Kjell Svensson

Integrating Facilities Management Information

A Process and Product Model Approach

VETENSKAP OCH KONST
KUNGL TEKNISKA HÖGSKOLAN
Royal Institute of Technology
Construction Management and Economics

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To *Bodji, Mabel,*
Gustav and Johan-Olof

Preface

This dissertation is the final result of many years of work which has comprised engaging, compelling, instructive, stimulating and enjoyable experiences. I have learned a tremendous amount during this period of time about IT and its application in several areas. The work encompasses both an industrial and an academic ingredient. This mixture has made the work more time consuming but at the same time it has made it extra valuable and quite unique. The work started as a number of development projects under my supervision at the National Board of Public Building (KBS). The Board was the largest property manager of Sweden and was also responsible for providing and constructing buildings for the Swedish state. The second phase, the academic research aspect of the work, began in the middle of 1993 after the Board had been reorganised into a set of smaller companies/organisations. As a result of this reorganisation all development work ceased and I moved to the Royal Institute of Technology (KTH) where a research grant from the Swedish Council for Building Research (BFR) and NUTEK has given me the opportunity to continue and deepen the experiences from KBS.

I would like to thank all the people who have contributed to the work with their magic, faith, time, energy, vision, passion, support or friendship. There are a number of people I wish to name. First of all I would like to thank Prof. Bo-Christer Björk, my supervisor, for keeping me on the right track and helping me to focus on the relevant issues. Other persons I especially would like to thank are Prof. Brian Atkin for good advice on the FM issues and research matters, Prof. em. Hans G Rahm who has followed and encouraged the work all the time and the two ‘hackers’ of our department , Sebastian Gustin and Robert Noack who have helped me with managing the power of computers. Robert has also been very helpful in the final work of the thesis. I would also like to thank everybody else at the department for providing a creative and stimulating environment. The work would not have come into reality without the support of Prof. Stefan Sandesten at KBS. Also the people from industry deeply involved in the prototype projects have encouraged and been a stimuli in the work. Many of these persons are named in appendix 1 of the thesis. Last but not least, during the years of research work I have enjoyed the good restaurants of KTH.

Stockholm, April 1998
Kjell Svensson

Contents

Abstract

The purpose of the study was to develop suitable information structures to support main processes of facilities management (FM). The approach chosen to create these structures was to develop a generic FM process model and a building product model. The research method used was a system analytical approach involving the definition of activity models and object-oriented conceptual schemas. The existing national construction classification system (the BSAB System) was an important point of departure in the research work.

The resulting models were evaluated through prototyping. Three different prototypes were developed,: the Klara prototype (a system for planning, operation and maintenance of building services systems), the Blandaren prototype (an object oriented database system for FM) and the Kronoberg prototype (a GIS-like system for facilities management information). All the prototypes used data from real facilities. The prototype systems demonstrated that the product model (the KBS Model) fulfils the requirements of flexibility, stability, adaptability, comprehensibility and cost-effectiveness, which are discussed in this thesis. The generic process model, which was mainly tested in one of the prototypes, should provide better conditions for integration by capturing main aspects of the essence of FM and by providing an overall structure for information handling within FM.

In parallel with the evaluation of the prototype work, a conceptual schema (the Spatial Arrangement Model) was developed. This is based on experiences from the prototypes and done in collaboration with the standardisation work for building construction within the STEP (STandard for the Exchange of Product model data) activity.

The overall result of the research provides basic prerequisites for the development of commercial IT systems for FM as well as an input to international standardisation efforts.

Keywords: facilities management, information technology, process model, building product model, prototyping, thesis

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List of Used Acronyms or Abbreviations

The list contains most of the acronyms or abbreviations used in the thesis.

AAM	Application Activity Model
ABS	Abstract (in EXPRESS)
AEC	Architecture, Engineering and Construction
AIC	Application Interpreted Constructs
AIM	Application Interpreted Model
AMA	Allmänna Material- och Arbetsbeskrivning [Swedish for General Material and Workmanship Specifications]
ANSI	American National Standards Institute
AP	Application Protocol
ARM	Application Reference Model
BPM	Building Product Model
BPR	Business Process Re-engineering
BSAB	Byggandets Samordning AB [Swedish for Building Co-ordination Centre]
CAD	Computer-Aided Design/Drafting
CAFM	Computer-Aided Facilities Management
CASE	Computer Aided Systems Engineering
CDR	Control Data Repository
CIFM	Computer Integrated Facilities Management
CIS	Computer-based Information System
CODASYL	Conference on Data Systems Languages
COM	Component Object Model
CORBA	Common Object Request Broker Architecture
CSTB	Centre Scientifique et Technique du Bâtiment [French for Centre for Building Science and Technology]
DFD	Data Flow Diagram
FM	Facilities Management (Facility Management)
FTP	File Transfer Protocol
GARM	General AEC Reference Model
GDP	Gross Domestic Product
GIS	Geographic Information System
GUI	Graphical User Interface
HTML	HyperText Markup Language
HVAC	Heating, Ventilation and Air Conditioning
IAI	International Alliance for Interoperability
ICAM	Integrated Computer Aided Manufacturing
ICON	Integration of COnstruction Information
IDEF0	ICAM Function Definition Model
IDM	Integrated Data Model
IFMA	International Facility Management Association

IS	Information System
IT	Information Technology
LAN	Local Area Network
POE	Post Occupancy Evaluation
RATAS	RAkennusten Tietokone Avusteinen Suunnittelu [Finnish for Computer-Aided Design of Buildings]
SDAI	Standard Data Access Interface
SfB	Samarbetskommiten för Byggnadsfrågor [Swedish for Joint Working Committee for Building Problems]
SGML	Standard Generalised Markup Language
SPARC	Standards Planning Requirement Committee
SQL	Structured Query Language
SSADM	Structured Systems Analysis and Design Methodology
STEP	STandard for the Exchange of Product model data
STRADIS	STRuctured Analysis, Design and Implementation of Information Systems
TCP/IP	Transmission Control Protocol/Internet Protocol
TNO	Nederlanse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek [Netherlands Organisation for Applied Scientific Research]
TQM	Total Quality Management
UDC	Universal Decimal Classification System
UI	User Interface
UML	Unified Modelling Language
UoD	Universe of Discourse
WAN	Wide Area Network
VTT	Valtion Teknillinen Tutkimuskeskus [Finnish for Technical Research Centre of Finland]
WWW	World Wide Web

1 Introduction

1.1 Background

Current use of IT in 'facilities management' is not sufficient

Operational spaces, in and around buildings, provide a framework where work and other human activities take place. The costs related to the usage of buildings have come into focus during the last decade due to e.g. increasing pressures for cost-efficiency and the slump both in the economy and the facilities market. The total cost of premises is often second only to labour costs on the balance sheet of various organisations. In order to improve the productivity and efficiency of premises, a strategic approach is taken more and more in 'facilities management'. It is based on a comprehensive view of the organisation and is increasingly expected to be more successful than the traditional way of focusing on reducing running costs. Both owners and users of the buildings expect to have more complete and compatible technical and functional output for their financial investments.

Both new and existing facilities should meet usage requirements. 'Facilities management' should therefore view facilities and their usage throughout their whole life-cycle. The activities within the facilities set requirements for them and their management. Closer co-operation between usage and management should prove more economical for the organisation using the facility. Better coordination between design, construction and usage of the facilities should improve the life-cycle cost.

The efficiency and productivity of organisations can be further improved through the use of information technology (IT). IT may be used for intelligent rationalisation of methods and processes and for more effective decision making. IT has become a strategic resource in design and construction, in 'facilities management' and in almost all sorts of organisational work.

The use of IT in 'facilities management' has so far normally not been very efficient. IT tools for different sub tasks in 'facilities management' have been developed in a decentralised manner, often not using the latest IT technology available. A remedy for this lack of efficiency could be the use of consistent and appropriate data/information structures. The development and testing of such structures is the subject of the research work described in this thesis. By using such structures in the further development of new IT systems for 'facilities management' a more efficient information handling could be achieved.

Figure 1:1 shows three fields of action: the usage of facilities, design and construction of new facilities and management of existing facilities. Management should be carried out in close co-operation with the usage of the facilities. It should also be both the starting and finishing point of the design and construction of new facilities. Within these different fields of action and in the interaction between them, information and IT play an important part. The interaction is an important part of the domain of the research work described in this thesis.

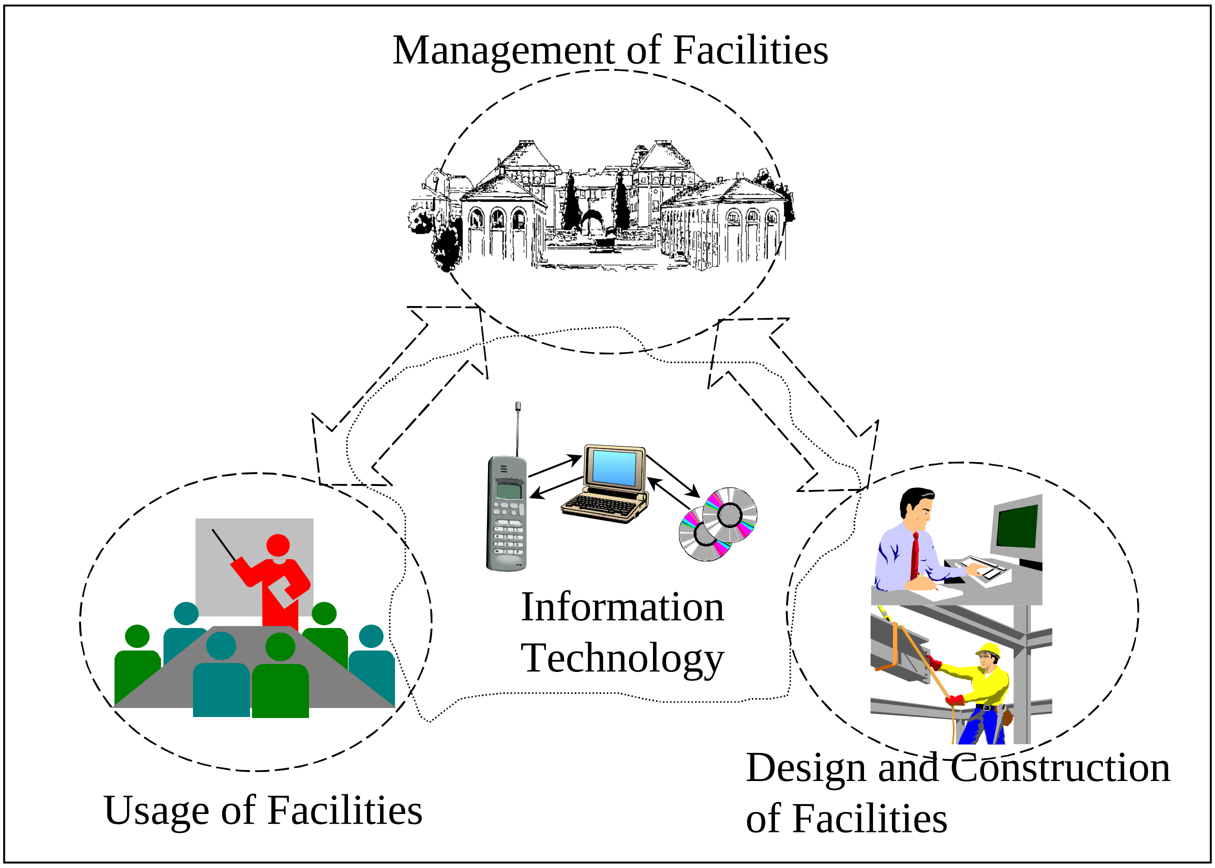

Figure 1:1 Facilities management should be carried out in close interaction with the core business processes performed in the facilities and with the design and construction activities changing the facilities.

Macro economic significance of facilities management

Sweden has a population of almost 9 million[1] and the total floor space in buildings is estimated to be 650 million sq. m.[1], which is an average of 72 sq. m. per inhabitant. The market value of buildings in Sweden is estimated to be at least 3000 billion SEK[1] and together they represent a major part of the nation's fixed capital formation. Typical construction costs for a medium-sized office building

[1] Source: the Statistics Sweden (Statistiska Centralbyrån , SCB)

in Sweden are approximately SEK 9000-12000 per sq. m.[2] and the average running cost for the same type of building is approximately 300-400 SEK per sq. m. per annum[3]. Running cost is the cost of operation including energy and maintenance.

The running cost is best influenced at the beginning of the life-cycle of the building. This is particularly important for components which have a relatively high running cost, such as heating and other service systems and surface finishes both outside and inside the building. Both *Westin* [1989] and *Bejrum et al*. [1996] have examined the cost of facilities from a life-cycle perspective. They both came to the conclusion that this perspective is relevant in all phases of the facility's life-cycle.

During the first year of the existence of a facility its running cost is approximately one-tenth of the total cost (capital cost plus running cost). Over the facility's total life-time (i.e. 60 years) running cost is approximately 80% of total cost including capital cost [*Erlandsson*, 1988]. Total running costs together with refurbishment costs of the buildings in Sweden could be estimated at 150 billion SEK per year[4]. This means that, at present, the cost of managing existing buildings is larger than the amount invested annually in constructing new ones. It also means that the total annual running and capital cost of the whole national building stock is equal to over 20% of the GDP (Gross Domestic Product) of Sweden. Also, more than 75% of the buildings in Sweden are more than 20 years old[4], which means that an increasing amount of refurbishment can be expected in future.

All in all these figures show that increased efficiency in facilities management and more economical use of the existing stock of buildings is an issue of great significance for the economy of the whole country.

1.2 Origins of 'Facilities Management'

The history of managing facilities is as long as the history of complex buildings. As long as there have been buildings, there has been a need to plan and organise their use and maintenance, which is the essence of 'facilities management'. The origin of 'facilities management' as a professional service, may be traced back to the early 1900s when scientific management and its subsequent use in office administration was first introduced [*Mole and Taylor*, 1992]. Text books about office management written at the beginning of this century included information

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[2] Source: the Swedish Federation of Architects and Consulting Engineers (Arkitekts- och Ingenjörsföretagen)
[3] Source: the Swedish Federation for Rental Properties Owners (Sveriges Fastighetsägarförbund)
[4] Source: the Statistics Sweden (Statistiska Centralbyrån, SCB)

on how to lay out an office building to maximise its efficiency. In the USA, there has been a long tradition of constructing large commercial and industrial buildings. These buildings have included substantial service installations. As a result, the need to use and operate such complex buildings efficiently has gradually developed. In parallel, there was a need for the buildings to be sufficiently flexible and adaptable to changes caused by commercial pressures and other circumstances.

World economics and global changes seem to play a significant role in the evolution of 'facilities management'. The main catalyst in the 1960s towards increasing its role was the introduction of computers in the workplace [*Then,* 1994]. The energy crisis in the 1970s emphasised the importance of limiting the cost-in-use of facilities and the need to manage life-cycle cost rather than construction cost alone. During the 1980s buildings became more and more complex and the term intelligent buildings was frequently used [*Atkin*, 1988]. This has increased the need for more sophisticated operation of a building. As a result of an international crisis within the real estate market in the 1990s, an increased focus on maximising net rental income of premises began to emerge. All these international trends have played a similar role in influencing the way facilities are managed in Sweden.

1.3 Modern Perspective on 'Facilities Management'

Basic resources in any organisation are people, equipment and materials as well as premises in which to house them. Such resources together represent the basis for fulfilling business objectives in an organisation. Today, the costs of premises and labour are the major fixed costs on the balance sheet of most organisations. Successful 'facilities management' could provide a positive influence on both of these items.

The core business (primary processes) of an organisation, are those activities which constitute its main purpose. Such matters are normally in direct contact with the client. The function of 'facilities management' is to support the core business. Typical examples of core business are shown in table 1:1.

To comply with this, a shift in thinking on the role of 'facilities management' is required. Typical 'facilities management' functions such as security, cleaning, planned maintenance, and space management should be made to work better for the core business of the organisations. These functions should be carried out in such a manner that they add value to the core business rather than simply represent a cost that diminishes the 'bottom line'.

Table 1:1 Typical examples of core business

Type of organisation	***Core business***
housing company	provide tenants with suitable housing
hotel	provide accommodation, including catering
hospital	provide health-care services
property company	develop and manage its portfolios to maximise the return on its capital
university	carry out research and provide professional education

The term facility is defined as "a physical structure or installation, including related site works, serving one or more main purposes" [*ISO*, 1994]. A building is defined as "a type of facility comprising partially or totally enclosed spaces and providing shelter", which is a subset of facilities. Finally, spaces are defined as "three dimensional spaces within and around buildings and other facilities, bounded actually or theoretically". The facilities manager has to provide the core business with premises, including operational facilities and an indoor climate that facilitates and supports the core business. The market value of premises is partly a function of the extent to which facilities are well managed. In the broad sense, the 'facilities management' includes property management, construction management and asset management, all related to the facilities/buildings of the organisation. The facilities/buildings have one or many purposes within the organisation. This also means that the 'facilities management' should be carried out in close relationship with the organisation and its core business.

1.4 Impact of New Business Philosophies on 'Facilities Management'

Compared with today, business and other organisational work of yesterday was normally carried out in a much more stable situation. The products or services did not change so often and this also meant that buildings and equipment had to change little and seldom. This situation is now different. Today, organisations must frequently adapt their operational environment to new requirements. This is a result of various changes in society, such as greater competition and an increasing use of IT. This means also that the management of buildings and their equipment must be more dynamic and flexible.

Industrial organisations have their origins in the idea of distributing and dividing work. *Schein* [1988] gives the following definition of an organisation: "*An organisation is the planned co-ordination of the activities of a number of people for achievement of some common, explicit purpose or goal, through division of labour and function, and through a hierarchy of authority and responsibility*."

In all organisations there exists a series of tasks (activities) which are repeated within space and time, with a start and a stop and which ideally create/add value to the customer/client [*Melan*, 1992]. This flow of repetitive tasks (activities) is called a process. Traditional organisation schemas describe the different vertical functions within an organisation and its hierarchical levels. Organisations try different methods to improve their work. Focusing improvement efforts on the horizontal processes of an organisation rather than the vertical functions, has proved efficient [*Melan*, 1992].

Davenport [1993] describes the origins of business improvement through improvement of the organisational work. Improvement could be achieved either through changes in the process or by higher quality of the result produced (product or service). The first major instance of formal business improvement was the use of product inspection as the final step in a manufacturing process. This began back in the 18th century, parallel to the industrial revolution. With the industrialisation and mass manufacturing quality control become increasingly important.

During the 20th century the development has gone from quality control which mainly focuses on the final inspection of already produced goods to quality assurance which focuses on the production process and aims at preventing the production of faulty goods. As the last step in this development there is Total Quality Management (TQM) which can be seen as a management theory involving six elements: focus on the customer, top management commitment, focus on the process, let everybody be committed, improve continuously and base decisions on facts [*Bergman and Klefsjö*, 1994].

In the 1930s a second approach to business improvement was developed and this approach is frequently called ‘quality control’. It involves strict analysis and control of the production processes or service operations. Today, the term ‘total quality management’ is often used but the purpose is still to make continuous improvement of the result produced by a strong focus on quality. By quality is meant “*the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs*” [*IVF*, 1994]. Such characteristics could be the ability of a product or service to satisfy the requirements and expectations of the internal or external customers.

In the mid-to-late 1980s many companies around the world began to suspect that continuous improvement was insufficient. Towards the end of the 1980s, the idea of redesigning or re-engineering business processes gained popularity. The methods used to replace an existing process with a new process is often called (business) process re-engineering (BPR). *Hammer and Champy* [1993] define process re-engineering as *“the fundamental rethinking and radical re-design of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed*”. With BPR, the objective is to make the value adding work more efficient in order to maximise customer value and minimise the cost. The BPR method could also be combined with tools of different kinds.

Two important tools in the struggle to improve the efficiency and productivity of organisational work are benchmarking and information technology (IT). Benchmarking provides a tool to help organisations learn about competitors [*Bergman and Klefsjö,* 1994]. Benchmarking can provide both the challenge to improve the work and an insight into how to perform better and at lower cost. An example of the use of benchmarking applied to information management in FM is provided by Construct IT Centre in Salford [*Atkin et al.,* 1997]. IT is used as a tool to provide better support for the information management process, for instance using CAD systems, document management systems, intranets etc.

Traditionally, ‘facilities management’ has meant technically competent work within a relatively static atmosphere and in a typically reactive manner. Problems have been solved when they have arisen. The increasing competition within the FM sector has led to a situation where this is not enough. A large amount of capital is invested in buildings and equipment and this capital must also be used from an organisationally comprehensive view. This means that the facilities managers must work outwards from the purposes and requirements of the core business. ‘Facilities management’ must be incorporated into the core business and must also be performed on a strategic level. To achieve maximum benefit from the corporate resources the facilities manager must also be able to work proactively.

1.5 Defining ‘Facilities Management’

The English term ‘facilities management’, or frequently the abbreviation FM, is used in this thesis. In American literature the singular term ‘facility management’ is normally used.

There are a number of descriptions of what is meant by FM, e.g. [*Mole and Taylor,* 1992], [*Barrett,* 1995] and [*Atkin,* 1997]. There is no standard definition of the term. Below are four different examples of definitions. The most widely accepted is probably the following , (**definition 1**):

"The practice of co-ordinating the physical workplace with the people and the work of the organisation, integrating the principles of administration, architecture, and the behavioural and engineering sciences" [*US Library of Congress*, 1983].

By 1993, this description had become more concrete and had evolved into the following, (**definition 2**):

"Facilities management is the active management and co-ordination of an organisation's non-core business services, together with the associated human resources and its buildings, including their systems, plant, IT equipment, fittings and furniture; necessary to assist that the organisation achieves its strategic objectives" [*Owen*, 1994].

Also a definition from the Department of Surveying at Salford University stresses the physical infrastructure and the contribution to the primary business, **(definition 3)**:

"An integrated approach to maintaining, improving and adapting the buildings of an organisation in order to create an environment that strongly supports the primary objectives of that organisation" [*Barrett*, 1995].

Finally, a definition from the "Centre for Facilities Management" at Strathclyde University in Glasgow, **(definition 4)** is described below. This definition represents a partly different view of FM compared with the three above.

"A continuous process for managing (creating and sustaining) facilities on the behalf of the organisation's operating environment and not only the physical environment. It is tuned to the strategic need of the organisation" [*Alexander and Andersson*, 1994].

Common to almost all of the four definitions above is that they somehow deal with the activity, object, client and aim of facilities management. This is shown in table 1:2.

Table 1:2 Comparison of different definitions of the term 'facilities management'

Concept	***Wording used in each definition***
Activity	1. co-ordinating the physical workplace with the people and the work of the organisation
	2. active management and co-ordination
	3. an integrated approach to maintaining, improving and adapting
	4. a continuous process for managing
Object	1. the physical workplace
	2. buildings, including their systems, plant, IT equipment, fittings and furniture
	3. the buildings
	4. facilities
Client	1. the people and the work of an organisation
	2. the organisation
	3. the organisation
	4. the organisation's operating environment and not only the physical environment.
Aim	1. -
	2. to assist that the organisation achieves its strategic objectives
	3. create an environment that strongly supports the primary objectives of the organisation
	4. tuned to the strategic need of the organisation

To be able to judge whether the purpose of FM is fulfilled, the performance of the FM work should be measured. All definitions, more or less exclude a mechanism that provides opportunities for measurement, control and influence over FM work. A synthesis of the different descriptions above and the observation of the lack of control and feedback is achieved by formulating the objective of FM as below.

