) that there was not enough room to draw a relationship line. In the case of SUPPLIER this was probably due to the fact that there was no room on the sides of the box. For PROCUREMENT PATH it was probably due to the fact that it was not possible to calculate a simple path from the other entities. It should not be assumed that the missing relationship line is between PROCUREMENT PATH and SUPPLIER although it well might be. It can be seen that drawing, and more importantly the re-drawing and checking, of the ERD can be very tedious and error prone.

Figure 6 lists the entities, though not the relationships, that are involved in the procurement process. On examination it can be seen that the entity PROCUREMENT PATH has sub-types of DESIGN AND MANAGE, MANAGEMENT CONTRACTING, CONSTRUCTION MANAGEMENT, DESIGN AND BUILD and TRADITIONAL. These sub-types inherit the same type of information (attributes) from the entity PROCUREMENT PATH and combine it with their own attributes, see also Fig. 5. The concept of entity and sub-types are a simple form of inheritance in that common entities can be grouped together under one entity. This grouping together of entities also simplifies the ERD of Fig. 5. The fact that the entity PROCUREMENT PATH has sub-types is denoted by the three small circles in the top right-hand corner of the box. The PROJECT entity has no sub-types but SUPPLIER does. It is also desirable to describe the entities so that users will understand what the entity represents (see Fig. 7).

The activity dependency tool

The main aims of the activity dependency tool are to verify that the decomposition process described in the previous section is correct. In addition, this tool can help in identifying the dependencies between the various processes, thus information flow can be better described. The output of the activity dependency tool is the Process Dependency Diagram. An example of this diagram is shown in Fig. 8. The arrows show internal and external events that can trigger operations affecting the process under consideration. External objects (two stacked boxes) can also be used to show sources of information to be used by particular processes.

The matrix processor

So far the user has developed the activity and data models in parallel with only the minimum of checking of the interaction between them. The next stage is to carry out an Interaction Analysis to ensure that the right information is available to be acted upon by the function and vice versa. The matrix processor shows interactions between the functions and entity types (Fig. 9). For example the process ASSESS CLIENT REQUIREMENT creates (C) the entity CLIENT and updates (U) the entity type CLIENT REQUIREMENT. The matrix processor is used as a checking aid to verify the effects that functions can have on data or entities and which functions use which entities.

Once the matrix of entities against functions has been validated, the matrix processor can 'cluster' the groups of functions that interact with a particular set of entities. This divides the information model into logical parts which can then be implemented as separate systems. This allows the system to be developed in stages whilst still working within an overall structure. The systems developed in this way will be integrated and yet will be developed a stage at a time.

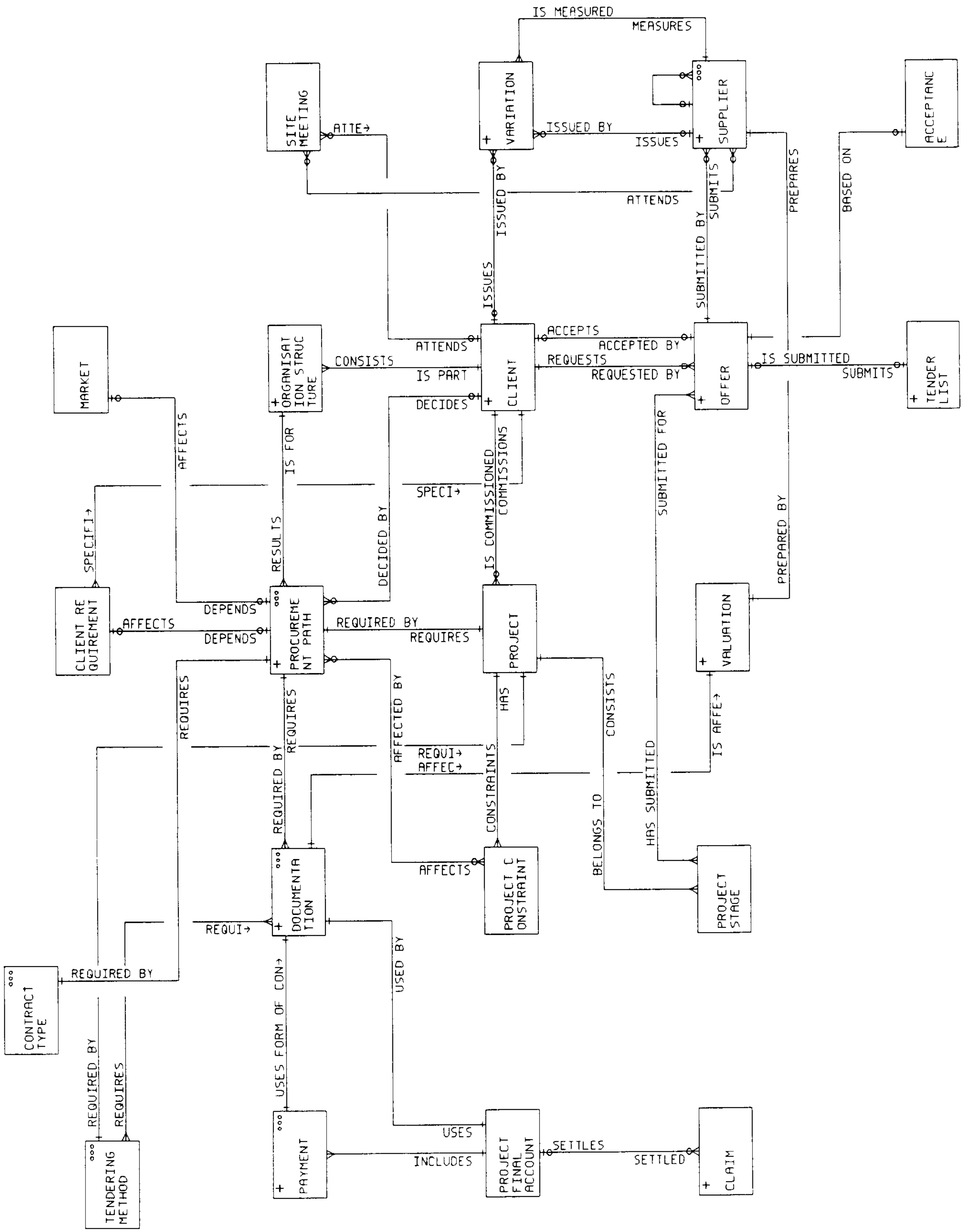

Figure 4 Entity Relationship Diagram

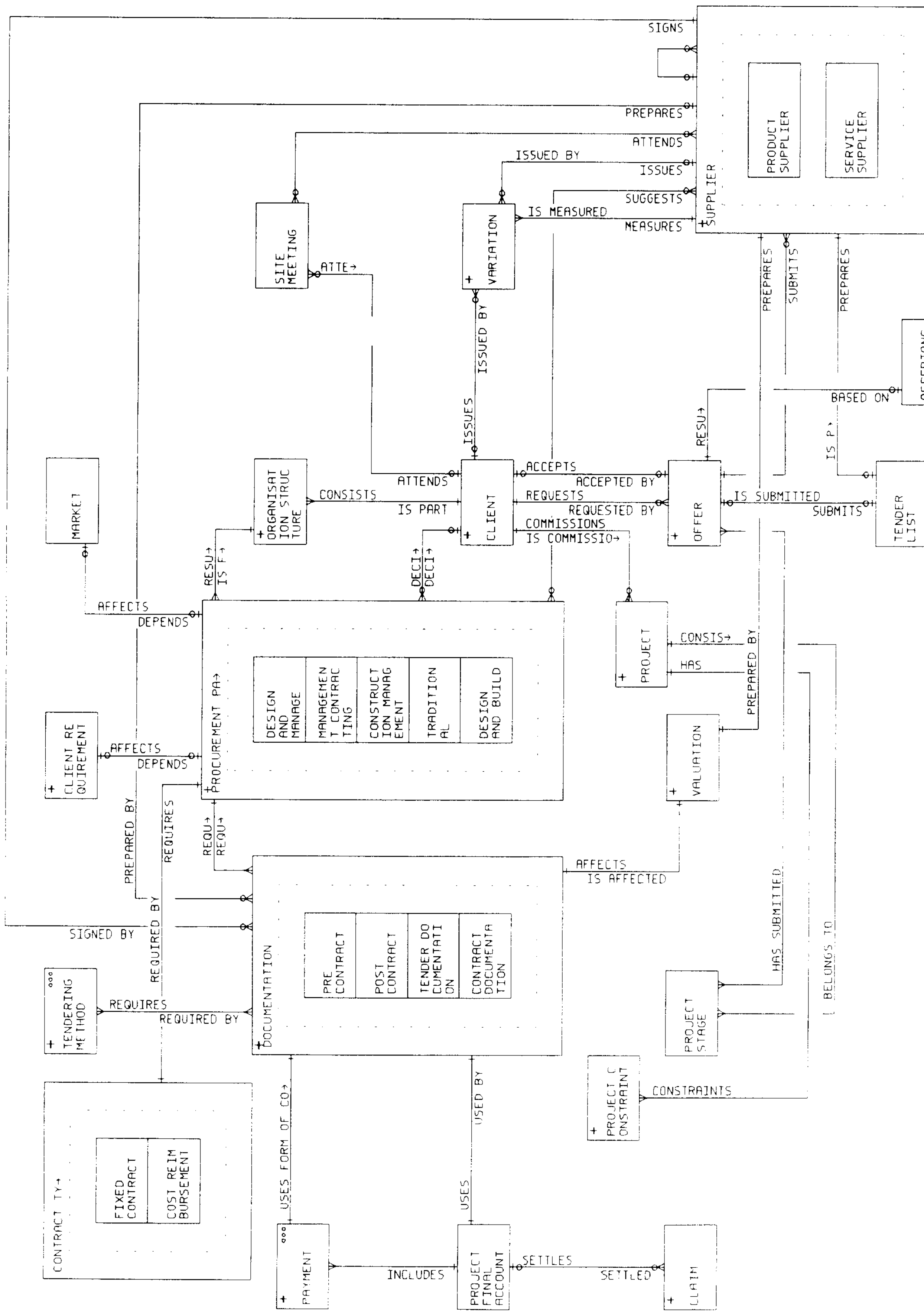

Figure 5 Extended Entity Relationship Diagram

Model : PROCURE 29 Oct. 1992 09:48
Subset: (complete model) page 1

Entity Hierarchy

Entity: ACCEPTANCE
Entity: CLAIM
Entity: CLIENT
Entity: CLIENT_REQUIREMENTS
Entity: CONTRACT_TYPE
  Subtype: COST_REIMBURSEMENT
  Subtype: FIXED_CONTRACT
Entity: DOCUMENTATION
  Subtype: CONTRACT_DOCUMENTATION
  Subtype: TENDER_DOCUMENTATION
  Subtype: POST_CONTRACT
  Subtype: PRE_CONTRACT
Entity: MARKET
Entity: OFFER
Entity: ORGANISATION_STRUCTURE
Entity: PAYMENT
  Subtype: FINAL_PAYMENT
  Subtype: INTERIM_PAYMENT
Entity: PROCUREMENT_PATH
  Subtype: DESIGN_AND_MANAGE
  Subtype: MANAGEMENT_CONTRACTING
  Subtype: CONSTRUCTION_MANAGEMENT
  Subtype: DESIGN_AND_BUILD
  Subtype: TRADITIONAL
Entity: PROJECT
Entity: PROJECT_CONSTRAINT
Entity: PROJECT_FINAL_ACCOUNT
Entity: PROJECT_STAGE
Entity: SITE_MEETING
Entity: SUPPLIER
  Subtype: SERVICE_SUPPLIER
  Subtype: PRODUCT_SUPPLIER
Entity: TENDERING_METHOD
  Subtype: SERIAL_TENDERING
  Subtype: EXTENSION_CONTRACT
  Subtype: NEGOTIATED_TENDERING
  Subtype: SINGLE_TENDERING
  Subtype: SELECTIVE_TENDERING
  Subtype: OPEN_TENDERING
Entity: TENDER_LIST
Entity: VALUATION
Entity: VARIATION

Figure 6 List of entities

Model : PROCURE Sept. 03, 1992 13:19
Subset: (complete model) page 1

Entity Definition

Entity:	DESIGN_AND_MANAGE
Description:	The client appoints a single firm to design and deliver the project. It could be contractor or consultant based.
Subtype of:	PROCUREMENT_PATH
Entity:	MANAGEMENT_CONTRACTING
Description:	The client appoints a management contractor to deliver the project to an agreed price and on time.
Subtype of:	PROCUREMENT_PATH
Entity:	CONSTRUCTION_MANAGEMENT
Description:	A construction firm is approached to provide management service, but the specialist contractors enter into direct contracts with the client.
Subtype of:	PROCUREMENT_PATH
Entity:	DESIGN_AND_BUILD
Description:	In design and build, the client goes directly to the contractor who does both the designing and the building. The production team providing services such as assessing the building contractor's design or monitoring the work on site.