Activity "*The continuous management of*
Object *the workplace*[5] *and operating environment of*
Client *the organisation*[6] *at all levels*[7]
Aim *with the purpose of providing user*[8]

satisfaction and value for money"

However, a verbal definition is not enough when trying to analyse FM from an information point of view. The concept FM includes a lot of different and diverse activities, dealing with space planning and space usage, operation and maintenance of buildings and their services systems, security, catering, landscaping, cleaning etc. All of these activities require information that must be structured in an appropriate way. This is of extra importance when developing information systems for FM using IT. One way to analyse and describe the in-

[5]The term workplace is taken in the broadest sense to denote those locations where people might also congregate for a purpose other than work.
[6]Organisation denotes any sort of co-operative activity.
[7]Levels include at least operational, tactical and strategic.
[8]The term user covers anyone occupying the facility for whatever reason.

formation requirements of FM is through process modelling which is done in chapter 3 below.

1.6 Role of IT in Facilities Management

There is a need for facilities management organisations, as well as other (business) organisations, to improve their efficiency in order to survive. The effective use of information technology (IT) has become one way of improving competitiveness.

According to *Bos* [1995] the following five main advantages of an efficient facilities management information system can be recognised.

- Better support of the primary organisation.
- An increase of the life expectancy and value of the building.
- Optimisation of appliance management.
- Optimisation of maintenance activities planning.
- Better quality of the individual working environment.

To carry out FM business, or any other business or other organisational work efficiently, tools are needed to handle essential information. Therefore, appropriate information systems are useful to business - core business or FM business - to achieve the corporate goals of the organisation. The FM process is fundamentally a service and management function. A central issue is the information and the ability to collect, monitor, analyse, store, facilitate, utilise and present it.

Change of organisational practice involves various new tools. To use IT for this purpose is claimed to be an efficient improvement activity in business organisations and processes [*Johannesson et al*., 1996]. IT supports and influences the business processes in many different ways, such as improved communication, better decision support and better service to clients. Thus, business process development through IT is an area of primary interest and importance. The development of information systems (IS) and improvement of business processes are highly integrated with each other. The people involved in developing new IS and those involved with the business processes and their improvement must be able to communicate. This is often done through models. By using clear information models, the business people should be able to describe the (business) processes that the IT system is going to support [*Jacobson et al*., 1995].

In developing information systems the necessity of adequate information structures is an emerging question. This is emphasised e.g. by [*Jacobson et al.,1995*] and [*Johannesson et al.,* 1997]. Due to the rapid development of IT towards increasing user-friendliness, more standardised applications and open systems, external conditions for integration of processes are available to a significant degree. However, in parallel with the speedy development of the IT-tools, many users of IT-systems experience problems with poor relevance and integrity of the information handled. In particular, the necessity for adequate information structures is a question arising when developing systems to handle information automatically and rationally during the FM process. This has been pointed out e.g. by [*Teicholz*, 1992] and [*Wikforss*, 1997].

1.7 Aim and Objectives of this Thesis

Significant for the development of IT systems for FM in the past has been an unsystematic and fragmented approach, as remarked e.g. by [*Barrett*, 1995] and [*Teicholz*, 1992]. Another characteristic is the lack of a consistent infrastructure for the FM information. The present situation means that facilities managers frequently have considerable problems in adopting and using modern information technology. Also, the underlying technology (the IT) itself is changing dramatically. A central feature for enabling an efficient use of IT is the need for consistent information structures, defined particularly for FM.

The **aim** of the research was to *develop suitable information structures to support the processes for FM*. Specifically, the **objectives** were twofold:

- To develop a building product model, to be used as a basic information structure for the use of IT within FM. The main purpose with the model was to *provide an infrastructure for FM information*. The model must *fulfil certain requirements to be appropriate for FM.*

- To develop a generic FM process model in the provision of IT support within FM. The main purpose of the generic process model was to *provide better conditions for integration*. The model should also *capture important aspects of the essence of FM.*

The objectives meant developing and testing appropriate process and product models as conceptual structures. Systematic information systems development methodologies were applied. The main purpose was to support integration of FM information and of FM systems. This should include both the organisation with different disciplines and functions (lateral integration) and the life-cycle (design, construction and usage) of the facility (horizontal integration).

1.8 Structure of the Thesis

Chapter 1 (Introduction) gave an introduction to the thesis by describing its general context (facilities management) and the problem addressed (managing facilities information). FM was described from a general perspective through e.g. its history and objectives. Current thinking about the improvement of the organisational work of FM through the use of IT was discussed. Finally, the chapter described the aim and objectives of the research.

Chapter 2 (Research Methodology) describes the methodology used in the research described in this dissertation. The methodology is mainly based on the systems approach and the system analysis process as a problem solving technique. In addition, the prototyping methodology is discussed.

Chapter 3 (The FM Domain from an Information Handling Perspective) continues the characterisation of the FM process by describing its scope. The current situation in managing FM information and the current best practice using IT in FM is also discussed. The FM process is viewed as integrated with the core business of the organisations using the facilities and with the life-cycle process of facilities. The chapter also illustrates the configuration of the FM activities out of the core process activities. Finally, the chapter presents a series of generic process models for facilities management work.

***Chapter 4* (**The Technology: Object-Oriented Building Product Modelling) describes the state-of-the-art in development methodologies and techniques used when developing information systems within this research project. Traditional information systems development methodologies have now incorporated the object-oriented paradigm. An important feature of systems development is the use of models. Building product modelling means conceptual modelling of the building. The evolution of the product modelling technique is to a large extent catalysed through the international standardisation and development work of "STEP" [*ISO*, 1993a]. The chapter also presents a number of research projects within the domain of this research (product modelling for FM), which were reported after the main part of the research work was done.

Chapter 5 (Functional Requirements for a Building Product Model for FM) presents the main line of causal reasoning of this thesis, in a number of assumptions forming a logical chain. The reasoning starts by stating that the inefficiency of current IT applications for FM is mainly due to a lack of integration and ends with the description of requirements that a BPM developed for integrating IT systems for FM, should fulfil. Some of the assumptions are mainly defended by references to available literature on the subject, others are the main subject of research of this thesis.

Chapter 6 (The KBS Model - A Proposed BPM Structure) describes the structure of a neutral building product model - the KBS Model. It is based on national (and also partly international) building classification systems and has been influenced by the methodology and principles of the STEP standard.

Chapter 7 (The Three Prototypes) describes three prototype projects where the theories of the previous chapters were evaluated. The introduction consists mainly of short descriptions of the scope, objective and context of each prototype. Then each of the three prototypes is described, mainly with regards to how the proposed product and process model structures were tested.

Chapter 8 (Results and Discussion) summarises and evaluates the findings of the research interpreted from the current state-of -the-art situation. The chapter also includes the description of a proposed building product model developed after the bulk of the work of this thesis was done, but as a result of the experience gained in this research.

Chapter 9 (Conclusions and Recommendations) contains generalisations concerning the value of the proposed structures for facilities management information, based on the findings of this research. It also formulates some recommendations for practical applications and future research.

2 Research Methodology

Introduction

The research methodology applied in the thesis is described in this chapter. The description includes both an argumentation for and an explanation of the chosen method (the systems approach). The chapter ends with a description of the research process of this thesis.

2.1 Research Method of this Dissertation

According to *Phillips and Pugh* [1994] important characteristics of scientific research are that it is based on an open system of thought and that researchers examine data critically and generalise and specify the limits of their generalisations. According to them there are four elements to form a PhD: the background theory, focal theory, data theory and the contribution.

- The *background theory* reviews the literature in the field of study.
- The *focal theory* describes what the research is about and why it is done.
- The *data theory* justifies the relevance and validity of the proposed solution of the research.
- The *contribution* evaluates the importance of the contribution made to the discipline by the research.

This thesis has tried to apply the above guidelines.

A traditional way of studying a scientific problem is the analytical approach. It means breaking the problem down into parts and by studying them in separation, acquiring knowledge about the problem. The analytical approach has been used e.g. by physicists and natural scientists ever since the 16th century. Biologists and social scientists were among the scientists who first became dissatisfied with the analytical approach and this happened during the first half of the 20th century. They would rather study an organism as a whole without having to break it apart into pieces. This view of the problem as a whole is termed ‘systems view’ or ‘systems approach’ [*Schoderbek*, 1990].

The systems approach

The systems approach supplements the traditional analytical approach. The concept ‘system’ is originally defined by the science called general systems theory which handles the description of systems, their properties and regulations (characteristics) by using formal, mainly mathematical, concepts and methods. This view of science provides the basis for different theories for different particularised systems approaches e.g. systems analysis, systems engineering (design of software and hardware), operations research (mathematical handling of decision systems) and cybernetics (communication and regulation of technical, organisational and other sorts of systems) [*Schoderbek et al*., 1990].

Systems analysis

Systems analysis provides a methodology for description, analysis and planning of complex systems [*Gustafsson et al*., 1982]. Systems analysis is founded on the two concepts 'system' and 'model'. The system concept represents the part of reality (UoD) one is studying and the model concept often represents the appropriate representation of the system.

According to *Schoderbek et al*. [1990], a system could here be defined as "a set of objects together with relationships between the objects and their attributes related to each other and to their environment so as to form a whole".

The system concept is very general and could be used in almost any area of reality. The system boundary divides reality into two parts: system and system surrounding. The system is influenced by the surrounding through inputs (influence) and the system influences the surrounding through outputs (behaviour).

Nawar [1997] gives the following abstract definition of a system: "A system is any set of interrelated and interacting entities or components which function together as a unit to achieve a specific objective". Such entities are confined within the boundaries of the systems, receiving inputs and collectively processing their outputs towards the specific objective.

The research domain in this thesis is FM and the use of IT within FM. The use of IT should strengthen the ability to accomplish the objectives of FM. The description of the objectives of FM (cf. section 1.5) includes the role of FM within an organisation and includes elements such as workplace, operating environment, organisation and user satisfaction. The study of IT in FM also includes the general role of information within FM.

The analysis and problem solving work carried out through system analysis is based on a model of the studied problem area. The modelling process includes two steps: conceptualisation and representation [*Gustafsson et al*., 1982]. The first step means conceptualisation of the part of reality we are studying into a mental model (a model in one's mind) and the second step means representation of the mental model as a formal model.

These models could be of different sorts e.g. physical scale models in two or three dimensions , analogy models where the analogy between a phenomenon in the represented system (reality) and another phenomenon in the model is made use of for modelling purposes, or symbolic models where the structure (components and relations) of the model is represented by symbols.

Models are generated through abstraction or representation of the system. This representation should imply that essential properties of the model correspond to properties of the system it represents. A suitable model is generated if its behaviour is similar to the behaviour of the system when influenced in a similar way.

A way of making research into the behaviour of a system is to experiment with the model by varying different intervening variables. This is called simulation. By varying the input into the model or the structure of the model, different results/outputs are generated. If the model is a good one these changes of its output should correspond to similar changes in the system. This sort of simulation normally requires computers.

The systems analysis process

Problem solving e.g. research using systems analysis, is carried out as a systems analysis project [*Gustafsson et al.*, 1982] and includes the following stages:

- **Problem perception**: This means an awareness or insight into the problem and the problem area. One is realising or noticing something which is perhaps not obvious to others. It generates a quality of understanding and insight. A mental model of system and research problem is generated.

- **Problem formulation**: The problem description generated in the problem perception stage is normally a relatively vague mental model of the problem. To be able to handle this in a scientific manner, a more precise description is required. The problem description should be structured and formal. In this thesis the problem is described in the aim and objectives of the research project. The research domain is also described.

  The problem formulation provides a solid description of the purpose of the project. An appropriate problem formulation is fundamental for the following stages of the systems analysis project. In this case problem formulation concentrated on defining requirements for data exchange and sharing in FM.

- **System modelling**: A model of the problem area or system is generated. The model of the system is a theoretical description which can help one understand how the system works or how it might work. The model must be relevant to the purpose of the research. In the specific case of this thesis conceptual schemas are the basis of the model of the area studied.

- **Model validation**: The purpose of validation is to determine whether the constructed model gives an appropriate and sufficient description of the system and its characteristics to help solve the problem defined by the problem formulation. The validity and relevance of the model is tested and it should determine if the model is useful for its purpose.

  According to *Gustafsson et al.* [1982] a complete validation of the model includes 'data validation' (quality of input data to the model), 'hypothesis validation' (the structure and behaviour of the model seems right) and 'technical validation' or 'verification' (to validate whether the model is actually functioning as supposed).

- **Problem solving**: Problem solving means making an analysis to find a satisfactory solution to the problem or a way of dealing with it. The analysis and problem solving are done according to a defined purpose and by using the generated model. Different techniques are available e.g. various operation analysis and simulation techniques. *In this case, the problem to be solved was data exchange and the method used was building prototypes doing this, based on the 'conceptual schemas' developed.*

- **Evaluation of results**: Result evaluation means making a decision about the significance, value or quality of the solution to the problem, based on a careful study of its good and bad features. The results obtained are compared with the original purpose of the research. In the research described in this thesis the results are evaluated by observing how well the information system and data exchange requirements were achieved.

- **Presentation of results**: This involves making the results available to those concerned and also the way in which this is done. The results should be presented in an easily comprehensible way which is also consistent with the problem formulation. Formal descriptions such as the EXPRESS language help in presenting the results unambiguously.

- **Implementation of results**: Implementing the results means putting them into effect. Results are implemented into reality, if it is a purpose of the research. If you implement the results you carry them out in order to change or control the situation which generated the problem perception.

Information acquisition is required in several of the stages above, e.g. modelling, validation, problem solving and result presentation. Methods for this could be e.g. measuring important parameters, case-studies, polling, interviewing selected persons, and normally also literature studies.

Prototyping

On a generic level, research can be classified into work which discovers and describes existing reality (explorative research) or which aims at creating a new reality (e.g. new technology or processes) which needs to be evaluated and justified. The research described in this thesis aims at developing appropriate information structures for FM to be used when developing FM information systems. An important methodology used in this research is thus prototyping.

Prototyping is a research process which includes conceptualisation. In this type of research prototyping is used as an approach for constructing and evaluating models and other information structures. Generally, prototyping could be defined as a design process for products. Basically, it includes four steps:

1. Defining a 'conceptual model' of the problem area.
2. Surveying possible technical solutions.
3. Prototype development.
4. Testing - mostly by heuristic methods, e.g. by using a test panel of experts.

The design is done step-by-step and each step is discussed and evaluated with feedback to previous steps [*Lundequist*, 1995].

Prototyping is regularly used especially within software (computer system) development [*Budde et al*., 1992] where according to Budde a prototype could provide:

- an operational model of the application system
- a concrete and common basis for discussion between developers, users, management and others
- a basis for further system development
- an evaluation (of the user interface) of the application system

The prototype developed could focus on different issues:

- the problem or business needs
- the information system model
- the software specification

- the user interface

A dilemma in the type of research discussed in this thesis is that really reliable experiments are very difficult to set up. The IT-tools developed in the research project are aimed at having a significant effect on the process they are used in e.g. the FM process. The method best suited to study and evaluate the research is prototyping.

An important feature of prototyping is that in many instances the only way to evaluate a prototype is against the functional requirements on which it has been based. There is often no existing reality which the prototype could be compared to. A building design represented as a miniature model can thus only be compared to the requirements of the client and other interested parties.

This has also some important consequences for the evaluation of building product model proposals. It is difficult to compare different proposals to each other since the underlying functional requirements often vary. The only realistic comparisons are between each model and its own stipulated requirements.

2.2 The research work process

The research work reported in this thesis contained five major phases: domain analysis and description, information systems methodologies review, theory development and model definition, prototyping, and finally research evaluation. The research process is schematically described as an IDEF0-model[9] in figure 2:1 below.

Each of the five phases included a number of activities. The work was highly iterative, which meant that normally a pair of consecutive activities were run through twice. The research process also provides the logic structure of how the thesis is presented and organised, which is described below.

9 IDEF0 is described in Appendix 4.

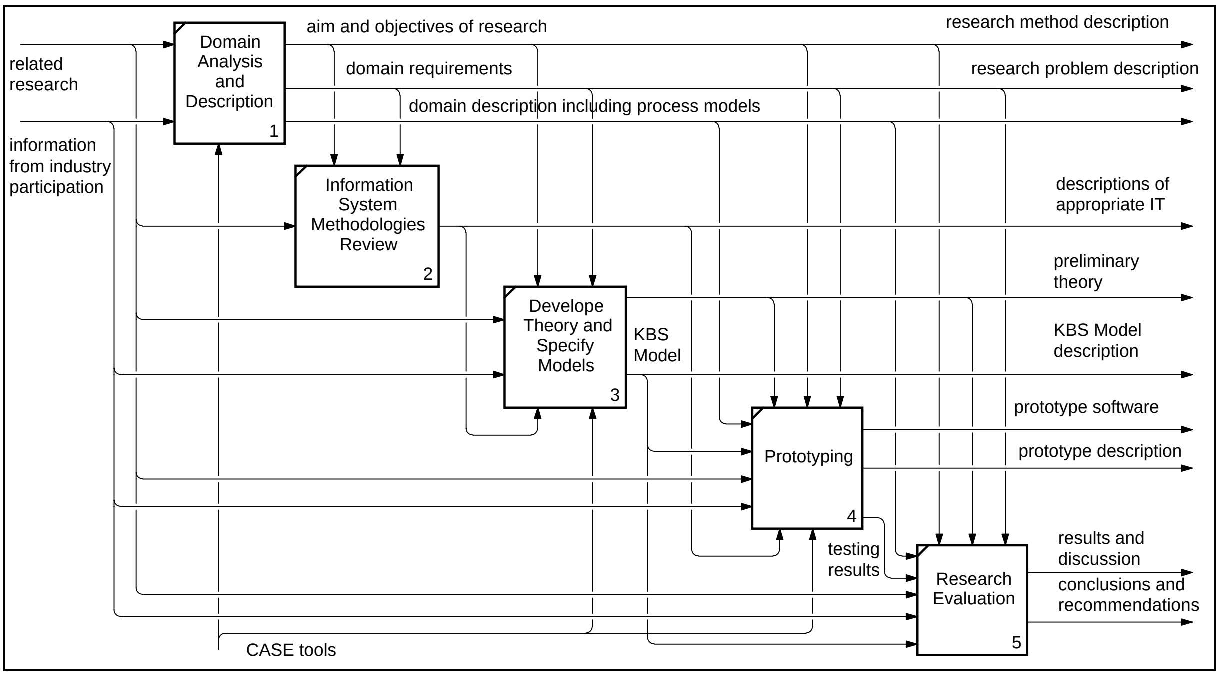

Figure 2:1 The research process with its five main phases

Domain analysis and description

The activity within this phase meant initially observing and analysing the area of interest, i.e. facilities management work and the use of information within this work. The research question was formulated on the basis of this experience and the aim and objectives were decided (chapter 1). The FM domain was then further analysed and a generic FM process model defined (chapter 3).

Information systems methodologies review

Together with process modelling, basic tools to create solutions to the research problem were conceptual modelling techniques, especially as applied in building product modelling. Chapter 4 contains a review of the state-of-the art in building product modelling.

Develop theory and specify model

A preliminary theory was developed by amalgamating the author’s own experience and information with knowledge accumulated at the National Board of Public Building, together with a study of literature and domain (chapter 5). A building product model for FM purposes- the KBS Model - was developed (chapter 6).

Prototyping

The prototyping part of the research work meant implementing the developed conceptual framework and conceptual model. The validity in practice of the theories was studied in three different prototypes. The prototypes were planned and implemented and this is described in chapter 7.

Research evaluation

The research evaluation meant studying the results of the prototypes. The preliminary theories were evaluated and some refinements made. At this stage more literature studies of work done in parallel by other researchers were carried out. The research evaluation is described in the concluding chapters of the thesis.

3 The FM Domain from an Information Handling Perspective

Introduction

This chapter provides a description of the FM domain from an information handling perspective. It starts by further describing (compared with chapter 1) the scope and essence of FM. Then, the relationship of FM to other processes, the integration of the life-cycle phases of facilities through information and current structuring of information to support FM are described and discussed. Finally, a set of proposed generic FM process models and benefits from their use are described and discussed. The chapter, taken as a whole, is a domain description and a basis for the further research work that is described in the following chapters.

3.1 Scope of FM

The purpose of the models presented in this chapter is twofold:

- Firstly they were developed with the aim of providing a basic framework which would help in the overall planning and design of IT applications for FM, by specifically including consistent feedback mechanisms and generally stronger integration features.
- Secondly they function in this thesis in a way similar to the process models (IDEF0 models) which are mandatory parts of the presentation of STEP application protocols (described later in chapter 4). That is they define the scope and context of the conceptual schemas presented later in this thesis.

It should be noted that although the models presented here aspire to a high degree of generality and should be seen as a part of the theoretical contribution of this thesis, the validation of these is weaker than the validation of the conceptual schemes (the KBS Model) presented later on. This should be born in mind when reading this chapter.

According to *Kincaid* [1994], FM emerged through the integration of three main strands of activity: property management (real estate), property operations and maintenance, and office administration. This view gives a valuable background for understanding the different task lists in Appendix 2 describing the scope of FM. Using the different descriptions of the scope of FM as a basis, a synthesis structure is proposed as described in table 3:1.

Table 3:1 FM functions decomposition table

Grouping of Functional Areas	***Functional Areas***	***Function Types***
Real Estate and Financial Management	Long Range Facility Planning	Real Estate Strategy
		Plans on different time frames
	Annual Facility Planning	
	Facility Financial Forecasting and Budgeting	
	Real Estate Acquisition and Disposal	Site Acquisition
		Building Acquisition
Customer Management	User Support	User's Perception
		User's Participation
		User's Satisfaction
Spatial Management	Spatial Management, Operation and Planning	Space Management
		Interior Planning
		Interior Installation
Operation and Maintenance	Operation	Energy and Media Management
		Inspection
		Operation
	Maintenance	Preventive Maintenance
		Repair Maintenance
Renovation, Rebuilding and Expansion	Planning and Design	Programming
		Architectural Design
		Technical System Design
	Renovation and Construction	Renovation and Construction Work
		Management Work

The structure of the table emphasises the hierarchical dimension in the description of the scope of FM. In the middle column of the table, one can identify eleven different functional areas. These resemble to a high degree the IFMA's (International Facility Management Association) list of functional areas, of which two versions are described in the beginning of Appendix 2. In the left-hand column of table 3:1, these functional areas are aggregated into five groups: real estate and financial management, customer management, spatial management, operation and maintenance, and finally renovation, rebuilding and expansion. The functional areas are in the right-hand column of the table subdivided into function types. A majority of these function types are then subdivided into different functions, as described in the latter part of Appendix 2.

The scope of FM should include all three levels of the decision pyramid of the FM organisation:

- The strategic level, where one is concerned with the long-range aim and direction of the FM functions. This includes setting objectives in response to the purpose of the FM functions and carrying out long-term planning, taking the external requirements into consideration. The strategic level has responsibility for the result and profitability. The work is carried out for instance by planning, modelling and simulation.

- The tactical (managerial) level, where one is concerned with making the totality function within the FM organisation. This includes identifying needs and defining goals that meet these needs. The tactical work includes for instance controlling, analysing, programming and budgeting, often on a yearly basis. The work includes defining routines and methods, setting standards, drawing up schedules and securing resources.
- The operational level, where one is concerned with the day-to-day decisions in operating the facilities.

These levels are the same in most organisations. Figure 3:1 below gives a schematical description of management and information usage on different levels within an FM organisation. On the different levels in the decision pyramid there are different information requirements for instance for control and decision making by the facilities managers.

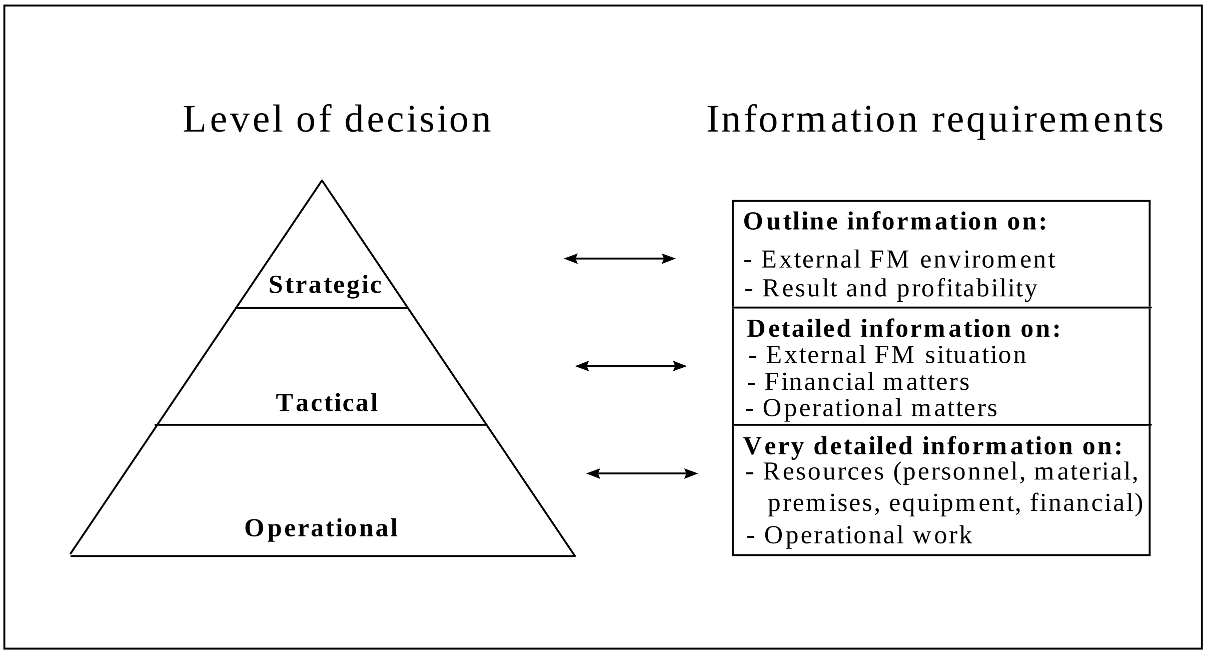

Figure 3:1 The decision pyramid of an FM organisation

When planning the future IT support it is necessary to categorise the FM function into strategic, tactical and operational types [*Barrett*, 1995]. So far, IT applications for FM has mainly been developed for operational functions. The long term effectiveness of using IT in FM is probably dependent on the effective use of IT at the strategic level [*Barrett*, 1995].

One more aspect of the scope of FM could be mentioned. According to *Nutt* [1994a], the responsibilities of FM functions cover five primary types of resources: physical, spatial, environmental, human and financial. Resources are all the means available to the FM functions for the execution of the activities necessary for realisation of their objectives. This also means that information and knowledge about these different resources are needed. It also implies that the development of IT systems for FM must consider these different resources.

The primary types of resources could be identified as follows within the functional structure described in table 3:1 above. Real estate and financial management is primarily concerned with financial resources. Customer management is to a high degree concerned with human resources. Spatial management deals with both environmental and spatial resources, while operation and maintenance functions are mainly concerned with either environmental or physical resources. Finally, renovation, rebuilding and expansion functions are to a large extent concerned with physical resources.

3.2 Essence of FM Work

In organisations people, equipment, materials and the premises housing the people, equipment and materials are basic resources. These resources together represent the means for fulfilment of the business objectives of the organisation. Premises and staff are today normally the two major standing costs on the balance sheet of many organisations. Successful FM could have a positive effect on both by making the working environment more efficient.

The objective of FM was defined in the introduction as the continuous management of the workplace and operating environment of the organisation at all levels with the purpose of providing user satisfaction and value for money. As described in the previous section, there are many different functions included in the scope of FM and a majority of them are directly concerned with the operational premises of organisations. The facilities manager should always see that the profitability of the organisation is in focus, that users of the premises are satisfied and what added value he/she could provide to the organisation. Key aspects of FM are the following. The facilities manager should e.g.:

- Ensure that the organisation achieves maximum benefit from its premises, yet without loosing an overall organisational perspective.
- Facilitate an improvement in the competitive position of the organisation through e.g. more efficient premises and equipment and support and information service.
- Facilitate future changes in the use of premises by providing a long-term FM policy and planning.
- Add value to the culture and image of the organisation.

- Generally work to prevent problems from arising rather than just react after they have arisen.
- Deliver effective and responsive service to the user of the premises.

The basic functions of planning and controlling and the approach to FM practice may vary between different types of facilities managers. Important facets when classifying FM organisations are according to table 3:2.

Table 3:2 Examples of classification of FM organisations

Facet	***Classes***
location and size [*Barrett*, 1995]	single office, single site, localised site, multiple sites nationally or spread internationally
type of ownership	public, private
main focus of the business of the organisation	facilities user, facilities owner, property investor, facilities manager
function of the facility	dwelling-houses, office-buildings, hospitals, factories, etc.

Regardless of how the FM practice is carried out, it requires knowledge and information. To be able to evaluate the practice of FM, one must be able to measure both the activities and their consequences. These could be evaluated from technical, economic, functional or aesthetic perspectives and all require information.

3.3 Relationship of FM to other Processes

FM is part of other processes

Organisational work can be studied both from a process perspective and from a functional perspective. In a business enterprise there are functions (departments) for e.g. production, sales, finance and other organisations have other types of functional subdivisions. The process perspective of an organisation focuses on the horizontal processes and emphasises the wholeness. In contrast, the functional perspective focuses on the different vertical functions of the organisation.

When studying organisational work from a process perspective, three important elements are: the process, its inputs and its outputs. The process consists of the activities carried out to transform input into output. Inputs may be money, material, energy, humans and information and outputs may be products, services and information. Normally the inputs come from the external environment of the process and outputs end up in the environment. Sometimes an output from one process may be an input in another, or the same process. The latter phenomenon is called feedback. To sum up, a systems approach and process approach are used when analysing the FM domain.

FM is related to other processes. One is the life-cycle of facilities and another is the core business of the organisation that the FM serves. The FM activities are concerned with the facilities which are primary resources within the core business of the organisation. This means that the FM activities are carried out in close association with the core business process. The most characteristic and basic resource handled in the FM activities is one, or often many, buildings (properties) supporting the business objectives of the organisation.

FM provides one of the primary resources of the core process

The basic unit of FM is the functional space [*Then and Akhlaghi*, 1994]. To a large extent the business processes set the requirements for the premises used in the core business. These requirements are transformed into descriptions of the operational spaces and they are realised through physical building parts. A refurbishment project starts with a set of physical building parts that should be transformed to fit new requirements.

In most organisations one can distinguish between the core business and the non-core businesses. The core business (primary processes) of an organisation includes those activities which are producing the results which are the main purpose for the existence of the organisation and which normally are in direct contact with the client. The FM process is carried out, to a very large degree, in close association with the core business. The facilities management is performed in and upon the facilities which are primary resources within the core business of an organisation. FM may be viewed as planning, supporting and monitoring the use of individual units of space in relation to organisational requirements [*Then and Akhlaghi*, 1994]. FM could be described as management by objective, which means that there is an objective that one should attempt to achieve and that is to help the core business become efficient. Feedback and control information show to what extent one succeeds.

The interaction between the core business and the FM processes is described in figure 3:2 below. The FM processes must add value to the core business by enabling it to realise its objectives through operational premises and related FM services.

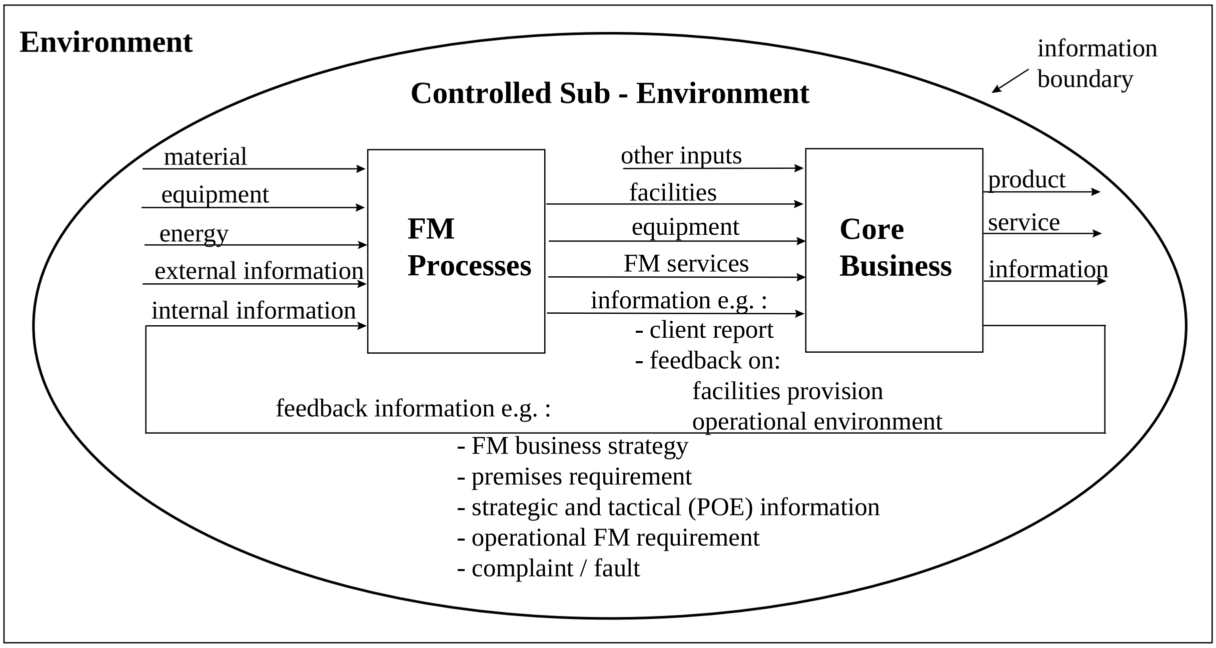

Figure 3:2 The relationship between the Core Business and the FM Processes

On the strategic level of the FM planning, the core business should provide the FM processes with an FM business strategy and information about facilities requirements and demands. On the tactical level, the core business should provide the FM organisation with strategic and tactical (i.e. POE) information. In the day-to-day activities, information about operational FM requirements and complaints/faults go from core business operation to FM operation. The status of facilities provision and operational environment and other client reports go as feedback information from the core process to FM.

Recurrent construction projects form an integral part of FM

Within the FM processes the life-cycle of facilities and their sub-parts could be seen as integral parts. The life-cycle of each of these parts consists of a design phase, a construction phase and a usage phase. The aim of the design and construction phases is to create facilities that satisfy the needs of the users/tenants within a framework of constraints imposed by building clients/users and society in general. This means that the design and construction work have their points of departure in the usage phase of the facilities. Experience from the existing building should be, and often is, used in the design and construction of a new building. The choice between refurbishing an existing building or constructing a new building, possibly together with demolition and recycling the old one, is taken during the briefing/programming phase. This means that every construction project could be seen as an integral part of some particular FM process. Existing buildings too, are rebuilt to fit new purposes. According to *Nutt* [1994b], the rate at which the building stock is being adapted to new uses is increasing. Figure 3:3 describes the life-cycle of facilities from an FM perspective.

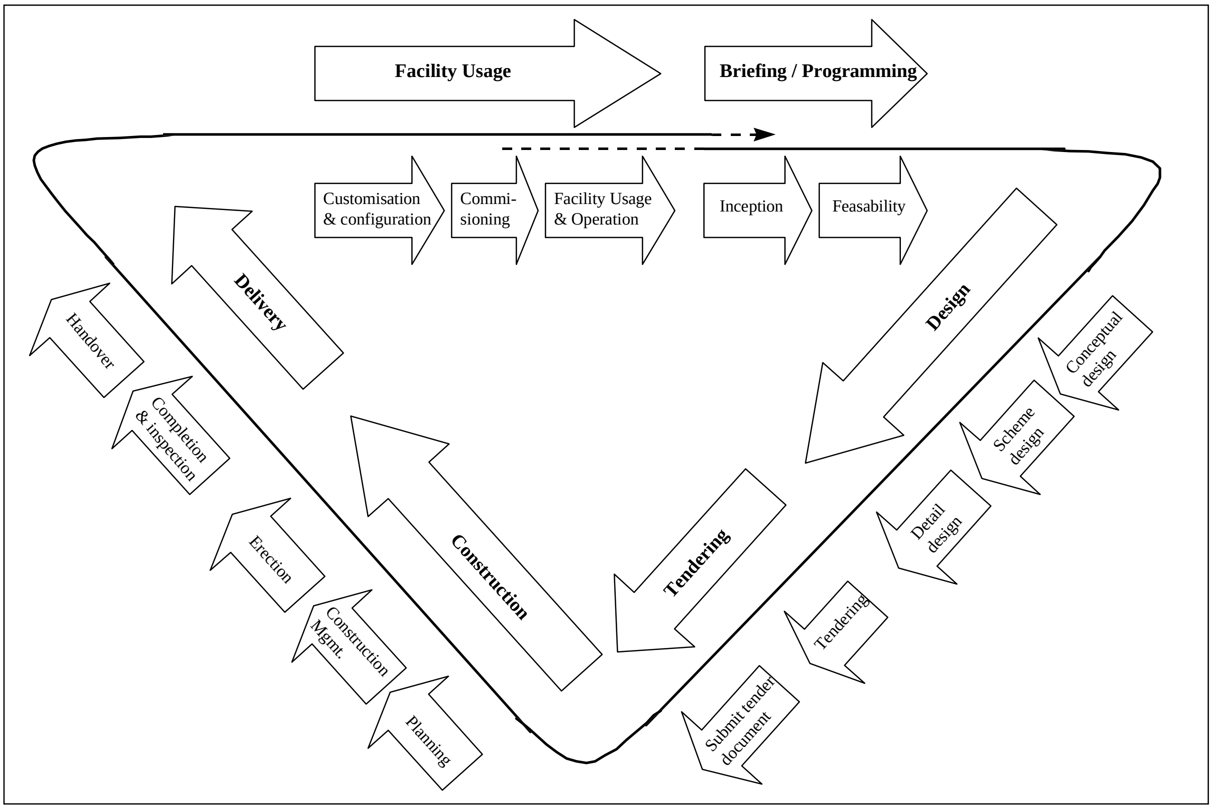

Figure 3:3 The life-cycle of facilities

This means a cyclical process where requirements of a new building take advantage of the experience within the organisation (or from other organisations) from the performance of existing buildings.

Another reason for the integrated life-cycle view of facilities is the economic impact of the running cost on the total cost. Construction costs represent only one portion of the overall life-cycle costs. On the basis of the average total lifetime of the facilities (60 years), the running cost is approx. 80% of the total life-cycle cost [*Erlandsson*, 1988].

3.4 Integration of Facilities Life-Cycle Phases through Information

Integration of the life-cycle phases of facilities

For both technical and economic reasons it is valuable to integrate the life-cycle phases of facilities. In the forward direction the design, construction and usage phases are related for obvious reasons by the tendering and delivery activities. The design of a new building is preceded by a briefing/programming phase. Integration in the other direction means feedback and iteration within the three phases of design, construction and facility usage, but also backward integration from the construction and usage phases to the design phase. The integration of the facility product life cycle is described in figure 3:4.

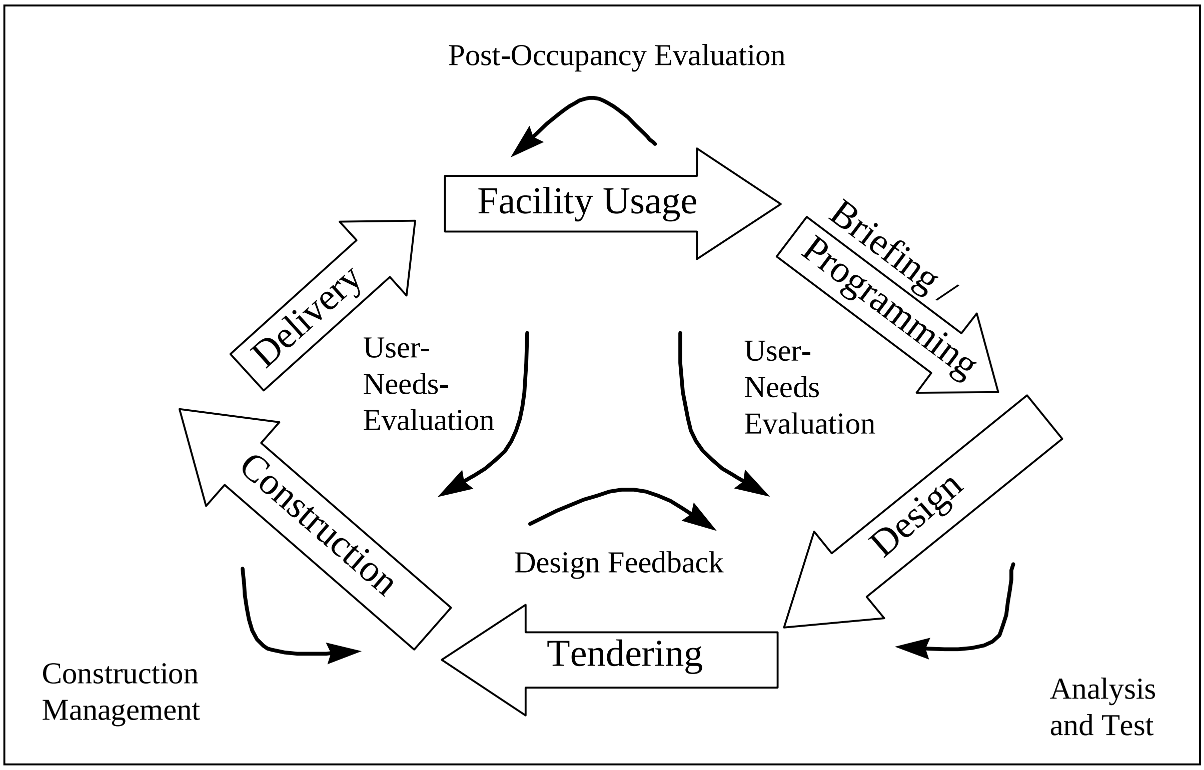

Figure 3:4 Integration of the life-cycle of the facility

Two information flows of major concern to the facilities manager are post-occupancy-evaluation (POE) and the evaluation of the user-needs. Post-occupancy-evaluation means the continuous evaluation of the suitability of a facility/building for the needs of the organisation using it. In this, the users are involved to a high degree. The initial work when designing a new building involves three major players, the client, the end user and the design team. In the decision process, the end users are often not sufficiently involved. The end-result is, therefore, that the new building does not meet their requirements sufficiently. This could be largely avoided by more appropriate use of evaluation of user-needs. *Bröchner* [1996] analysed the use of IT to improve the feedback from facilities management to design and construction. From an empirical background, *Laitinen* [1998] stressed the value of a more formalised and structured evaluation of user-needs in or even before the briefing/programming phase.

The information waste in the life-cycle of facilities

Figure 3:5 describes the relative amount of information about the facility during the different phases of its life-cycle.

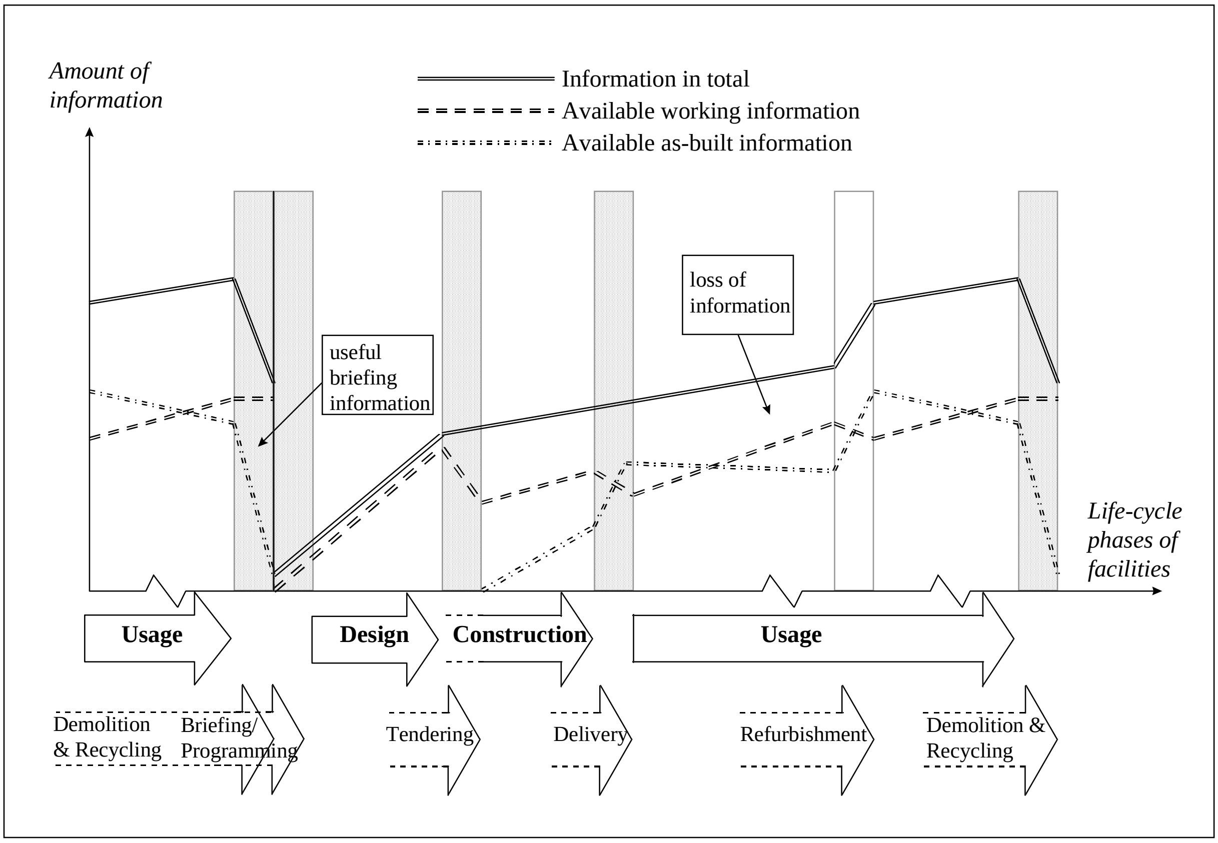

Figure 3:5 The relative amount of construction information used during the life-cycle of a facility.

The alteration in the available information between the different life-cycle phases is emphasised. Two types of information classes concerning the degree of accuracy of the information are here distinguished, namely, working information and as-built information. Working information is any information from initial planning right through the design process and the construction phases. As-built information is information that describes the building as it actually has been constructed, including changes on site which were not included in the original design documentation.