Figure 7 Typical descriptions of the Entity Relationship Diagram

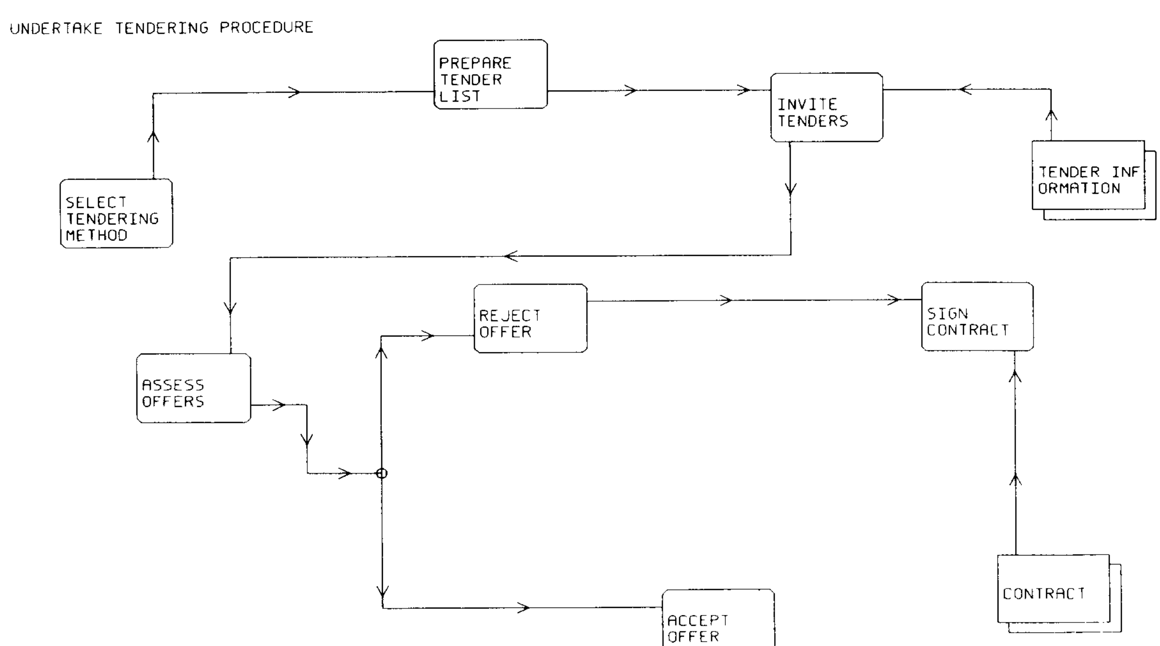

Figure 8 Activity Dependency Diagram

Cell Values:

- No reference

C - Create

D - Delete

U - Update

R - Read only

Business Function \ Entity Type	DOCUMENTATION	PROJECT FINAL ACCOUNT	PAYMENT	VALUATION	VARIATION	CLAIM	SUPPLIER	CLIENT	CLIENT REQUIREMENTS	PROCUREMENT PATH	MARKET	PROJECT CONSTRAINT	TENDERING METHOD	CONTRACT TYPE	ORGANISATION STRUCTURE	TENDER LIST	SITE MEETING	ACCEPTANCE	PROJECT	PROJECT STAGE	OFFER
ASSESS CLIENT REQUIREMENTS								C	C	U											
ASSESS MARKET CONDITIONS										U	C										
ASSESS PROJECT CONDITIONS										U									C	C	
ACCEPT PROCUREMENT PATH										C											
SUGGEST ALTERNATIVE										C											
SELECT TENDERING METHOD									R	R	R	R	C						R		
DECIDE ON TYPE OF CONTRACT							R		R	R	R	R	R	C							
PREPARE CONTRACTS	U									R			R	R							
PREPARE TENDER DOCUMENT	U												R								
ISSUE INTERIM CERTIFICATE	U	U	C	R																	
SETTLE FINAL ACCOUNT	U	C	R	R	R	R	R														
ISSUE FINAL CERTIFICATE	U			R	R	R															
PREPARE PROGRESS REPORTS	U			R																	
CHECK PROGRESS	U			R																R	
PREPARE ACCOUNTS	U		R	R																	
DECIDE ON FORM OF CONTRACT	U						R			R											
SIGN CONTRACT	U						R	R													R
PREPARE DRAWINGS	U																				
PREPARE SPECIFICATIONS	U																				
PREPARE BILL OF QUANTITIES	U																				
ISSUE INSTRUCTIONS AND VARIATIOS	R				C	C								R							
ARRANGE SITE MEETINGS	R						R	R									C				
INVITE TENDERS	R						R													R	
EVALUATE WORK				C																R	
ESTABLISH ORGAN[illegible]ATION STRUCTURE							R	R		R					C						
PREPARE TENDER LIST											R					C					
APPOINT SERVICE SUPPLIER							C				R										R
APPOINT PRODUCT SUPPLIER							C				R										R
REJECT OFFER																					U