As a result of the delivery process, the amount of as-built information reaches a maximum just before hand-over because a lot of working information is transformed to as-built information. On the other hand, a lot of information stays with the parties involved in the creation process and is not delivered to the client and/or the operator of the facility, which means that the amount of both working information and as-built information available decreases during the delivery phase.

If the information gained during the design and construction processes is in a non-digital representation, which was the normal situation until recently, the loss of information during the hand-over process is significantly larger than if the facility information is represented in a digital form. The loss of information will leave the operator/facilities manager less prepared to perform adequately. In a refurbishment process, a lot of information from the original design and construction processes is required. It is normally costly and difficult to procure.

The amount of information handled in drawings

Drawings are widely used for exchanging information in the construction industry. Drawings are often more versatile and comprehensive than textual information. In their daily work, facility managers use drawings inherited from the design and construction stages, as described above. Approximately half of all drawings needed to erect a building are handed over to the usage phase of the building [*Hommik*, 1994]. Of the as-built drawings received by facilities managers, roughly only a third are active documents in the sense of being used often or modified [*Haugen*, 1990] and [*Svensson et al.*, 1994].

Modern buildings are increasingly complex. They include a growing number of different elements. According to statistics from one of the biggest real-estate owners in Sweden, Vasakronan, a medium-sized (about 5000 sq. m.) office building requires a total of 500-600 drawings to be completed [*Hommik*, 1994]. This number could be subdivided into different disciplines as in table 3:3.

Table 3:3 Number of drawings used to describe a medium sized office building

Drawing type (discipline)	***Total No.***	***No. to archives***
Architecture	100	50
Construction	100	100
Mechanical services (HVAC)	150	60
Electrical & control systems	200	60
Total number	550	270

To these numbers, geographical maps and surveys must be added. During the life-time of a building, smaller refurbishments generate about fifty new drawings every ten years. At least twice a century, major conversions are required which add about another 250 new drawings.

Each of the drawings required to describe and construct a building contains a considerable amount of information. As an example, an ordinary architectural plan on a scale of 1:100 describing a 1000 sq. m. floor-plan contains roughly 500 building entities, i.e. rooms, walls, floors, ceilings, columns, openings, windows, doors, stairs, surface materials and fittings and furniture [*Appelqvist*, 1997]. Each of these entities is described by between 10 and 100 or sometimes even more attributes during the design and construction processes. On average, other drawing types used in the construction industry would probably not contain fewer entities.

Ensuring the correctness of the building description

A vast majority of the buildings that exist today and will be utilised for dozens of years to come, are documented on paper only. New designs are being made in CAD, but often still do not provide geometrical and other data in a useful format for the FM processes. Any meaningful development aimed at providing IT systems for FM must take into account existing facilities, their documentation and currently used IT systems. Existing, paper based information can be transferred into digital format using a number of techniques [*Svensson et al*., 1994]: redrafting, digitising, scanning, calibration of scanned drawings, vectorisation of scanned images and a number of hybrid viewing and editing tools.

Often, field measurements are required to get as-built information into the databases of the IT systems. This is an expensive way of capturing information but often unavoidable. The economic consequence is that often more than half of the total cost of the new IT system is for capturing and feeding data/information into it [*Teicholz*, 1992].

Comparison of design and construction with FM

While the design and construction processes can be characterised as pre-occupational, project-based and iterative, the FM process is mainly post-occupational, continuous and repetitive. The building design and construction processes together are to a high degree a merchandise-producing process, while FM is mainly a services-producing process. The professionals involved in the design and building processes are specialists who work together in a team created especially for each project. The FM professionals are often more generalists, with the objective of integration and management.

These differences between the design and construction processes on the one hand and the FM processes on the other have effects on information handling in the different categories of processes. For example, FM decisions in the design and construction phases are more often functional or economic than purely technical. Much of the information handled in the FM process must be stored during long periods and is used only now and then.

3.5 Current Methods for Structuring FM Information

The multi-disciplinary nature of FM information

The FM process is an integrating and co-ordinating activity and the information used is of a very multi-disciplinary nature. Thus, it could be classified according to different views, according to Table 3:4.

Examples of current types of documents/information concerning the building and handled in FM are: as-built and other documentation of the building, operations and maintenance instructions, documents/information describing the usage and user of the facility and contracts of different sorts.

Flexibility and adaptability must be basic requirements in information systems for FM. This must have a bearing on the collection, storage and usage of data/information. It must be possible to handle and analyse different sorts of information with the help of tools and the FM application systems. Some currently used methods, which to some extent encourage but sometimes also constrain this need to achieve flexibility and adaptability, are described and discussed below.

Table 3:4 Classification of FM information

Classification View	***Classification criteria***	***Classes***
Information Technology	Type of representation	digital, non digital
	Format	ASCII, TIFF, etc.
Content	Type of usage area	technical, financial, administrative
	Functional area	real estate and financial management, service management, spatial management, operation and maintenance, and renovation, rebuilding and expansion
	Level of decision pyramid	strategic, tactical and operational
	Representation	textual, numeric, integer, real, graphical, etc.
	Degree of accuracy	working information, as-built information
Time	Degree of time relation	syneronous (real-time) information and non-syneronous (delayed) information
	Life-cycle phase	briefing/programming, design, tendering, construction, delivery, usage, demolition & recycling
	Event-traced	simple, approved, stored, archived, etc.

Classification systems for building parts

The SfB System was developed at the end of the 1940s in Sweden by a co-ordinating committee for the construction industry, SfB (Samarbetskommitten för Byggnadsfrågor). The objective of the SfB System was to rationalize the flow of information between different players in the construction process in order to avoid mistakes and loss of time [*Giertz*, 1995]. Figure 3:6 describes the main structure of the original SfB System [*CIB*, 1973].

There are three different classifications that propose to widen the scope of SfB; CBC/SfB in Denmark [*Bindslev*, 1994], CI/SfB in Great Britain [*CIB*, 1973], and BSAB in Sweden [*SB-Rekommendationer*, 1987]. The SfB system and its successors have primarily been used for classification of information related to the design phases of the overall construction process. Whether the tables could also be used in the FM process has not fully been examined yet. *Häggström* [1997] has made a proposal to do such an analysis. *Bergenudd* [1997] has examined the information structure in technical documents used in facilities management work.

Materials				**Works**	
Facet: Substances and formless materials		Facet: Made for specific element			
Table 1 Resources		**Table 2 Building Elements**		**Table 3 Work Sections**	
a	open	0	general accessories, iron mongery components for	A	open
b		1	element of substructure	B	
c	c		element of superstructure	C	
d	metal	2	-primary elements	D	Sundry materials
e	stone - natural	3	-complementary elements	E	Materials for concrete works
f	stone - artificial, concrete, etc.	4	-surface element	F	Building bricks and blocks
g	burnt clay		element of utility service	G	Structural units (prefabricated)
h	gypsum, asbestos cement, etc.	5	-mainly piped, ducted		Long units
i	wood	6	-mainly electrical (incl. transport)	H	-profiles, bars, etc.
j	fibre (board), paper		fixture, room equipment	I	-pipes, tubes
k	cork, chips (board), etc.	7	-general	J	-thread, wires, mesh, etc.
m	felt, wool, etc	8	-special		Insulating materials
n	asphalt, linoleum, rubber,			K	-heat, sound, vibration

Figure 3:6 Structure of the Swedish SfB System, 1950. After Giertz *[1995].*

Chart and code of accounts

Basic figures concerning economic/financial occurrences are registered in a chart or code of accounts plan. This means that costs and receipts are sorted in different classes. The primary classification is into different accounts. For a more functional classification, they can be sorted into classes describing organisational units, products or projects according to the code plan [*Senning*, 1985]. For general business accounting and coding a fairly rough classification is sufficient. The "BAS 90" chart and code of accounts and code plan is widely accepted within industry and trade in Sweden [*SABO*, 1993]. The classes of the "BAS 90" are accounted for in a key scheme in figure 3:7.

POSITION								Control accounts for internal auditing etc.
Balance-sheet accounts		Accounts for BFL[*] profit/loss stages					Accounts for other BFL profit/loss stages	
Assets	Liabilities	Income/ Revenue	Expenditure/Costs				*Finance* Income/ Revenue	Optional
			Materials/ Goods	Labour	Other	Other	Expenses/ Costs *Extra ordinary* Income/ Revenue Expenses/ Costs Appropriations Tax	
Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9

Figure 3:7 Key scheme of classes in "BAS 90". After SABO *[1993]*

Many industrial sectors have tried to achieve standardised charts of accounts which on the one hand, follow legislation and current tradition, and on the other, pay attention to characteristics and structure within the specific sector. There is at least one example of such a sector-adjusted chart of accounts in the FM sector of Sweden, namely "FastBAS 93" [*SABO*, 1993].

The classifications of the chart or code of accounts and construction classification tables are two orthogonal types of classifications. Whether they could be used together and with the possibility of mapping information between them, has so far not really been analysed.

Characteristic values (key values)

A handy resource in the planning, analysis and budgeting work of the FM operation is provided by characteristic values. A characteristic value describes the relationship between two or more quantities. Examples are energy consumption [kWh per sq. m. and year], maintenance cost [SEK per sq. m. and year] and vacancy rate [area not leased per total area]. Particular types of characteristic values for facilities relating cost or income to the core business are often used, e.g. [cost per day and hospital beds] or [no. of personnel per sq. m. of premises].

[*] BFL is acronym for bokföringslagen [Swedish for accounting regulation/act]

A good use of characteristic values is to measure the effect of different influencing factors. Typically, such factors are construction year, type of material or construction, type of use or tenants, the qualifications of the FM staff, or to what extent IT is used in the FM functions. An obstacle when using characteristic values is that they are not sufficiently standardised. For instance, different area terms are used, or the definition of maintenance cost or operation cost often differs between different facilities managers. This must be taken into consideration. Another problem is that many organisations cannot produce the reliable input data which is needed to calculate characteristic values.

Databases

Database technology has been used for quite a long time within FM as computerised record-keeping systems for simple information. They have functioned as collections of data files with the basic operations add, retrieve, change, and delete data within the database.
Traditionally, these database systems have handled large volumes of simple, mainly alpha-numerical data. Each system has uniformly stored information (data items) for a specific application, with minimal internal structure of the items. The format of the structured data has not been standardised but is specific for each brand of database system. Therefore, it has normally not been possible to easily transfer information from one system to another.

The systems predominately used in new systems today are relational databases which offer quite a lot of flexibility compared to earlier systems in combining data from different sources.

3.6 IT Strategy for FM

The requirements for information handling in an FM organisation could be clarified through the development of an IT strategy. The incorporation of IT in FM without an overarching information framework, more often than not, leads to the generation of voluminous, poorly focused and irrelevant information [*Barrett*, 1995]. Examples of Swedish studies which have clarified this are [*Wikforss*, 1997], [*UFOS*, 1996] and [*Norberg and Torstensson*, 1996]. They all describe the benefits of developing an IT strategy and they all describe, although partly differently, what is meant by an IT strategy. Basically, it consists of the following four parts:

- **Purpose** - description of the business visions and measurable goals (objectives) of the IT and information usage.
- **Information requirements/strategy** - description of the information scope and information usage required to fulfil the above purpose.

- **Hardware and software (IT) platforms** - descriptions of IT platforms needed to realise the above information strategy.
- **Realisation** - description of how the IT solution described above should be carried out.

The IT strategy describes the organisational scope, objective and context concerning information and information systems. Normally, an IT strategy should aim for process re-engineering, not just computerisation of existing processes and routines. The chain of activities required to develop an IT strategy for FM is to a certain degree described by models in the 'ISFM' structure developed by *Majahalme* [1995], and is briefly discussed in chapter 4.

In the system development process (as described in section 4.1), the activity of developing an IT strategy should be carried out in advance of or in parallel with the first stage of the specific system development work. The generic FM process model presented below could be useful element or tool in the elaboration of such strategies.

3.7 Proposed Generic FM Process Model

Taking the objective of FM as a starting point, a generic FM process model was developed. The model is described below, at different levels of detail, with IDEF0-notation.

The purpose of the high-level FM model described below is to achieve a basic structure on which a particular system, together with its applications, could be built as a layered architecture. The FM model should facilitate the endeavour towards integration of the FM process and systemisation (classification) of the FM information.

The proposed model consists of four parts: core process, configuration of FM, execution of FM, and controlling of FM, as shown in figure 3:8. The four parts are further detailed below.

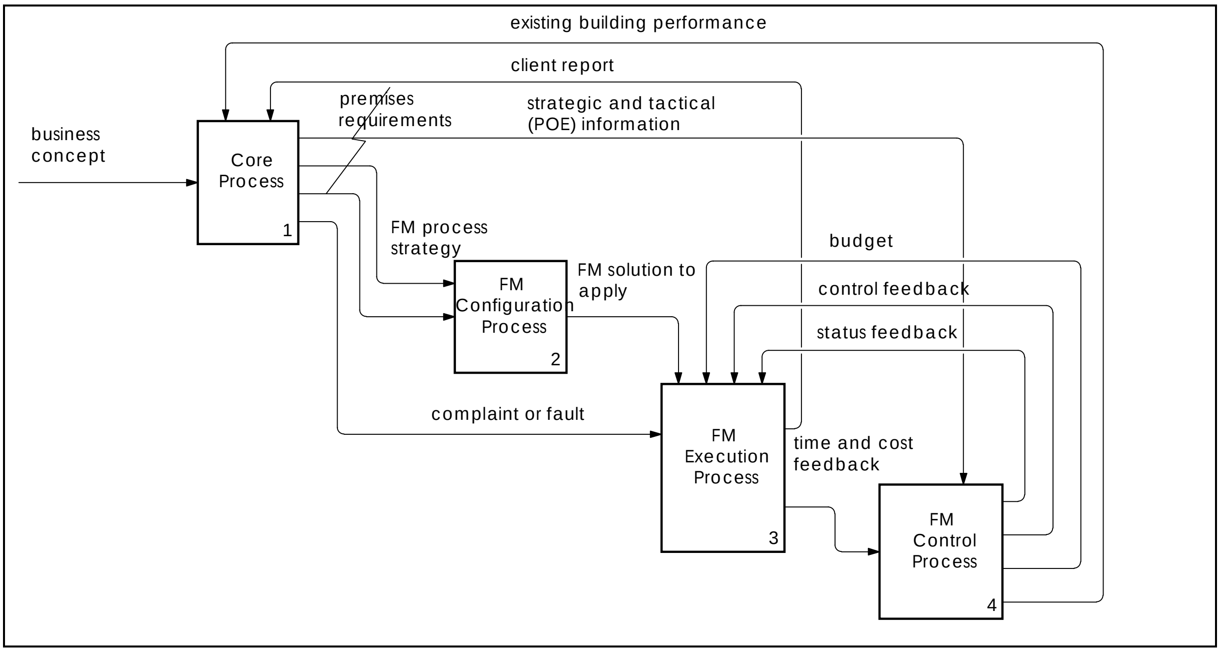

Figure 3:8 An overview of the Generic FM Process Model

The original idea of the FM model was to describe an FM information process that would eliminate some of the shortcomings of existing FM systems. In part these were discovered in an analysis of FM systems used within the National Board of Public Building [*Svensson et al.*, 1989] and elsewhere [*Teicholz*, 1992]. Typical shortcomings are:

- Feed-back information is rarely used.
- Different systems are not integrated.
- Technical and economic aspects of FM are handled in completely different systems.

A first version of the execution and control parts of the generic FM process model was used in the Klara prototype project, described in chapter 7. Other important influences for the evolution of the proposed model have been:

- Descriptions of the importance of control processes [*Haugen*, 1990].
- The “a/z-model” of *Bindslev* [1995] which gives a logic structure of classification systems.
- Descriptions of the importance of linking the FM process with the core process [*Barrett*, 1995].

Core business processes

The core business processes can be divided into three decision and management levels: strategic (handling visions and goals), tactical (handling the strategy and planning of the business), and operational (actually producing the desired results), as shown in figure 3:9.

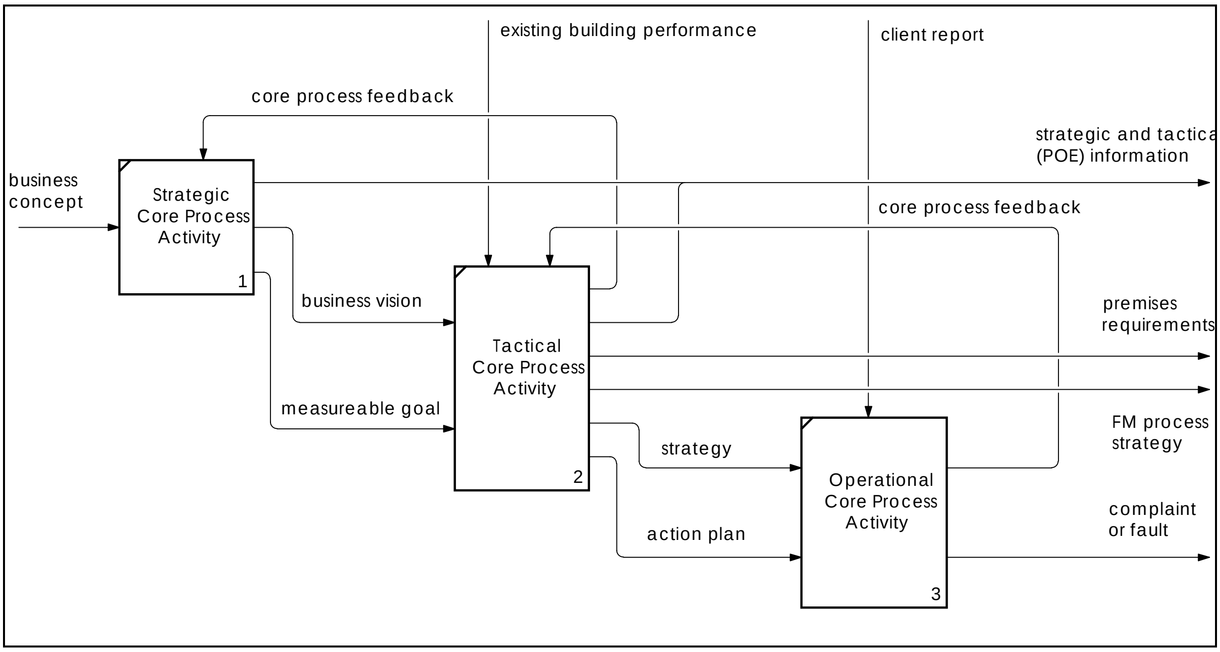

Figure 3:9 Core Process

The business concept is the starting point of the core business on its strategic level. The core business operations on this level determine the business visions and measurable goals. These are input to the work done on the tactical level of the core business. In its turn, this work produces strategy and action plans, such as yearly budgets, according to which the core business is operated. In connection with the FM operation, it should also produce a description of the premises requirement and an FM strategy. The FM strategy specifies how the FM business should be carried out and also includes measurable goals.

Configuring the FM

The configuration objectives of FM should include different values of the core business. The objectives for FM may vary according to the choice of strategy, but usually they should include four groups: quantity, quality, timing, and costs [*Riihelä*, 1994].

Figure 3:10 describes the planning and configuration of the FM organisation.

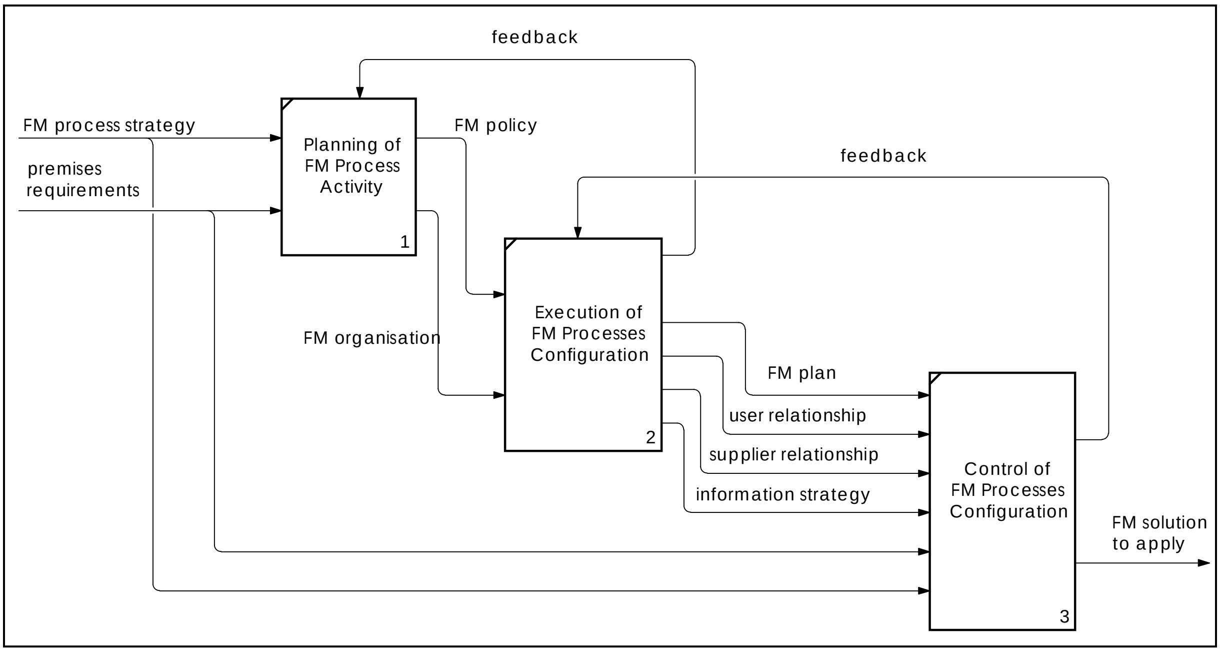

Figure 3:10 FM Configuration Process

The planning stage of the configuration process is concerned with FM issues on the corporate level. The activities should achieve a suitable FM policy and relevant FM organisation. The policy is "the master specification and operational 'bible' of the facilities management component of the organisation" [*Varcoe*, 1994].

The execution stage brings the policy and organisation into a workable FM solution. This includes an FM plan, guidelines and mechanisms for the relationship with users of the premises and suppliers and also standards and plans of action for information management.

The control stage, finally, evaluates the solution against the FM strategy and premises inventory against premises requirement. The evaluation should outline the overall view of the status of the facilities, as well as the quality of the FM solution [*Majahalme*, 1995].

Executing the FM

The execution part of the generic FM process model is, to use the words of *Bindslev* [1994], built on the idea of a common structure of "intellectual" and "manual" FM work. The model is described in figure 3:11. The association with the "a/z- model" should facilitate integration of an existing (SfB-related) classification into the FM process description. This is because the "a/z- model" was developed in close relationship to the CBS/SfB system in Denmark [*Bindslev*, 1995].

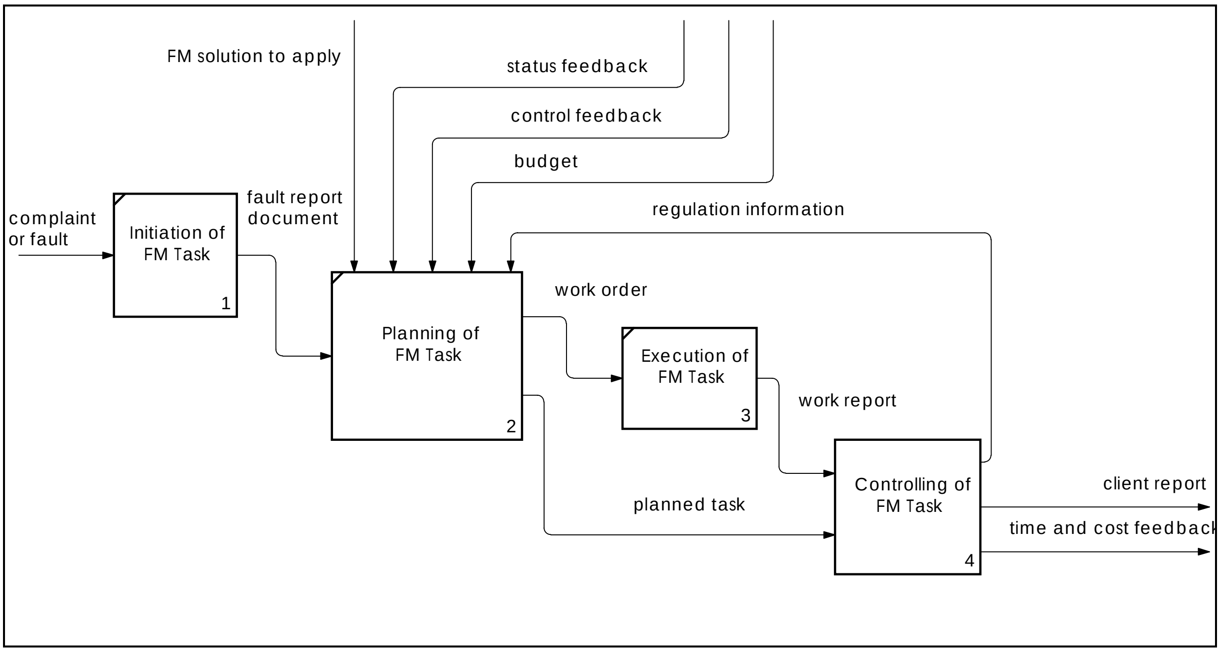

Figure 3:11 FM Execution Process

The execution part of the FM process model contains four stages (initiation, planning, execution and control and are carried out for any FM task. The initiation means to define the objective of the specific task. In the model, displayed in figure 3:11, this is done either because of an instruction from a plan, an error message or some other sort of non-scheduled input. Initiation of an FM task is followed by the planning of it. The planning stage means preparing activities concerning the specific task, acting as a decision mechanism, and results in work-order information.

Then the task is executed. After the task is carried out, there is a control to insure that the work corresponds to its specification in the plan. The control of the execution is further detailed as shown in figure 3:12. In the event of deviation, the necessary adjustment is made according to regulation information. After its completion, a work report is generated. The report is recorded and results in a message to the client (Core Process) and a time and cost message to the FM Control Process.

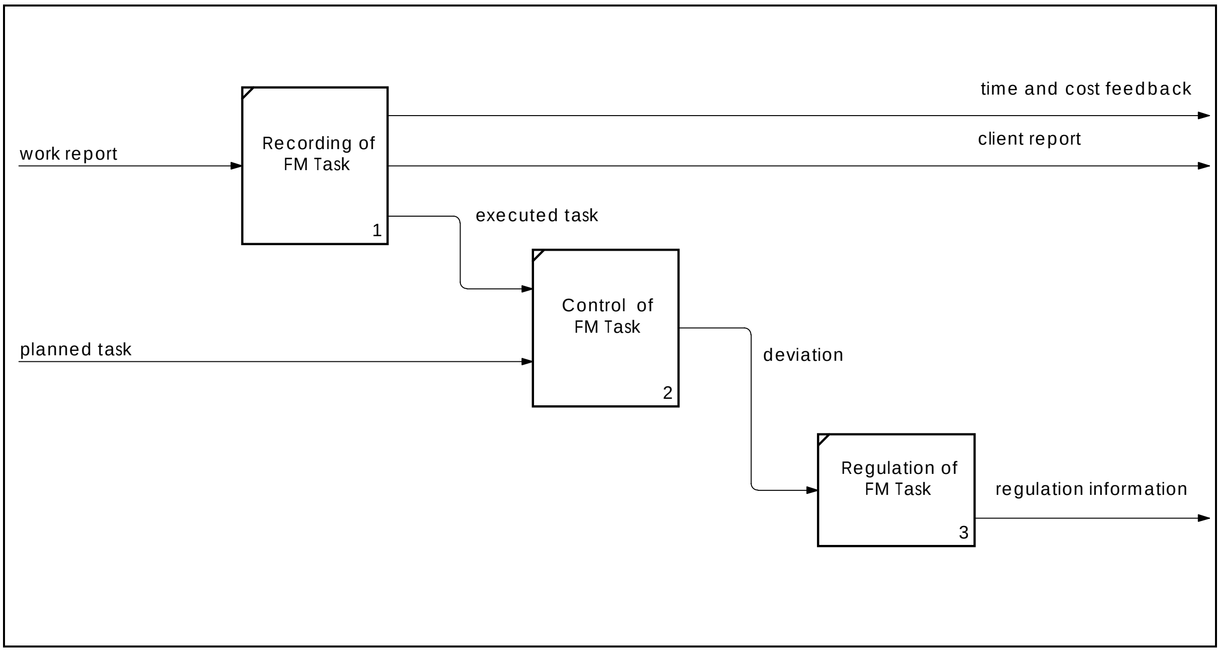

Figure 3:12 Controlling of FM Task

Control of FM processes

The control part of the FM process model is described in figure 3:13 below. It also contains the four stages initiation, planning, execution and control. The process is carried out at different intervals. The major part of the work is done on the tactical level of the FM organisation.

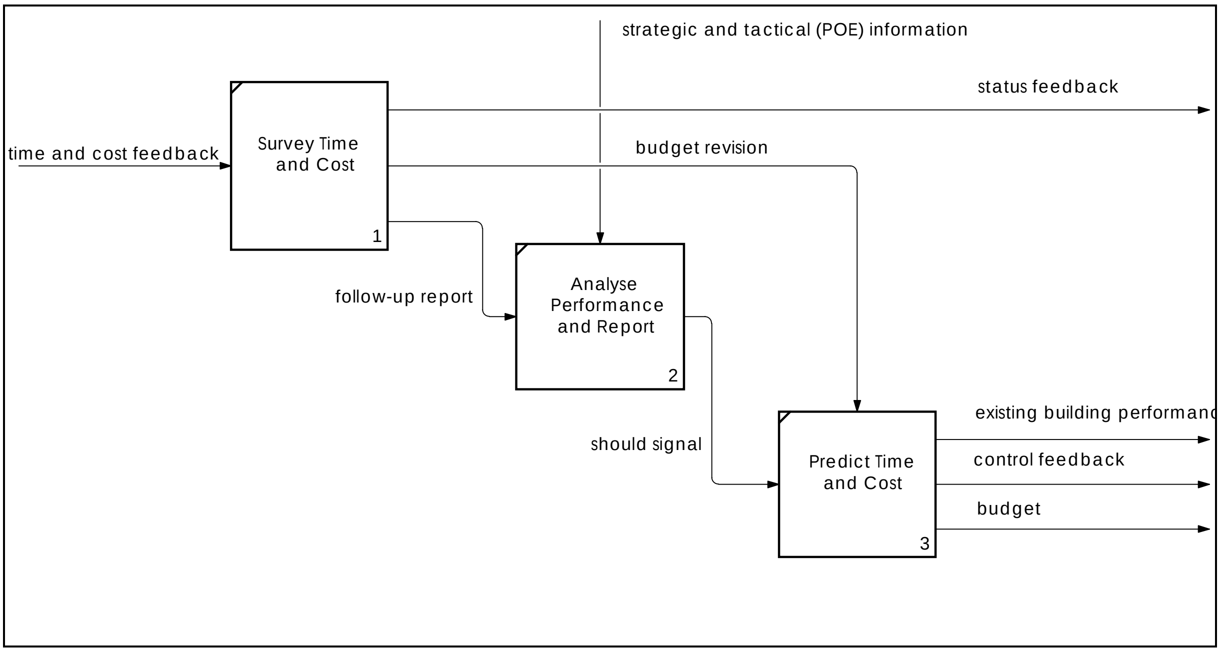

Figure 3:13 FM Control Process

The initiation of the FM Control Process is provided by adapted cost-and-time feedback information from the execution part of the generic FM process model. In the planning stage different status reports are compiled together on the basis of cost-and-time feedback information from the FM Execution Process. These status reports are used as a basis for the status reports sent to the execution activities, for budget revision (is-signal) and for follow-up reports used by the execution phase of the FM Control Process. In this execution phase the framework that should be implemented in the budget is decided on the basis of follow-up reports and the strategic and tactical (POE) signals from the core process. In the control stage a financial plan (budget) for the FM activities during a certain period is developed. This gives the do-signals to the FM Execution Process and for control feedback to the execution part of the generic FM process.

Evaluation of the proposed Generic FM model

The Core Process (figure 3:9), FM Configuration Process (figure 3:10) and the FM Execution Process (figure 3:11) in the Generic FM model were compared with a table received from the University of Strathclyde [*Alexander*, 1994] in a document called ”QMF-Process Overview”. The table was rearranged and some terms were renamed after the ideas developed in the generic FM process model described in this section. The result after these minor changes is described in table 3:5.

Table 3:5 Generic description of core business configuration and of FM operations on different organisational levels. [After a document received in November 1994 from Keith Alexander at University of Strathclyde in Glasgow]

Core Business Configuration on Different Levels of Organisation

	Initiation/ identification	***Planning/ design***	***Execution/ implementation***	***Control/ appraisal***
Per Whole Corporate	Core business mission	Objectives to meet mission	Required needs to meet objectives	Output against mission
Per Business Unit	Objectives to meet mission	Teams to meet objectives	Personnel and resources	Output against mission/objectives
Per Individual	Objectives to meet organisational mission	Job spec. to meet objectives	Individual’s work and needs	Output against objectives and needs

FM Functions on Strategic Levels

	Initiation/ identification	***Planning/ design***	***Execution/ implementation***	***Control/ appraisal***
FM policy	Policy in response to business mission	Policy in response to objectives	Policy in response to business needs	FM policy against business success
FM organisation	Organisational needs to response policy	Standards	Implement organisation	FM organisation

FM Functions on Tactical Level

	Initiation/ identification	***Planning/ design***	***Execution/ implementation***	***Control/ appraisal***
FM Facilities planning	1-5 years requirements	FM plan	FM plan	FM plan
Relationships with users	Communication needs with users	Communication mechanisms	Communication mechanisms	Relationships with users
Relationships with suppliers	Communication needs with suppliers	Communication mechanisms	Communication mechanisms	Relationships with suppliers
Information management	Information needs	Standards and action plans	Facilities Information Mgmt System	Facilities Information Mgmt System

FM Functions on Operational Level

	Initiation/ identification	***Planning/ design***	***Execution/ implementation***	***Control/ appraisal***
Asset Management	Asset requirements	Assets	Build/acquire/dispose	Result against the requirements
Change Management	Change requirements	Workplaces/ work processes	Changes	Result against the requirements
Service Management	Service requirements	Services	Source services	Service delivery against need
Information Management	Information requirements	Processes	Support informational needs	Information needs against processes
Technology Management	Technology requirements	Systems	Systems designs	Technology provision against need
Legislative Compliance	Statutory requirements	Processes	Processes to comply with legislation	Processes and effects of legislative change

The different FM functions and respective four stages (initiation / identification, planning/design, execution/implementation and control/appraisal), as described in the FM Functions parts of the table, are easily matched with the FM Execution Process of the generic FM process model in figure 3:11. The Core Business Configuration part of the table could be matched with the processes described in figures 3:9 and 3:10.

The close co-operation between the core business and the FM process was described earlier. A description of the core business itself could not be made without knowing of its details.

The FM Process Model has a cyclic (repetitive) structure. It contains different cyclic sequences which are run through with different periodicity. The different cyclic sequences have a different frequency (1 hour - 1 year) and different amplitude, i.e. involve different people more or less closely attached to the FM operation.

3.8 Conclusions

Traditionally, a process model is used in a system development project to:

- analyse and explain the process by describing the activities of the system domain
- describe the information/data flows in the process
- provide a basis for possible process re-engineering activities

This is valid for a specific process model describing a specific application. In this chapter a set of process models have been described. The objectives of these models are slightly different compared to specific process models. These models should act as a starting point for the development of application-specific process models and other application models.

By using the proposed Generic FM Process Model a framework for the development of IT applications for particular sub-tasks in FM, the resulting applications should be better integrated between themselves, easier to maintain over generation shifts in hard- and software and should be well focused on supporting vital information management tasks in the overall FM process.

Features in the models which should contribute to this include:

- The generic FM process model includes mechanisms providing feedback from the core business to the FM process (i.e. post-occupancy-evaluation) and from the FM process to the construction process (user-needs-evaluation).
- The generic FM process model explicitly models the relationships between the core business and FM work, and between technical, economic and administrative types of FM work.
- The generic FM process model facilitates the evaluation of the FM work both from a technical, economic and functional viewpoints, and the measurement of good value for money by its foundation of a tighter relationship between core business and FM work.

4 The Technology: Object-Oriented Building Product Modelling

Introduction

This chapter provides a survey of possible technical solutions to the problem of developing integrated information systems in general and integrated information systems for facilities management specifically. The discussion of the chapter is carried out from the point of departure of information systems and information system development methodologies. The end of the chapter is focusing on building product models and their usage in different research and development projects.

4.1 Traditional Information Systems Development Methodologies

Information systems and development methodologies

In its widest sense, an information system is any system that manages information. A more detailed definition is provided by *Buckingham et al.* [1987b] . "An information system is a system which assembles, stores, processes and delivers information relevant to an organisation (or to society), in such a way that the information is accessible and useful to those who wish to use it, including managers, staff, clients and citizens. An information system is a human activity (social) system which may or may not involve the use of computer systems." The definition raises a few questions.

- How is the information managed by the information system?

...assembles, stores, processes and delivers information...

This means that an information system includes a range of different information-handling processes such as capturing, transmitting, storing retrieving, manipulating or displaying information. It is not just a matter of storing information. All of these sub-processes set requirements for the IT used.

- What information is handled?

...information relevant to an organisation (or to society)...

This means that the information system should be developed out of the information requirements of the organisation. The type and amount of information are determined by the organisation and its goals and requirements.

- What is the objective of the information system?

...in such a way that the information is accessible and useful to those who wish to use it, including managers, staff, clients and citizens.

This means that the information must be e.g. structured and displayed so that it can meet the requirements of the organisation and its processes.

When an information system is developed, some formalised information-system development methodology is often used. According to *Madison* [1983], such a methodology is a recommended collection of philosophies, phases, procedures, rules, techniques, tools, documentation, management and training for developers of information systems. The state-of-the-art of information systems development methodologies is characterised by several hundred, more or less similar, methodologies [*Bubenko*, 1992].

The conventional approach in developing software for information systems contains six stages [*Daniels and Yeats*, 1971]. These are briefly described as follows according to *Avison and Fitzgerald* [1988] and *Booch* [1994].

1. The ***feasibility study*** is an analysis of the current information system, often manual, and its problems. This stage contains an investigation of alternative solutions. Each solution is described in terms of technical, human (operational) and economic costs and benefits. The result of the feasibility study should be the recommendation of one solution. Management will then decide, from this study, whether to continue to a more detailed study or not.

2. The ***systems investigation*** is a specification of the required information system through detailed fact-finding. This stage involves a thorough investigation of the specific application area. Which are the functional requirements, and are there any constraints imposed? To ensure that the investigation is thorough, different aids for documentation such as document or information flowcharts, organisation charts, grid charts and discussion records, are used. The deliverables of the investigation stage are detailed facts about the information system's application area.

3. The ***systems analysis*** is a detailed description of what the user expects the specific system to accomplish. The facts/results of the investigation of the system are analysed from an information handling perspective. The analysis should be made in such a way that the constraints of the implementation technology are not taken into account in an unnecessarily restrictive way at this early stage. The result is a detailed description of the behaviour of the system.

4. The ***systems design*** is the accomplishment of an implementable description of the information system. The requirements of the system analysis are transformed into different descriptions including descriptions of input and output of the system, processes to convert input data to output data, structure of the files

in the system, and how the implementation should be carried out. Again, the documentation of the systems design is often structured according to documentation tools provided in different methodologies.

5. The ***systems implementation*** is the implementation of the designed system. Sometimes a prototype of the complete system is implemented (a pilot run) before the implementation of the operational system. The results from the design phase are developed into program code. The deliverable of the implementation is a running system including systems documentation and systems education.

6. The final stage of the systems development process is the ***review and maintenance of systems***. The review should confirm that the requirements from the feasibility study are fulfilled in the implemented system. The maintenance aims to ensure the continued efficient running of the system.

In figure 4:1 the conventional approach for development of software for information systems is described as an IDEF0 model[10]

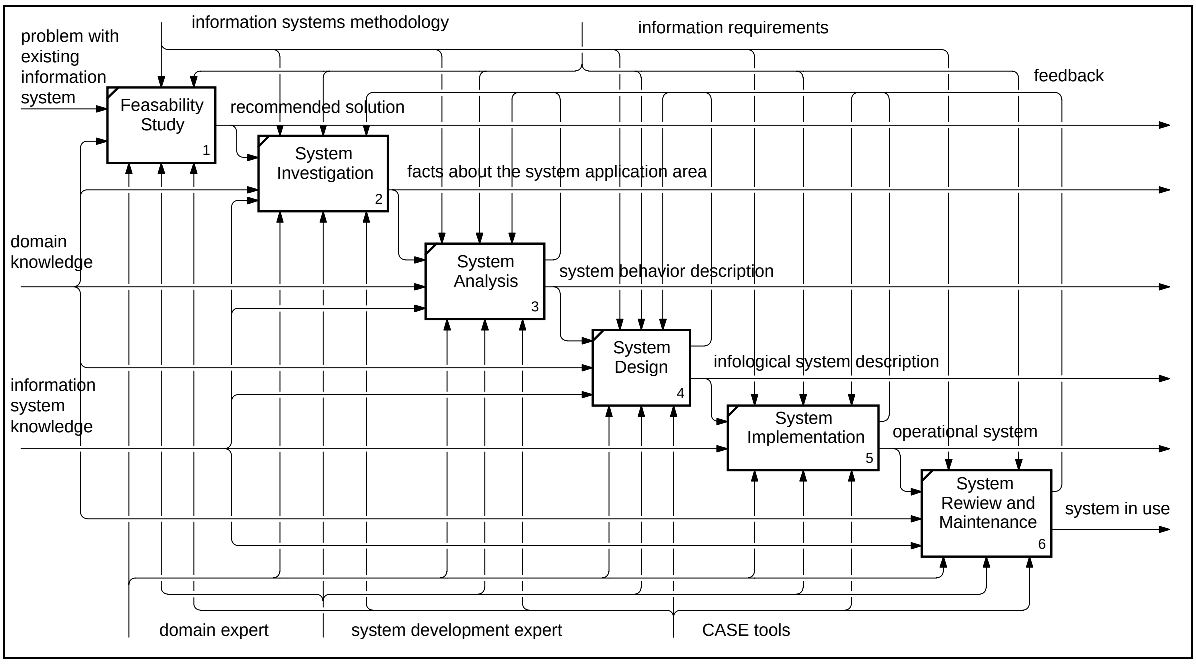

Figure 4:1 The conventional system development methodology

Techniques and tools are features in each methodology [*Avison & Fitzgerald*, 1988]. A technique is a way of doing a particular activity in the systems development process and any particular methodology may recommend techniques to carry out many of these activities. Examples of techniques are data flow dia-

[10] IDEF0 is described in Appendix 4

gramming, decision trees, decision tables, structured English, action diagrams, entity life cycle analysis, entity modelling and normalisation.

Broadly, the techniques can be divided into two categories, those that address process objects and those that address data objects. Data flow diagrams, decision trees and tables, structured English, entity life cycle analysis and action diagrams are all concerned with the analysis of processes while entity modelling and normalisation are examples of techniques for analysing data [*Avison & Fitzgerald*, 1988].

Each technique may involve using one or more tools. Tools in this connection mean normally computer tools, usually some software used to help the systems development process, i.e. CASE tools (Computer Aided Systems Engineering-tools). Examples of current tools of information systems development are fourth generation programming languages, data dictionary systems, project management facilities and visual modelling tools.

Examples of well-known (having a significant number of users) traditional information systems methodologies are:

- JSD (Jackson Systems Development) [*Jackson*, 1975]
- STRADIS (STRuctured Analysis, Design and Implementation of Information Systems) [*Gane and Sarson*, 1979]
- IE (Information Engineering) [*Martin and Finkelstein*, 1981]
- SSADM (Structured Systems Analysis and Design Methodology) [*Downs et al.*, 1988]

Structured (or process-oriented) methodologies start out from a functional decomposition, i.e. breaking down a complex problem into manageable units in a disciplined way. Data-oriented methodologies emphasise understanding and documenting data. The interest in data analysis derives partly from the development of databases.

Data models and different views of data

A basic element of development methodologies for information systems is their use of data/information/object models. The model is the basis of the methodologies' view of reality [*Avison & Fitzgerald*, 1988]. The data model describes structural and behavioural properties of the system [*Britts*, 1994]. The model is an abstraction and a representation of important elements needed to communicate between different partners involved in the system-development process.

The role of models within the system-development process is similar to the role of drawings within the construction industry or manufacturing industries. The models are the “drawings” of the IT industry. Both model and drawing represent a basis and help in constructing the buildings or the IT-applications. To fulfil this communicative function the dominant types of models are iconic, pictorial or schematic.

Modelling techniques use the mental method of abstraction, i.e. stripping a complicated system of unnecessary details to be able to focus on its essential characteristics relative to the perspective of the viewer.

The first development step in data modelling was to use a two-level schema. On the first level are the descriptions of physical and technical (data logical/syntactic) aspects, but also the logical/semantic aspects that are common to all applications. On the second level are sub-schemes that are specific to an application or group of applications. This two-level schema architecture is called the CODASYL-proposal. This means that there is quite a strong dependence between data in the database and the applications using these data.

The ANSI/X27SPARC DBMS framework [*Tsichritzis & Klug*, 1978] represents a three-level schema architecture. It was developed during the 1970s within the American National Standards Institute (ANSI) by the Standards Planning Requirement Committee (SPARC). The ANSI/SPARC architecture divides the system into three levels: external, conceptual and physical.

When data is shared between applications, it will be viewed in different ways by different applications. These varying views of the data are described on the external level of the framework. The external level data models describe these views without reference to implementation considerations. The scope of each external level model is to describe the information requirements of a particular application system.

The conceptual level data model (semantic data model or infological model) represents the overall view of the system, accommodating all the different application views which were expressed in the external models. The conceptual view is independent of the method of implementation - physical data independence. It is also separated from the external view - logical data independence.

The physical level model (the datalogical model) is a description of the information system as it is implemented in a particular system.

In figure 4:2 the three levels of the ANSI/SPARC architecture are described, including examples of the contents of information models on the different levels.