Figure 9 Grouped entity/function matrix diagram

Consistency checking

The tool can also be used to check the various data and function models for completeness and consistency (Fig. 10). These checks will not validate that the right model for the business is being built. They will, however, highlight missing and conflicting items. Removal of these errors will prompt an evaluation of the model which will uncover errors and misunderstandings before any work is started on building the computer system.

Maintenance

Once the system is in production it will have to be maintained. In other words as the enterprise changes, because of both internal and external events, then the software systems will have to be modified to take account of these changes. The IEF CASE tool has reports which can help in the maintenance phase (Fig. 11). Let us imagine that the entity PROCUREMENT PATH has to have extra attributes added. This entity may be used by a large number of functions. A Where Used Report

Model : PROCURE — Sept. 03, 1992 16:59

Subset: (complete model) — page 14

Consistency Check

Entity Type	PROCUREMENT_PATH
ERROR	: Each partitioning must be defined by a classifying attribute.
ERROR :	Each entity type must have an identifier to use the DSD.
SEVERE WARNING	: Each entity type must have an attribute for codegen.
WARNING	: An entity type should have maximum number of occurrences defined.
WARNING	: An entity type should have an average number of occurrences greater than 0.
Relationship	PROCUREMENT_PATH_SUGGESTED_BY_SERVICE _SUPPLIER
WARNING :	A relationship should have expected optionality defined.
Relationship	PROCUREMENT_PATH DECIDED_BY CLIENT
WARNING	: A relationship should have expected optionality defined.

Figure 10 Fragment of a consistency check report.

PROCUREMENT_PATH is used by:

Function ACCEPT_PROCUREMENT_PATH
Function ASSESS_CLIENT_REQUIREMENTS
Function ASSESS_MARKET_CONDITIONS
Function ASSESS_PROJECT_CONDITIONS
Function DECIDE_ON_FORM_OF_CONTRACT
Function DECIDE_ON_TYPE_OF_CONTRACT
Function ESTABLISH_ORGANISATION_STRUCTURE
Function PREPARE_CONTRACTS
Function SELECT_TENDERING_METHOD
Function SUGGEST_ALTERNATIVE
Function SUGGEST_PROCUREMENT_PATH

Figure 11 Where Used Report.

shows which functions use this entity and give an indication of the impact, and hence cost, of the proposed changes.

Validation of models

The models presented and described in the case study were validated by a group of professionals from the construction industry. The models support various procurement systems currently being used by the construction industry. These very high-level models will be detailed in the next stage of the analysis in order to produce practical databases which could be of use to the construction industry.

The way forward – object-oriented modelling

This paper demonstrates the strength of the Information Engineering Method as a modelling approach. However, a problem associated with this approach is the need to make compromises to reconcile the differing information requirements of various users of the information. The ICON project (Information Integration for Construction) being developed at the University of Salford is concerned with the creation of a generic information model for the construction industry. This will, through the enhancement of information engineering with object-oriented capabilities, allow the individual perspectives of different disciplines to fit within a single information model. In particular, the techniques applied will allow objects (or ideas) to be classified and aggregated in the manner most suitable for the requirements of each individual task of process, while still following a common underlying information model (see Fig. 12).

Conclusions

This paper shows that the use of a systematic method (information engineering) simplifies and improves the development of information systems in the construction industry. In addition, it illustrates the importance of defining a framework for information requirements rather than developing *ad hoc* applications. The procurement process analysed in the case study shows that the analysis phase starting at a very high level (strategic level) can be well defined. The translation of the data models into physical databases is more efficient and well structured as information is captured at all levels of the analysis phase. Finally, this paper concludes that the use of an automated information-modelling tool (IEF CASE tool) is very useful and more efficient than the manual approach. It also points the way forward to building on the information engineering approach using object-oriented modelling approaches.

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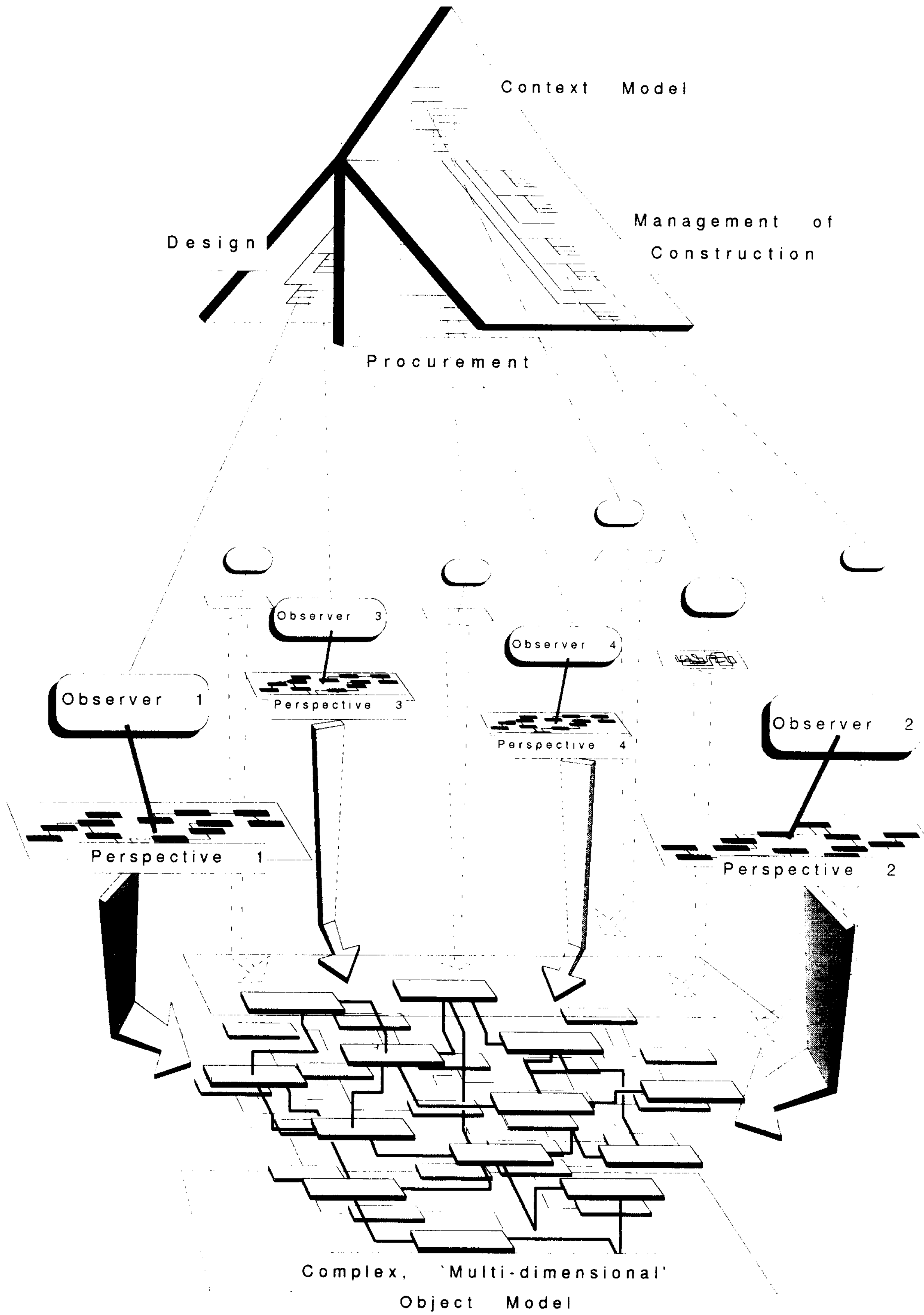

Figure 12 Different perspectives of the ICON model.

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