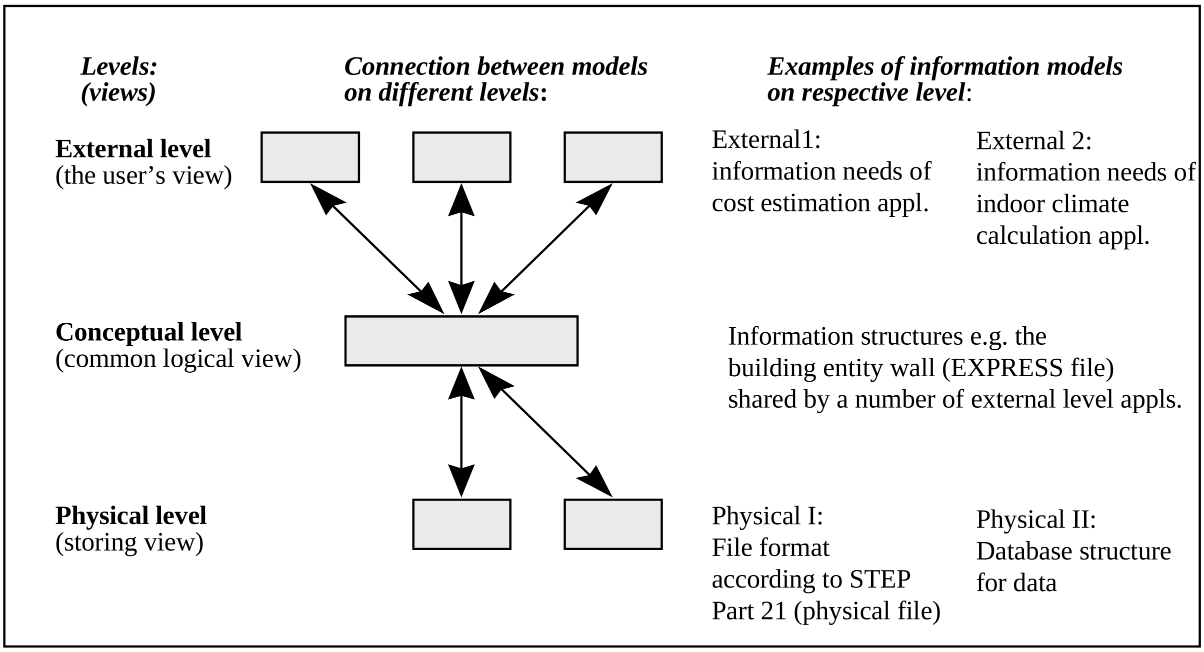

Figure 4:2 The three levels of the ANSI/SPARC architecture

4.2 The Object-Oriented Paradigm

Object-oriented programming

The alternatives to traditional methodologies are object-oriented (OO) ones. A feature of both traditional and object-oriented methodologies is the use of models. The primary reason for choosing OO technology, apart from the problems with traditional methodologies, is the endeavour to improve productivity and quality in the system development process. According to *Yourdon* [1994] the main reasons why this technology increases productivity and quality is the reuse of objects and prototyping facilities.

The basic ideas of object orientation were introduced over 20 years ago in the Norwegian programming language Simula [*Dahl et al.*, 1970]. The prefix object-oriented (OO) is used to denote a programming paradigm based on the major elements of object, class, encapsulation, abstraction, inheritance, and polymorphism, called object-oriented programming (OOP). Based on this, several object-oriented programming languages (OOPLs) e.g. Smalltalk, Eiffel, C++ and Java have been developed. Object orientation has also developed into a new paradigm for approaching problems, modelling systems and developing and handling systems.

The stages of an OO software development project are more or less the same as for the traditional methodologies. The basic concept of the object-oriented paradigm is the object. An object in a program is an independent and well-contained program (information) module with both (local) data and methods (operations, functions) which operate on the data. The object is addressable through a distinct interface. The data of the object describe its state and its methods describe its behaviour. Both data and methods define the properties of the object. The properties have values and these often change over time.

Data and methods are hidden (encapsulated) inside the object. The only way to reach them is by sending messages to the object. Communication between objects takes place using messages. This implies an effective method of building new, complex programs by combining existing program modules and, with security, both regarding data and methods. Every object has a unique object identifier. A certain method in a specific object is executed by sending a specific message to this object. The message only invokes a method, while the method itself inside the object specifies how it will compute its result. The implementation of the method is not described outside the class where it is defined.

In figure 4:3 the basic structure of an ‘object’ is described schematically. The figure includes an example of a class called Location. Location consists of data (co-ordinates X, Y) and three methods that initialise and return values for X and Y. The example is described using the programming language C++.

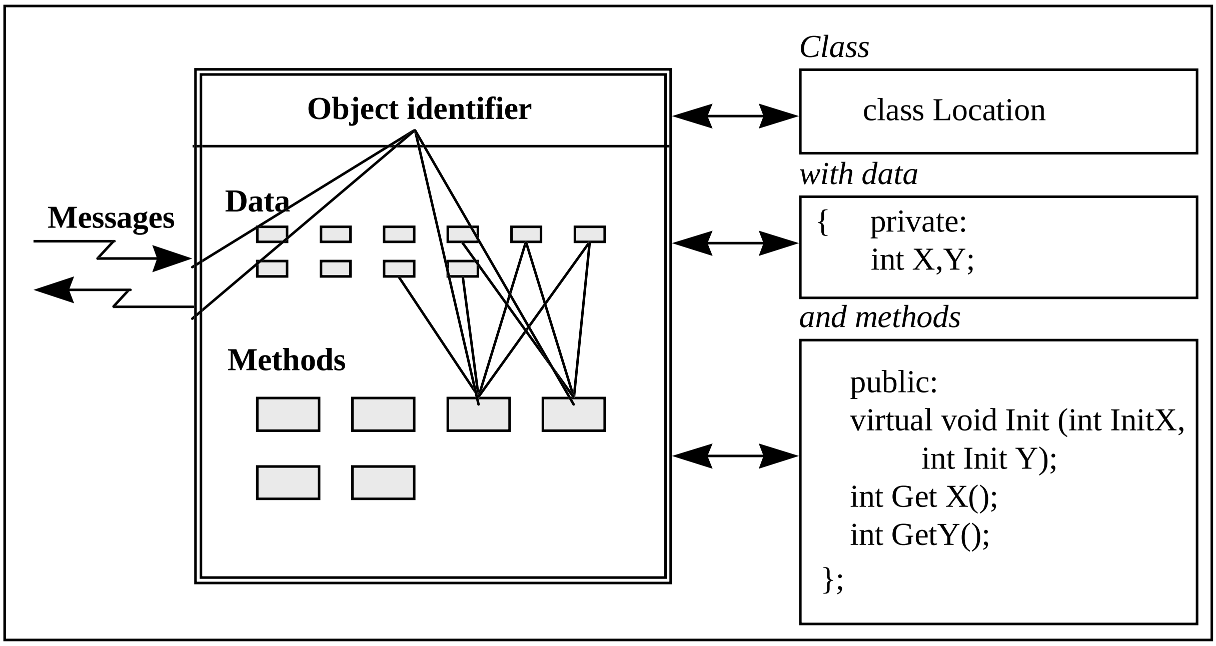

Figure 4:3 A schematic description of the object of the OO paradigm

A class (object type or type) defines the common properties for a set of objects with common structure and behaviour. The objects are members of the class which represents an abstraction of its objects. This structuring principle is called (object) classification. The class is a definition or template (mould) for the group of objects that belong to a certain class and each object is an instantiation of the class. The structure of the object is based on the class definition, which is unchanged during execution of the program. The objects, on the contrary, are dynamic, i.e. they are created, changed and deleted when the program is executed. The class concept allows developers/users to define their own (abstract) data types.

Inheritance (generalisation/specialisation) denotes a mechanism whereby a new class (the sub-class) can make use of properties (methods and variables) described in an existing class (the super-class). The sub-class inherits all properties of the super-class. In addition, new properties might be added or inherited properties might be redefined. Thus, the sub-class is defined by describing only its unique properties and otherwise it inherits the properties of the super-class. Inheritance can be used in many successive levels and a generalisation/specialisation hierarchy is established. Inheritance may be simple or multiple, depending on whether the new class inherits from one or multiple classes. Inheritance provides an effective way of sharing code between different applications, using code libraries and adapting existing program modules to partly new requirements.

Finally, it should be emphasised that the definitions and interpretations above of important concepts of the object-oriented paradigm, are still not standardised or even fully agreed on. The description above represents this author's interpretation of the concepts.

Object-oriented software engineering methodologies

The object-oriented paradigm for information systems and information technology is multi-faceted and each of the facets has its own benefits [*Yourdon*, 1994]. Important examples of this are:

- Object-Oriented Data Modelling (OODM) means that the focus during the systems development process is on high-level, user-oriented representation (objects) rather than on low-level, computer-oriented representation (data structures). Users can incorporate more directly the rich meaning of real world systems of the problem domain.
- Object-Oriented Programming Languages (OOPL) give the basic foundation for modularisation of software (in the same way as for hardware components) and support a high degree of software reusability. Encapsulation and inheritance support more productive and less error-prone programming.

- Object-Oriented Database Management Systems (OODBMS) can store and handle complex data types and complex data structures more easily than relational databases. Such data types are very useful for describing physical artefacts.
- Object-Oriented User Interfaces (OOUI) mean more end-user friendly application interfaces. These interfaces can be modified by the end-user or even developed by the end-user himself.

4.3 Conceptual Modelling

Conceptual modelling is a technique, used in the information system's development process, for representing knowledge about reality. The technique is based on database theory, linguistics, philosophy and psychology. An information system (IS) handles information about a specific part of reality. This part could be called area of interest, application domain, object system or universe of discourse (UoD). Reality contains things or phenomena, called objects or entities in the conceptual modelling technique. Examples of concrete objects are buildings, persons, tenants and invoices. Examples of abstract objects are measurement results, methods, and connections. An English synonym for object in OO modelling is entity.

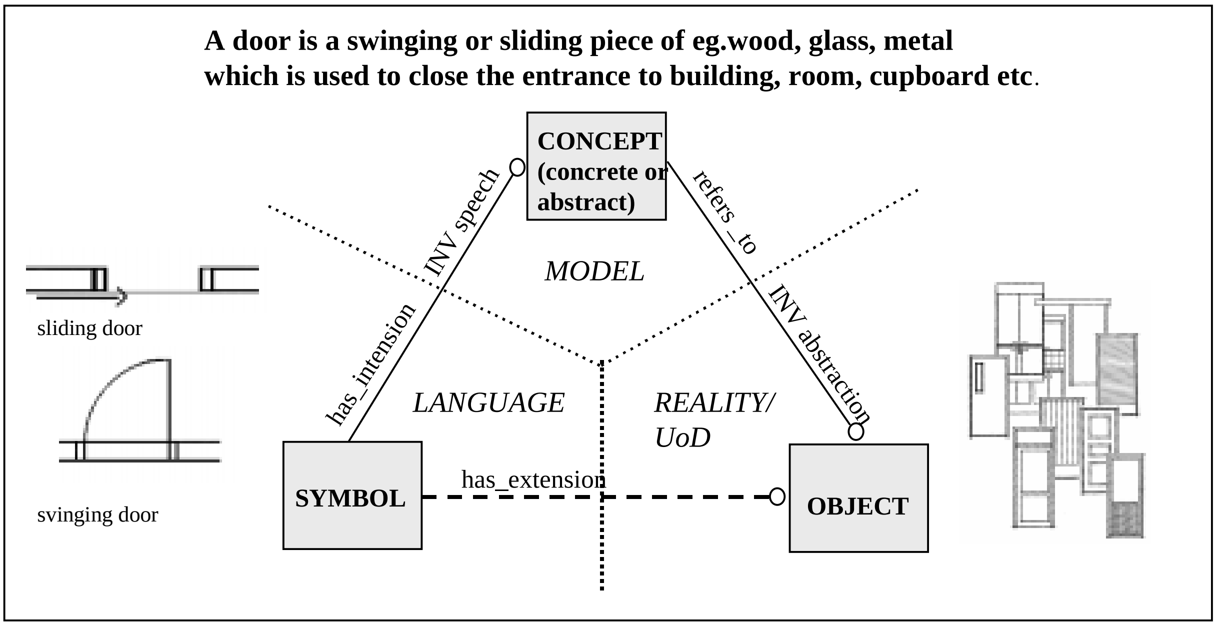

Figure 4:4 An adjusted version of Ogden's triangle

Conceptual modelling should be seen as a very natural technique to use when handling information about reality. People communicate about reality by using natural languages with words and expressions. The words and expressions (symbols) of a language have both an extension and an intension. By the extension of an expression is meant the object or set of objects in the real world to which the expression refers. The intension of a symbol means its sense; what is normally understood by the symbol. The relationship between the symbol, its extension and its intension is depicted as a triangle by *Ogden and Richards* [1923]. Figure 4:4 gives an adjusted version of this exemplified by the construction entity door.

The relationship of abstraction maps real world objects to their concepts and speech maps concepts to words (symbols). But there is only an indirect mapping between symbol and objects through the two direct mappings 'has intension' and 'refers to'. Every object normally has a concept, but there are concepts that can be expressed in words which have no corresponding real-life objects, for example "the perfect house".

In 1982 ISO published the report "Concepts and Terminology for the Conceptual schema and the Information Base" [*SIS*, 1985]. In this report a conceptual model is described as a collection of sentences expressing propositions that hold for a specific entity world. Also, the ISO report has proposed an abstract definition of a computer based information system containing three parts: a conceptual schema, an information base, and an information processor. The conceptual schema is "a consistent collection of sentences expressing the necessary proportions that hold for a universe of discourse". The information base is "a collection of sentences, consistent with each other and with the conceptual schema, expressing the propositions other than the necessary proportions that hold for a specific entity world". In practice, the information base is a collection of data stored in a specific format and describing the properties of the objects of the conceptual schema. The information processor is the mechanism that executes an action on the conceptual schema and/or information base in response to a command. These three parts together form a complete and logical system to describe, contain and manipulate information, as illustrated in figure 4:5.

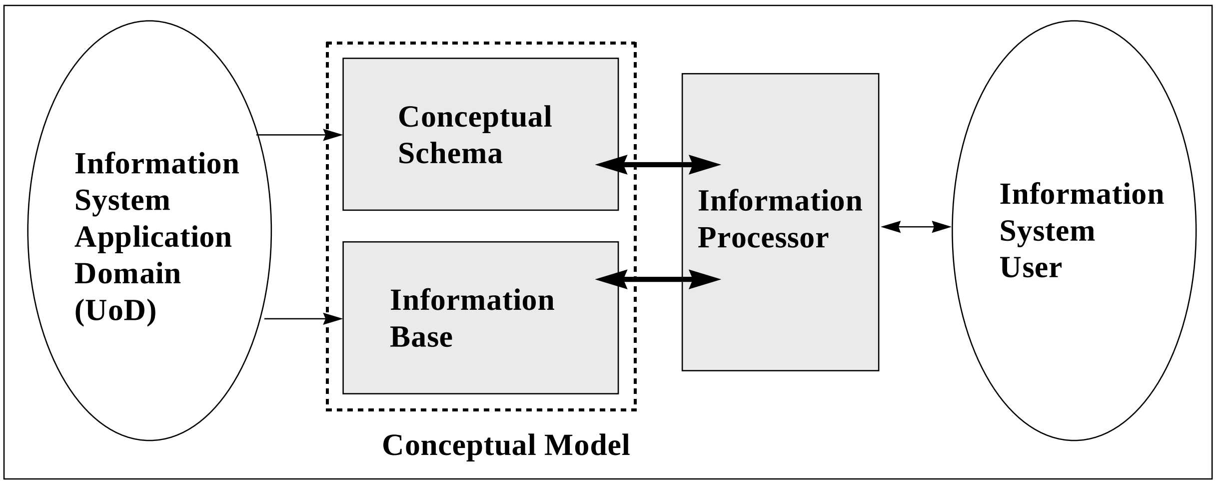

Figure 4:5 The three main parts of a computerised information system according to the ISO report

The conceptual schema is built from distinct and formal basic elements. These elements are defined by a modelling language together with a formal textual notation and/or graphical notation. Examples of such modelling languages and notations are E-R (Entity-Relationship) [*Chen*, 1976], NIAM (Nijssen's Information Analysis Method) [*Nijssen and Halpin*, 1989], IDEF1 and IDEF1X (ICAM DEFinition language) [*Appelton*, 1985], MOLOC using Prolog [*Johannesson et al*., 1996] and EXPRESS [*Schenck and Wilson*, 1994]. The conceptual schema is implemented by transformation into a suitable physical implementation format such as file or database format.

4.4 Object-Oriented Information Systems Development Methodologies

Today, most conceptual modelling for development of information systems is done using the object-oriented paradigm. Object-oriented information systems development methodologies represent a synthesis between conceptual modelling and object-oriented programming. The methodologies are based on the concepts of objects and classes and at least the characteristic features of abstraction, encapsulation and inheritance [*Yourdon*, 1994]. There is no single uniform development methodology of this type, but there are some quite widely used ones. Relatively well-known examples are given in figure 4:6.

These four examples of object-oriented methodologies cover partly different phases of the development life-cycle of the information system. Recently, a new modelling methodology has been developed jointly by Booch, Jacobson and Rumbaugh. It is called “The Unified Modelling Language (UML)” [*www.rational.com*, 1997].

All development methodologies mentioned in figure 4:6 above contain descriptions of their system’s development methodologies processes. As an example of this, the process of the OMT methodology is briefly described below [*Rumbaugh et al.* 1991].

The OMT methodology is subdivided into three phases: analysis, systems design and object design. The goal of the analysis phase is to develop a model of what the system will do. The analysis model should include information that is meaningful from a real-world perspective and should present the external view of the system. The basis for the analysis work is a problem statement (initial description of the systems requirements). The analysis results in three different models: the object model, dynamic model and functional model.

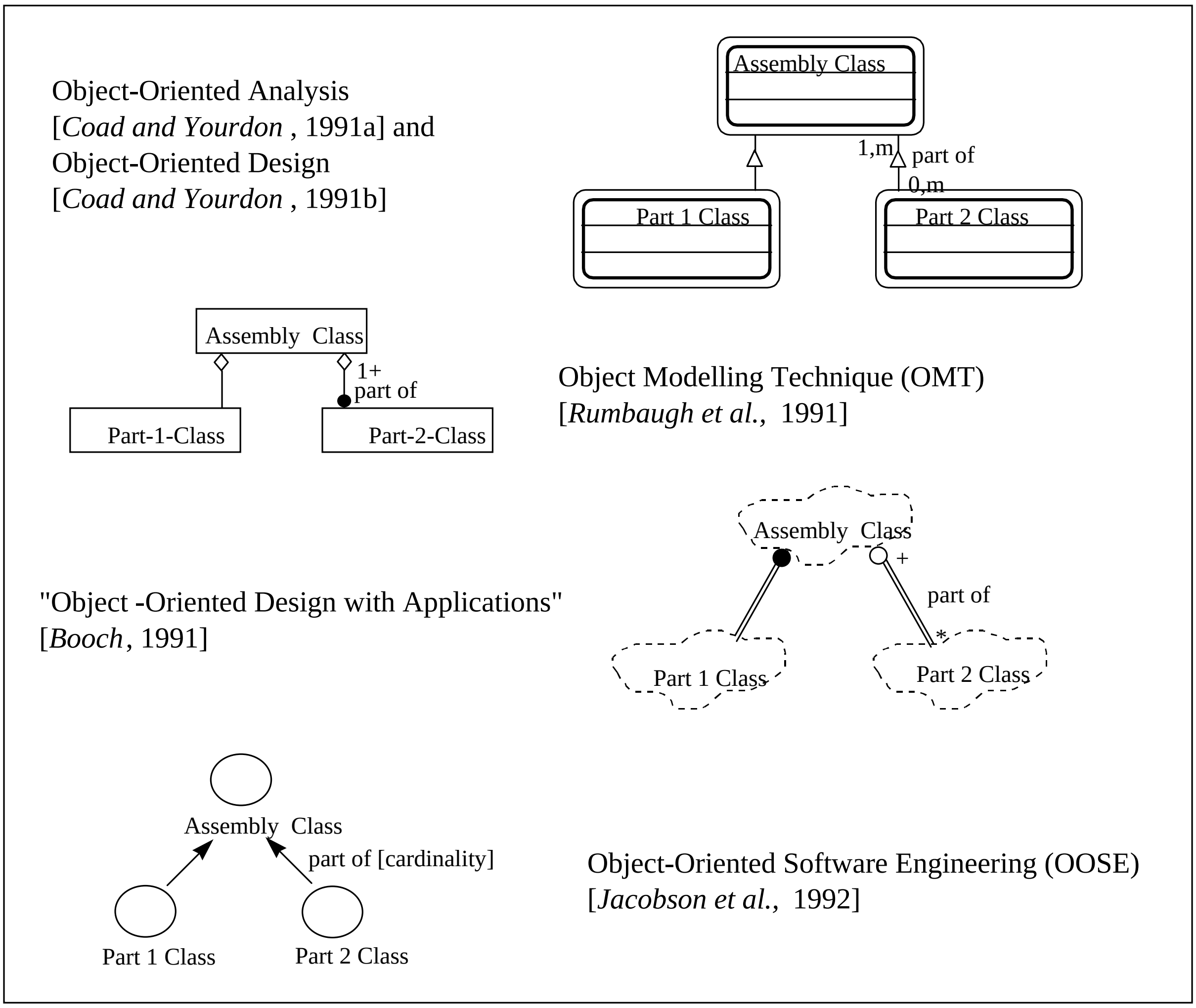

Figure 4:6 Examples of well-known OO information systems development methodologies

The development process of the object model contains seven steps:

- identify object classes
- begin a data dictionary
- add associations between classes
- add attributes
- add inheritance to improve the analysis
- control the access of data
- group classes

The resulting object model provides an object model diagram and related data dictionary.

The next sub-phase of the analysis is development of a dynamic model, which means state diagrams and a global event flow diagram. The third sub-phase is to construct the functional model. Finally, at the end of the analysis phase, the three analysis models are verified, and refined in an iterate way. The resulting documentation includes: a problem statement, object model, dynamic model and functional model.

The next phase of the OMT methodology is system design, during which the high-level structure of the system is chosen. The design process is carried out in eight steps. The documentation describes the structure of the system architecture and high-level strategy decisions.

Finally, object design adds details to the analysis models and provides a detailed basis for implementation. The design process also contains eight steps and the documentation contains a detailed object model, dynamic model and functional model.

The OMT methodology was not actually used in the research project but acts as a description of a comprehensive object-oriented system development methodology. Also the other three methodologies mentioned in the figure 4:6 include similar phases and operations.

4.5 Product Modelling

By product modelling is meant conceptual modelling of real or imagined products of different kinds. According to *ISO* [1993a] a product is “a thing or substance produced by a natural or artificial process” and product information is “facts, concepts, or instructions about a product”. Product modelling should serve information handling throughout the design, manufacturing and usage phases of the life-cycle of the product with the purpose of computer-integrated design of the product and/or computer-integrated manufacturing and /or computer-integrated information handling within the usage phase. The product model allows not only the exchange of geometry data but the exchange and sharing of all types of product data throughout the product’s life-cycle.

A building product model (BPM) is a product model describing a building. This means, for instance, that it is adapted to modelling spaces, which are the main purpose of the buildings. As a product, a building is characterised by the following features:

- Almost every building is unique.
- The building has a long life cycle, which puts high demands on exterior and interior, aesthetics, quality, economy and functionality.
- The building is both static (e.g. its frame) and dynamic (e.g. its installations)

- The building is connected to and co-operates with its environment both physically and organisationally. The building has an owner and is used in a business activity.

The construction process is characterised by the following:

- It has many co-operating parties with different roles and from different companies and authorities.
- The team designing respectively erecting a specific building normally changes from one project to another.
- A lot of information of different kinds is used during it.
- It is complex and iterative. With iterative is here meant e.g. the refinement of the design by repetitive studies.

The steps and the procedures from reality to a building product model based information system are described in figure 4:7 below. The description is similar to one in *Keijer et.al.* [1994].

In order to make it easier for companies to quickly learn to work with ever-changing partners the methodology for the process has in most countries become reasonably standardised. Traditionally, conventions for 2-D drawings and specifications have provided a high degree of standardisation, based on human interpretation of the documentation.

With a BPM-based information system, it should be possible to improve the exchange of information between the parties in the construction process and its phases. From the view of the building client, the expectations of the BPM-based information system is that it should make the exchange of information between the parties and phases of the building process more effective. This should give better and less expensive buildings, including their operation and maintenance.

The history of building product modelling goes back to the seventies [cf. *Eastman*, 1978], when the fundamental ideas were first formulated. A number of building product modelling activities took place during the eighties, primarily at some universities, but also at public building construction organisations. Three important activities could be mentioned here. The American AEC Building Systems Model developed at the University of Michigan [*Turner*, 1990], the Dutch GARM Model (General AEC Reference Model) [*Gielingh*, 1987] developed at TNO and the Finnish RATAS Model [*Björk*, 1989] developed in a Finnish national R&D programme. All three of these models had important influence on the work carried out with the KBS Model.

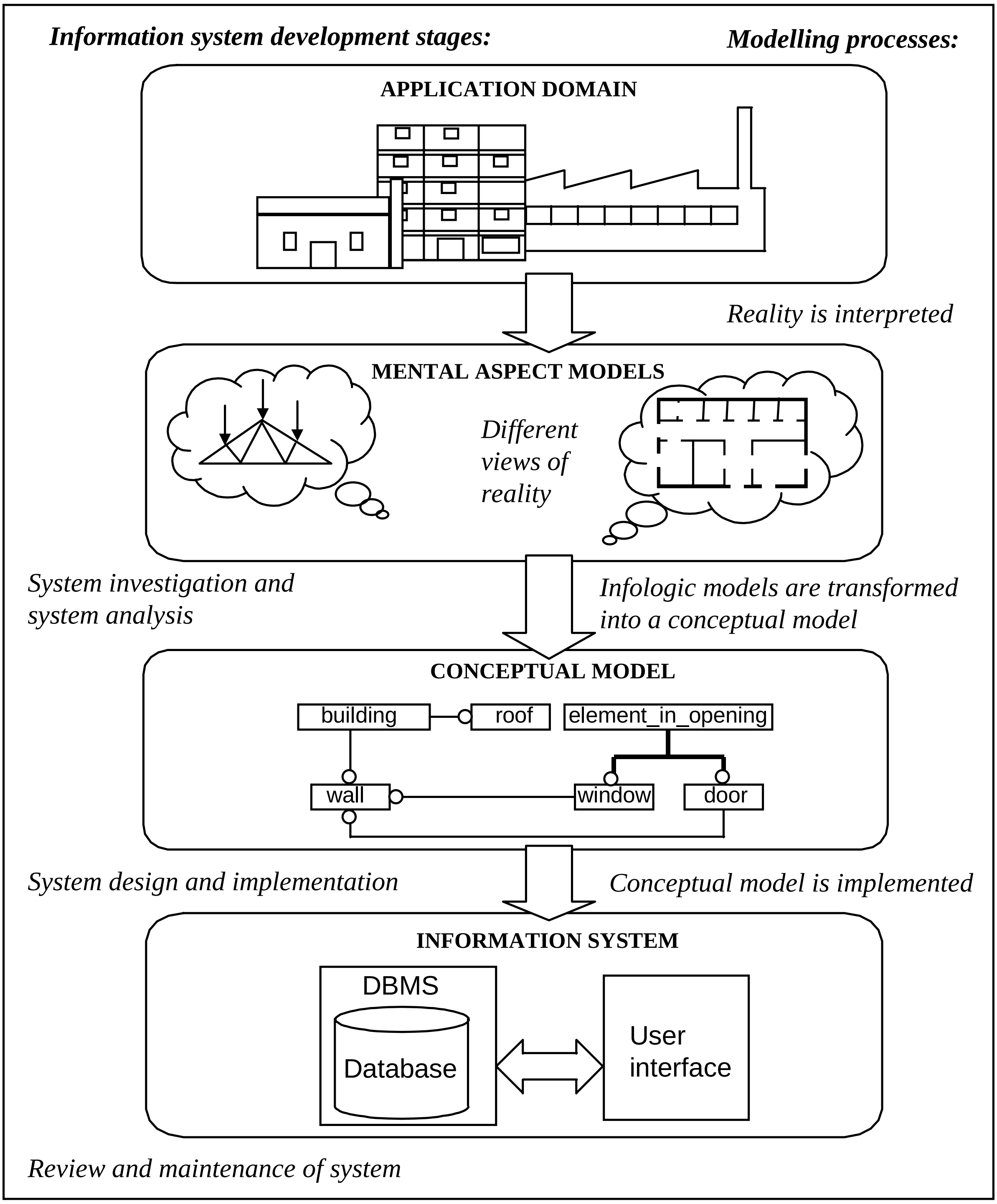

Figure 4:7 Schematic description of the development of a BPM-based information system

The "**AEC (Architecture, Engineering and Construction) Building Systems Model**" was developed by James Turner at the University of Michigan and the purpose was a high-level conceptual schema for AEC products. An AEC product model is defined as a unique combination of exactly one project type during one project phase. The product model in this case was a finished, occupied building, divided into systems.

The AEC Building Systems Model is built on a framework called the "AEC Global Model" including two types of models. Firstly, ones that are AEC-specific but general, e.g. models describing building project, building, site, general systems definition, and distribution network. Secondly, ones that are AEC-independent called "Common Technology Models". Examples of the latter type are models describing property, attribute, directed network, and enclosed area. These two groups together establish the general framework on which specific AEC Building Systems Models should be built. Examples of such system models are spatial, enclosure, circulation interior, communication, acoustic, structural, HVAC electrical, and lightning. This means that a layered structure was established between the different models, together describing the building product.

An AEC building project is defined as a project in which at least one building is built on a single site. The building consists of one or more building elements and one subtype of building elements is building systems. Analogously, the site consists of one or more site elements and one subtype of them is site systems. The AEC Building Systems Model also provides more or less complete taxonomies for buildings, building systems, sites and site systems.

The **GARM** was developed by Wim Gielingh at the Dutch research institute TNO. The purpose was a high-level general reference model for AEC product-definition data general enough to serve the needs of all AEC application areas. The model is based on the idea that the product information is clustered around so-called Product Definition Units (PDU:s), which can be any part of the product or the whole product. The information is given as a collection of characteristics of the product or part. Each characteristic is related to an aspect e.g. strength, cost, durability or safety. The meaning of a PDU and a characteristic is determined by a set of the following abstraction mechanisms:

- "Specialisation", which describes what application area the PDU belongs to. First PDU:s are subdivided into four major groups of AEC-product types: buildings, plants, ships and civil works. Then it is possible to further specialise the AEC products inside each of these groups. This can be done according to e.g. national or international element classification tables.
- "Decomposition", which describes how the PDU can be decomposed. The composition/decomposition hierarchy of PDU:s in general terms contains three classes: systems , parts and features.
- "Life-cycle", which addresses the different stages of the life cycle of a PDU. The distinction between the stages is based on clear differences in the type of information used. The stages and types of a PDU in GARM are shown in table 4:1.

Table 4:1 The different stages of a PDU in the GARM model

Stage	***Type of PDU***
as required	*functional unit*
as designed	*technical solution*
as planned	*planned unit*
as built	*physical unit*
as used	*operational unit*
as altered	*alteration unit*
as demolished	*demolition unit*

- “Classification”, which makes it possible to define a PDU on three different levels of generalisation/specialisation: occurrence, specific and generic.

The **RATAS** framework and models were developed in a Finnish R&D programme during the years 1988-91. It was one of the results of a project organised under the R&D programme known by its acronym RATAS (RAkennusten Tietokone Avusteinen Suunnittelu) [*Finnish for Computer-Aided Design of Buildings*]. The aim of the project was to define a conceptual model for structuring all data about a specific building to be used in design, production and maintenance.

A basic feature of the RATAS-model´s structure is an abstraction hierarchy with five levels: building, system, subsystem, part and detail. In order to describe the building product a description of how different objects are interrelated is required. Two types of relationships were used for this purpose: part-of and connected-to.

One important feature of the above models was the ambition to provide a framework for a single BPM. Another feature is that all three of the models were more or less concerned with all the phases of the life-cycle of buildings.

Today there already exist some different proposed BPMs, which all utilise object-oriented techniques. They have mainly been developed in different research projects carried out quite recently and none of them have been developed specifically for FM. Listed below, in chronological order, are a number of models which have been developed mainly during the 1990s. None of them were available when the main modelling efforts of the KBS Model project were carried out.

- The synthesis model of GSD, France [*GSD*, 1991].
- De Waard's “House model”, Holland [*de Waard*, 1992].

- The "Integrated Data Model" (IDM) of the COMBINE project, multinational [*Augenbroe*, 1993a].
- A conceptual model of spaces, space boundaries and enclosing structures, Finland [*Björk*, 1992].
- ATLAS, view type model for global architectural design, multinational [*van Nederveen et al.*, 1994].
- COMBI , Germany [*Ammermann et al.*, 1994].
- STEP AP for Building Elements Using Explicit Shape Representation (Part 225), [*ISO*, 1996a].
- ICON, Great Britain [*Aouad et al.*, 1994].
- Models Objects Bâtiment (MOB), France [*OTH*, 1994].

These product model proposals have mainly been developed for integration between different design disciplines and integration between design and construction. The proposals include data structures for the spaces and space enclosures of buildings and they can provide valuable input in the definition of product models specifically intended for FM. None of them is, nevertheless, as such directly sufficient to form the basis for a BPM for facilities management purposes.

4.6 STEP - STandard for the Exchange of Product model data

The STEP standard - its scope and objective

STEP is the acronym for STandard for the Exchange of Product model data. It is the informal name of the ISO standard 10303: Industrial automation systems - Product data representation and exchange. This standard consists of many parts i.e. it is a series of standards. In Part 1 [*ISO*, 1993a] the purpose of STEP is described as follows:

"ISO 10303 is an international standard for the computer-sensible representation and exchange of product data. The objective is to provide a mechanism capable of describing the product data throughout the life-cycle of a product, independent of any particular system. The nature of this description makes it suitable not only for file exchange, but also as a basis for implementing and sharing product databases and archiving."

STEP is developed by ISO TC184/SC4 (Sub-committee 4 - Industrial data of Technical Committee 184 - Industrial automation systems and integration) in co-operation with industry and universities around the world. The development of STEP includes:

- development of STEP methods, e.g. of the EXPRESS language, and development of the STEP architecture and framework
- development of different integrated resources (IR:s) used as a basis for product data
- planning and execution of application protocol (AP) projects

The different Parts of STEP

From an architectural perspective, The numerous STEP parts could be grouped into six main groupings - descriptive-methods, integrated-information-resources, application protocols, implementation methods, conformance-testing-methodology and abstract test suites [*Nell*, 1995].

Descriptive-methods
The descriptive-methods group forms the underpinning of the STEP standard. It includes Part 1-Overview [*ISO*, 1993a] which contains definitions that are universal to STEP and description methods, Part 2-19, including e.g. Part 11 EXPRESS Language Reference Manual [*ISO*, 1993b], describing the data-modelling language used in STEP.

Integrated-Information-Resources
This group contains the actual STEP data models which could be considered as the basic building blocks of STEP. The group includes three different types of resources:

- Integrated Generic Resources (Part 4199) used across the entire spectrum of STEP APs.
- Integrated Application Resources (Part 101199) which are more specific resources shared by a limited number of APs.
- Application Interpreted Constructs, AICs (Part 501599) which are reusable resource entities that make it easier to express identical semantics in more than one AP.

Application Protocols
The Application Protocols (APs) could be seen as the actual “products” of STEP and are more complex data models used to describe specific data applications, for example ship piping (Part 217) or building structural frame of steelworks (Part 230). The APs are the data exchange standards for practical use.

Implementation Methods
The implementation methods specify the representation and the techniques used for implementing the exchange of product data described by EXPRESS. Parts in the implementation method group are numbered in the 20s series (Parts 21-29).

Conformance-Testing-Methodology
The conformance-testing-methodology provides methods for testing of software product conformance to STEP standards, guidance for creating abstract test suites and the responsibilities of testing laboratories.

Abstract Test Suites
Consist of test data and criteria that are used to assess the conformance of a STEP software product to the associated AP.

The architecture of STEP

Figure 4:8 gives a description of different Parts of STEP and their relationship using EXPRESS-G notation . The figure includes most of the important Parts of STEP, their relationship to each other and give an indication of how they are used. Their usage is further described in the passage below describing the process of developing an AP.

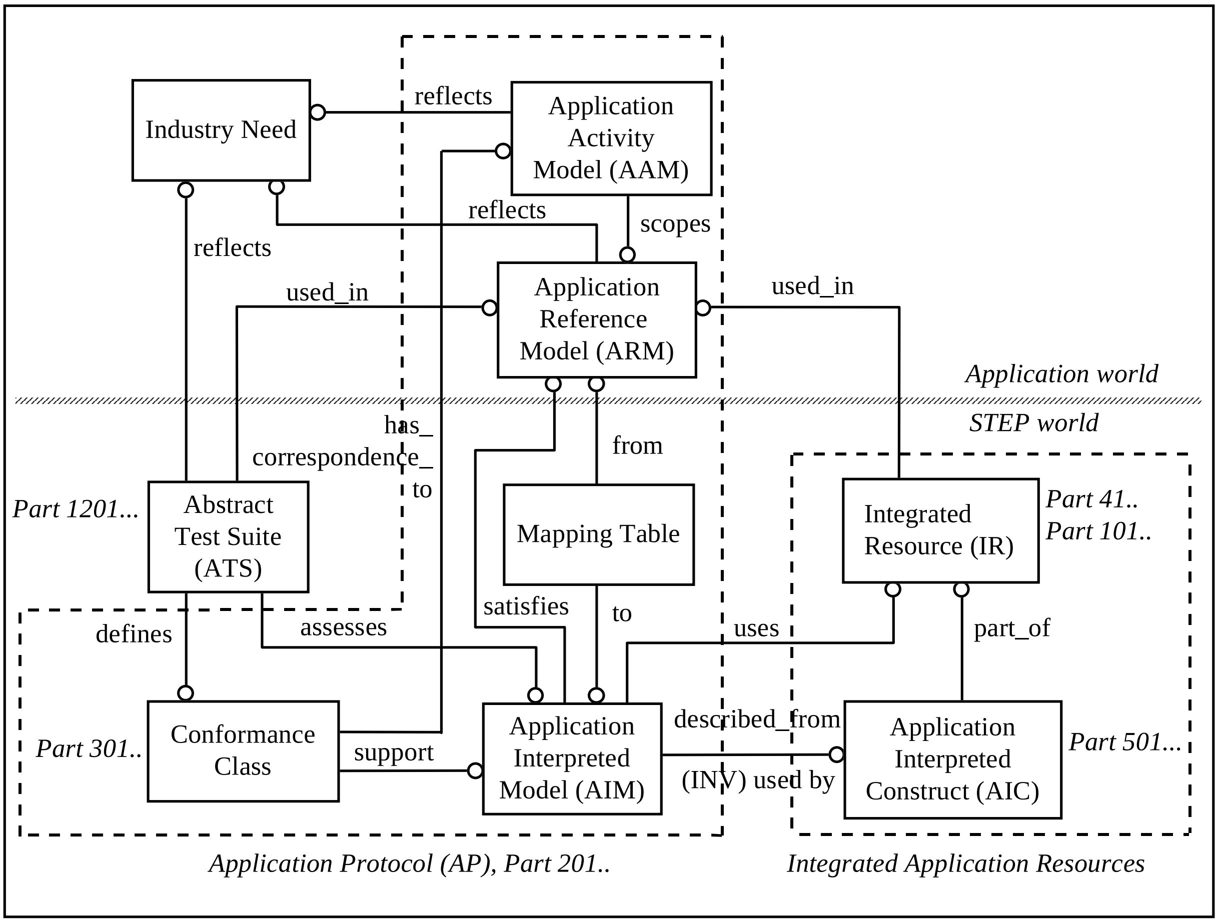

Figure 4:8 The architecture of STEP

EXPRESS and EXPRESS-G

EXPRESS is an information model specification language which was initially developed in the 1980s in order to enable the writing of formal information models describing mechanical products [*Schenk and Wilson*, 1994]. It is also one of the technologies that has been developed as a part of the STEP standard and is, since 1992, an ISO International Standard [*ISO*, 1993b]. EXPRESS-G was developed in 1990 as a means of graphically describing EXPRESS models. EXPRESS and EXPRESS-G are used in the STEP development process.

As models are frequently described with EXPRESS-G diagrams and in appendix also with textual EXPRESS, this thesis provides a guidance on how to read EXPRESS and EXPRESS-G in Appendix 4.

The development of an Application Protocol

In figure 4:9 the development of an Application Protocol (AP) is schematically described. This figure and the following textual description is based on *ISO* [1995]. Most of the concepts included in figure 4:8 above are included in the description of the development of an application protocol in figure 4:9.

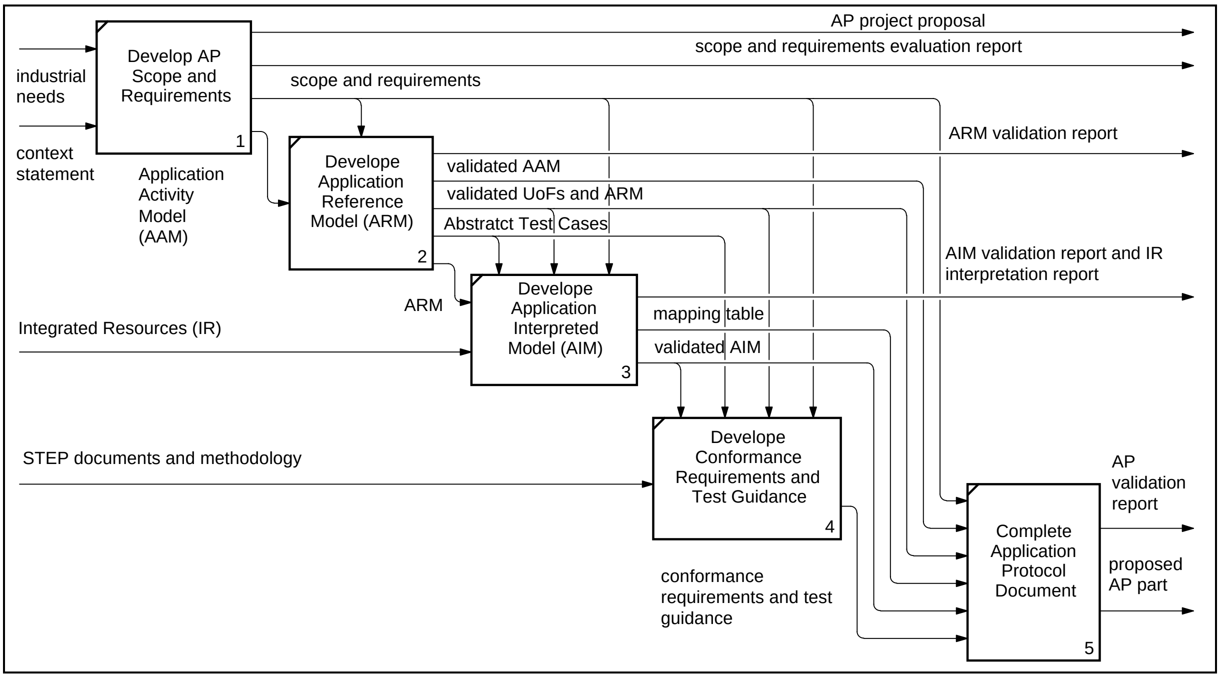

*Figure 4:9 The planning and development process for an Application Protocol. After [*ISO, *1995].*

Develop AP scope and information requirements

The scope states the domain of discourse of the planned AP. The scope statement describes the application context and functional requirements for the AP. The information requirements describe the input and output information requirement of the process within the application context and are documented by process models - application activity models (AAMs). Typically, these are done using IDEF0 diagrams.

Develop ARM
The information domain of the AP is defined by the use of an application reference model (ARM) which describes the information requirements and constraints for the specific AP. The ARM documents the required data and relationships and it is normally specified using EXPRESS-G. The ARM diagrams should be understandable to an application domain expert.

Develop AIM
The application interpreted model (AIM) specifies the interpretation of the integrated resources (IRs) to satisfy the information requirements of the AP described by the ARM. The integrated resources (IRs) are resource constructs, described in the Part 40 or Part 100 series, or application interpreted constructs (AICs), described in the Part 500 series, shared by one or many more AIMs. During interpretation of the integrated resources, the correspondences between the application objects and the constructs of the AIM are defined in mapping tables.

Develop conformance requirements and test guidance
Conformance testing means to determine the conformance of the specific AP to existing parts of the STEP standard. An abstract test suite (ATS) contains the set of abstract test cases (usage scenario) used for the conformance testing. A conformance class is a subset of the AP for which the conformance may be claimed.

The AP development process of STEP is based on the general information system development methodologies described in previous sections of this chapter. It also uses process modelling (in AAMs) as a basis for the product modelling.

Development within STEP in the building construction domain

Within the building construction sector, four different work items including conceptual schemes are in progress. These work items are:

- Building Elements Using Explicit Shape Representation (AP 225) [*ISO*, 1996a],
- Building Construction Core Model (Part 106) [*ISO*, 1996b],
- Building Structural Frame: Steelworks (AP 230) [*ISO*, 1996c] and
- Building Services: Heating, Vent. & Air Condition (AP 228) [*ISO*, 1996d].

Industry Foundation Classes

In parallel with the STEP effort a number of influential CAD developers and end-users in the US started to discover the strategic importance of integration methods. These companies, a large part of which are AutoCAD users, started an organisation called the IAI (International Alliance for Interoperability) in 1994.

What the IAI intends to do is essentially to develop and publish a building product model definition (called IFCs, Industry Foundation Classes). The main difference to STEP is that the IAI has the ambition to be less bureaucratic and aims at quicker results than the formal ISO procedures allow. After its start the experts participating in the IAI have, nevertheless, increasingly started to re-use technology and models developed within STEP. Many leading experts who earlier have been active in STEP work are now participating in IAI activities.

The alliance is open to all companies in the industry. Membership types include information providers, university and research organisations, vendors, clients, consultants, contractors, product manufacturers. By June 1997 there were approximately 500 members allocated to seven regions (chapters) across the world. The intentions with IFC are described by e.g. *Herold* [1997] and *Wix* [1997].

A first version, IFC 1.0, was released to members in February 1997. The scope for this was narrowed, compared to initial plans, and focuses on information exchange using a subset of Architectural, HVAC and FM systems. Version 1.5 [*IAI*, 1997] was released in January 1998 and it is concentrated on:

- structure and relationship of a limited core model
- definition of attributes of the entities in the core model
- standard format for sharing attribute and relationship information as either a static exchange via a standard file format (Part 21 of STEP) [*ISO*, 1993c] or a dynamic exchange via standard software interfaces.

Currently there is an on-going discussion about the relationship between STEP and IFC.

Merging classification and library functions with the building product model development.

Within both the organisations developing STEP and IFC there is an understanding of the need to merge classification systems used within the construction industry with different developed building product models. There is ongoing work on internationally standardised construction classification tables [*ISO*, 1997].

4.7 Other Emerging IT Techniques

Below a number of emerging IT techniques are briefly described. These techniques were to a very limited degree used in the three prototypes but have in the continued development of IT systems for FM and many applications become more and more used. In future developments of product data exchange for FM these should be taken into account and utilised.

Internet and Internet-related techniques

Communication through Internet and other TCP/IP nets has become a natural part of personal and organisational communication. Computers have more and more become a tool for communication. Internet, meaning an inter-network, is a global interconnection of people, programs, data and computers which was originally developed for military purposes. All information is digitised and the communication is using commonly agreed standards and protocols e.g. the OSI Networking Reference Model and the TCP/IP (Transfer Control Protocol / Internet Protocol). Using the Internet, any kind of digital information could be transferred from one computer to the other. Examples of important functions and services to the end-users of Internet are [*Turk*, 1997]:

- Electronic mail (e-mail) for easy person-to-person communication.
- File Transfer Protocol (FTP) to transfer files between FTP server and FTP client for e.g. common usage of libraries.
- World Wide Web (WWW) to provide access to (any) information on the Internet.

Spin-offs of Internet are:

- Intranets i.e. networks within organisations which use Internet technology to support the organisation's activities.
- Extranets i.e. networks accessed by an organisation and its partners to support their joint activities.

Document-centric information handling techniques and enabling standardisation

Electronic communication and distribution of electronic documents are at the moment perhaps the most rapidly developing IT technology. It may dramatically change the ways in which the communication and activities within organisations are arranged through space and time. The communication could be within a local project or globally, person to person or person with machine or application and it could be sequential or concurrent [*Turk*, 1997]. To be able to receive documents in electronic form and to process them has become a necessity in the relationship between organisations and in the new types of information services that are rapidly emerging.

A simple and secure transfer of electronic documents is a prerequisite for the growth of the market of electronic information services. This is a reason why standardisation is important. A lot of different formats for handling different types of information have emerged lately e.g. different document formats, SGML (Standard Generalized Markup Language) and HTML (HyperText Markup Language) .

Compound documents system architecture

To handle information in compound/composite documents, i.e. documents containing information of different sort e.g. textual and graphical information and also digital sound, it was earlier necessary to convert each type of information into the format in which each of the information types were created. Today this is not necessary. A much easier compound document handling technique can be used. Object Linking and Embedding (OLE) is an object-oriented technique that allows the integration of composite elements such as texts and graphics into an object. Component Object Model (COM) defines a standardised interface to the object which makes the object able to communicate with other objects. OLE functions are implemented on COM, which acts as a distributed object manager that allows distributed objects to exchange information. OLE and COM are specifications developed by Microsoft and have because of that become a sort of de facto standards.

In the client-server architecture for distributing computing, compound documents and compound software facilitate interactions between independent programs through object-oriented models. Off-the-shelf components are assembled at client and server ends of the system until it all works together, and the application solves the business process problem.

The next level of integration is the integration of applications. A framework for the integration of applications is provided by the CORBA (Common Object Request Broker Architecture) distribution standard. It allows messages between objects on an heterogeneous network of servers, that is co-operation between or integration of different systems or applications. Like COM the CORBA application relies on a specific object manager - the broker.

4.8 Current Ideas on the Use of BPM in FM Information Systems

This section reviews different research projects in which building product model structures for FM applications have been studied. None of the results were available when the main part of the research work for this thesis was carried out. The projects described in the chapter are:

- Application of Product Model Theory in Facilities Management [*Möttönen et al.*, 1994]

- Object-oriented Software Analysis of a Flexible Facility Management Information System [*Bos*, 1995]
- Information System for Facility Management (ISFM) [*Majahalme*, 1995]
- Development of an Integrated Facilities Management Information System Based on STEP - A Generic Product Data Model [*Cheng et al*., 1997]
- Formalising Building Requirements Using Activity/Space Model [*Maher et al*., 1997]
- Concepts of Space in Building Classification Product Modelling and Design [*Ekholm and Fridqvist*, 1997]

Application of Product Model Theory in Facilities Management

This project (the RATAS Maintenance Project) started at the beginning of 1991. The main objective was to improve the flow of information from the design and construction stages of the building to the usage stage [*Möttönen*, 1995]. The project applied the product model approach of the earlier RATAS projects [*Björk*, 1989] to the maintenance and operation of buildings. It did not place any emphasis on renovation or financial and administrative information. The project resulted in an object-based product model schema (figure 4:10) for FM - the Ratas Maintenance Model.

The basic structure of the model covers the maintenance of the property (property parts), the maintenance functions (tasks) carried out on these maintenance objects and the documents used by functions and which describe the maintenance objects [*Möttönen et al*., 1994]. Each maintenance object receives features (attributes and relations) from either its building object class or the resembling maintenance object class. The maintenance objects are subdivided into building, outdoor area, property equipment, and maintenance accessories. The building is subdivided into spatial system, structural system, technical system and building equipment while the outdoor area is subdivided into aerial system, fixed construction, technical systems, technical connections and outdoor area equipment. The structural and the spatial system of the building, as well as the outdoor area, are then modelled, as can be seen in figure 4:10. The figure is based on outlines provided by *Möttönen et al.* [1994] and does not include attribute names nor cardinalities.

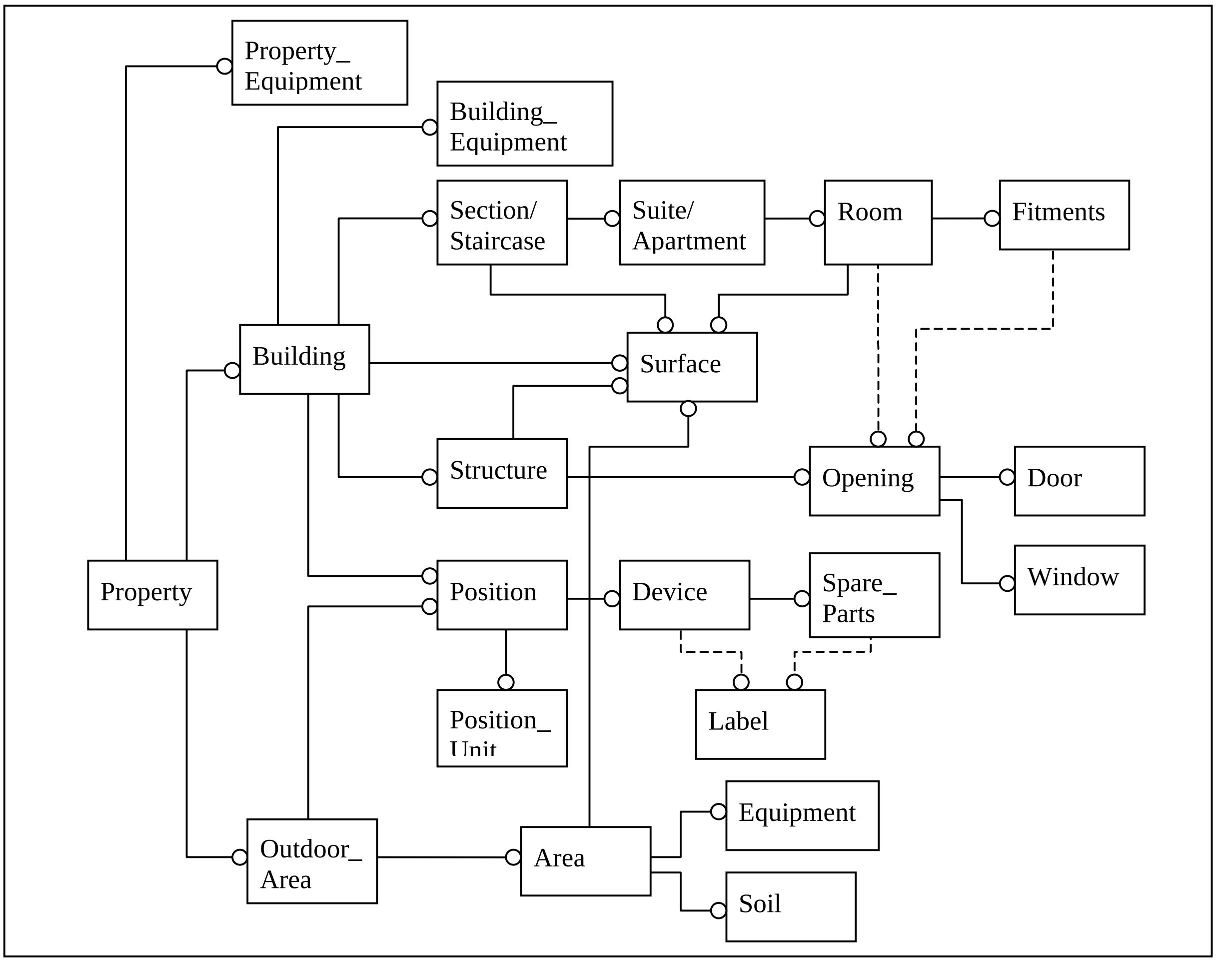

*Figure 4:10 Model of the maintenance objects. After [*Möttönen et al., *1994]*

The Ratas Maintenance Model has been used in different applications [*Möttö-nen*, 1995]. The project has also resulted in the development of new FM software or the further development of existing ones.

Object-Oriented Software Analysis of a Flexible Facility Management Information System

This research work examined the requirements of an FM information system (FMIS) [*Bos*, 1995]. The FMIS must manage large quantities of heterogeneous data/information in a user-friendly, integrating (intelligent) and flexible way to provide decision-support. A flexible FMIS is of decisive importance to support FM, which in its turn supports the core business. The kernel of a flexible FMIS will be an object management system [*Sim et al.*, 1994], incorporating databases and a knowledge base.

According to Bos, the FMIS should have the following necessary database functionality to meet the management requirements:

- Support a data abstraction hierarchy tackling the complex structure of the UoD of FM.
- Be capable of handling the complexity and large quantity of relations between the data abstractions.
- Support multi-media information.
- Be flexible to easily meet changes in requirements.
- Offer a uniform language and a user-friendly user interface.

As FM is "mainly concerned with the logistics, maintenance planning and space and resource management of buildings and their interior" [*Bos*, 1995] the structure of the building should be the backbone of the extendable hierarchical object model of the FMIS. The OOIS development methodology of OMT (Object Modelling Technique) [*Rumbaugh et al.*, 1991] was used in the research work.

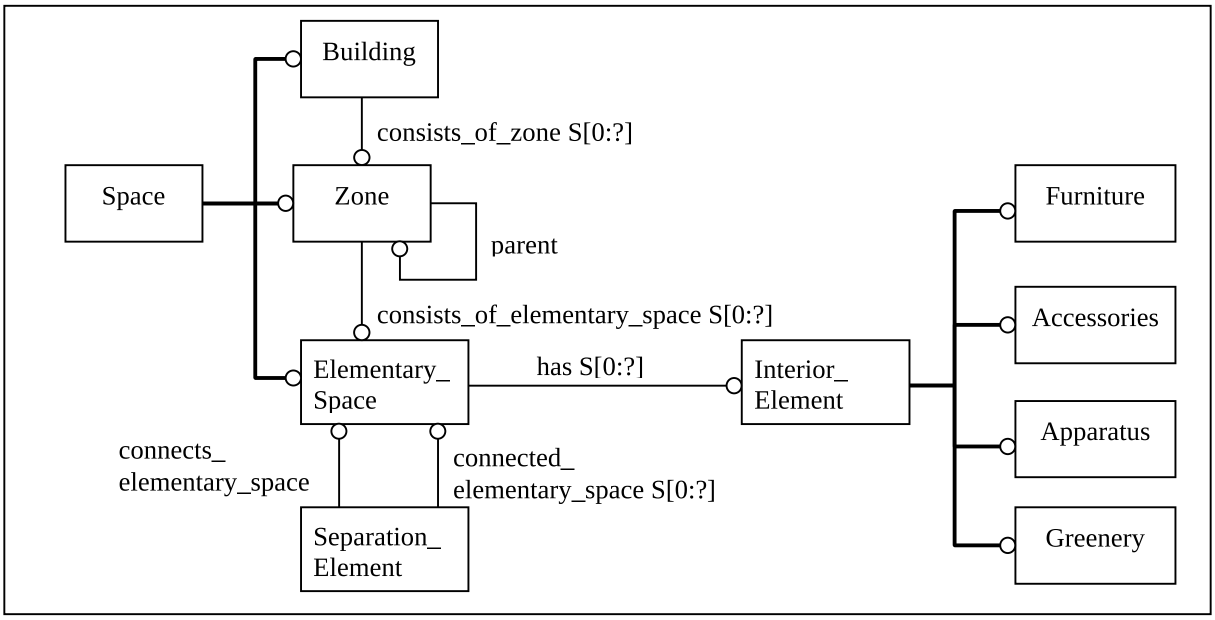

Figure 4:11 A partial and schematic description of the object model of FMIS. After Bos *[1995].*

The model was influenced by earlier models by *de Waard* [1992] and the COMBINE project [*Augenbroe*, 1993a], [*Augenbroe*, 1995]. In the model spaces, furniture, appliances and machinery are modelled as objects, while facility services are modelled as functions of these objects. A small and simplified part of a final object model is shown in figure 4:11 (where the original OMT-model has here been remodelled in EXPRESS-G).

Information System for Facilities Management (ISFM)

The ISFM structure is described in a doctoral thesis by *Majahalme* [1995].

The primary objective was to develop a model for a computer-based information system for FM (ISFM). It consists of four submodels:

- a Business Activities model for facility management (BAfm),
- a Management Activities model for facility management (MAfm),
- a COncept model for facility management (COfm), and
- a Documentation System model for facility management (DSfm).

All four models are meant to be generally applicable. They should serve as a framework for future IT applications within the FM domain. Together they form a formal information analysis method from core business idea to implemented IT systems.

The BAfm submodel is an activity model describing how the core business activities are related to the FM activities via strategies for FM and IT. The BAfm submodel generates input to the other submodels.

The MAfm is also an activity model with the purpose of formulating and categorising the FM tasks, as can be seen in figure 4:12..

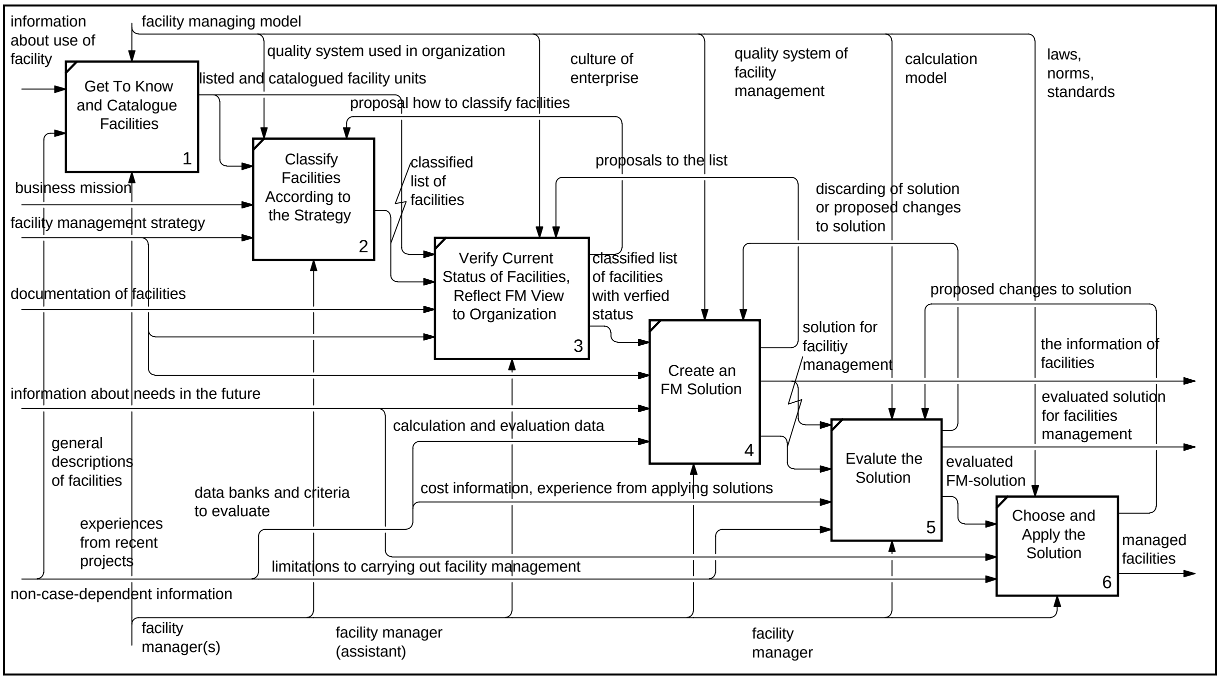

Figure 4:12 The MAfm model for facility management. After Majahalme [1996]

The six activities of the model are grouped into three stages (A, B, and C):

A: Provide a preliminary view of FM.

FM1 Get-to know and catalogue facilities.

FM2 Classify facilities according to strategy.

B: Determine the current situation of FM.

FM3 Verify current status of facilities.

C: Establish an IT solution for the FM.

FM4 Create FM solution.

FM5 Evaluate the solution.

FM6 Select and apply the solution.

The MAfm provides a way to formulate and categorise FM tasks. The output of the MAfm submodel is an IT solution for FM and managed facilities.

The COfm is a building product model for FM data. The overall structure of the conceptual model is described with EXPRESS-G in figure 4:13. The COfm is a framework for converting physical activities of FM into information structures.

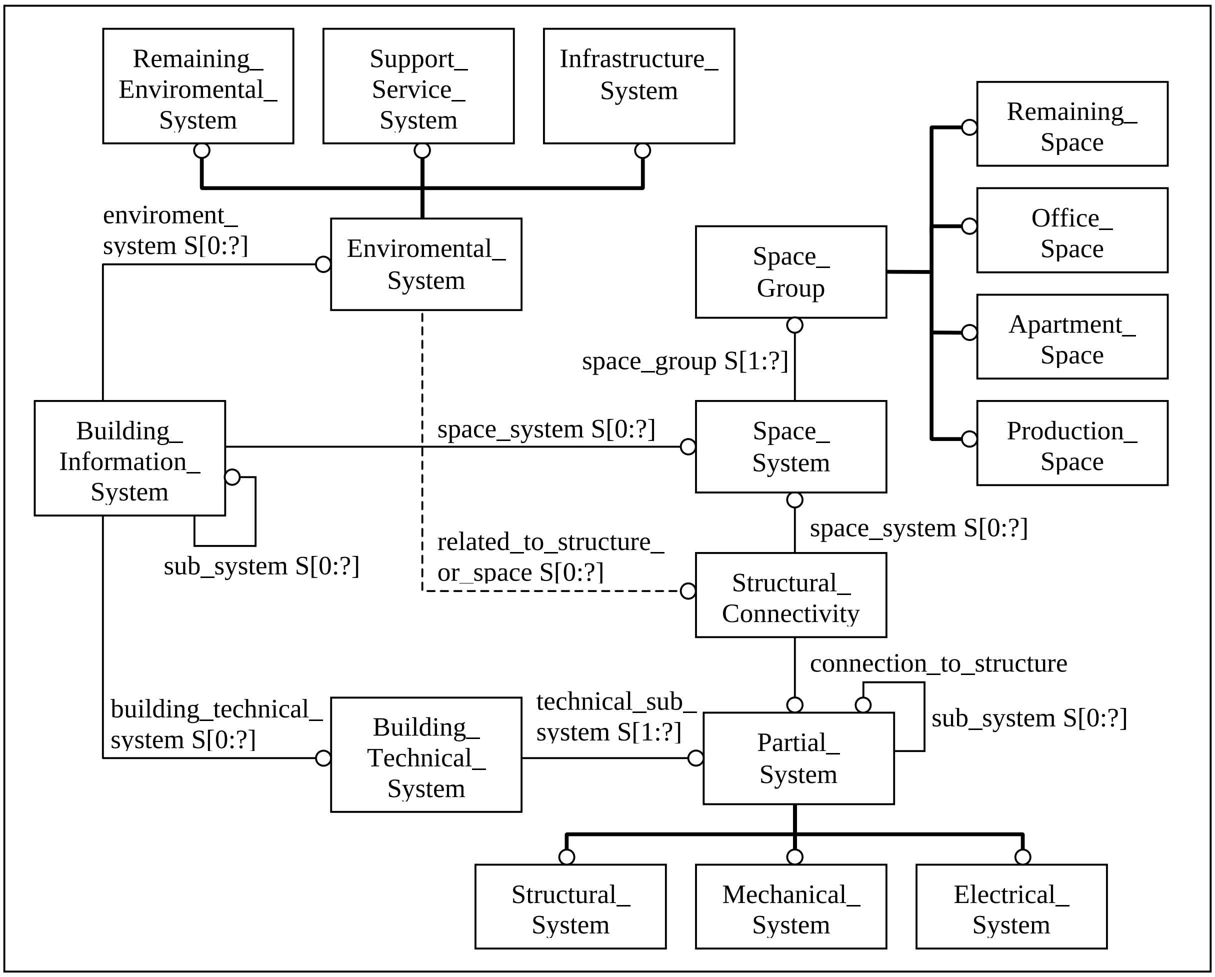

Figure 4:13 COncepts model for facility management. After Majahalme [1996]

The DSfm submodel describes the elements and their relationship to processing documentation for FM. The elements are facility, activities, a set of known activities, structure, data collection, presentation, implementation, and documentation. The DSfm provides a methodology for converting FM activities into digital information handling activities by providing means to archive, retrieve and implement data.

The ISFM as a whole provides an analysis method making it possible to focus the FM information domain and data structure. It was tested in five prototype applications.

An Integrated Facilities Management Information System Based on STEP - A Generic Product Data Model

This project developed an integrated facilities management information system based on a set of generic tools [*Cheng et al.*, 1997]. The two main objectives were:

- the centralisation of information common to all domain specific applications
- the exchange of product information based on an open and configurable mechanism

The new system meant to integrate three different existing information systems: a CAD system, an asset and maintenance management system and a building energy management system. The new system should substantially improve the integration of the systems.

The generic system architecture (and associated tools) conforms to the STEP standard. The initial task resulted in the development of a product model used for generating a Control Data Repository (CDR). The Nijssen's Information Analysis Method (NIAM) was used for the development of graphical schemes. The graphical model developed was then translated into EXPRESS, the formal data definition language of STEP. The database structure of the CDR was generated from the EXPRESS schema. An SQL compiler translates the EXPRESS schema into SQL (Structured Query Language) statements, which were imposed by the database management system of the CDR. The main structure of the prototype system is described in figure 4:14 below.

The product data in the CDR is available via the Exchange Control Mechanism (ECM). The data exchange takes place via STEP physical files as exchange media. The ECM gives open connectivity between various FM specific applications via the CDR and by using STEP physical files. If necessary, the STEP physical files are translated into or from a format compatible with the client application. A STEP_SQL gateway allows the CDR to be updated with data from any STEP physical file. A selective approach protects the CDR from unauthorised modification.

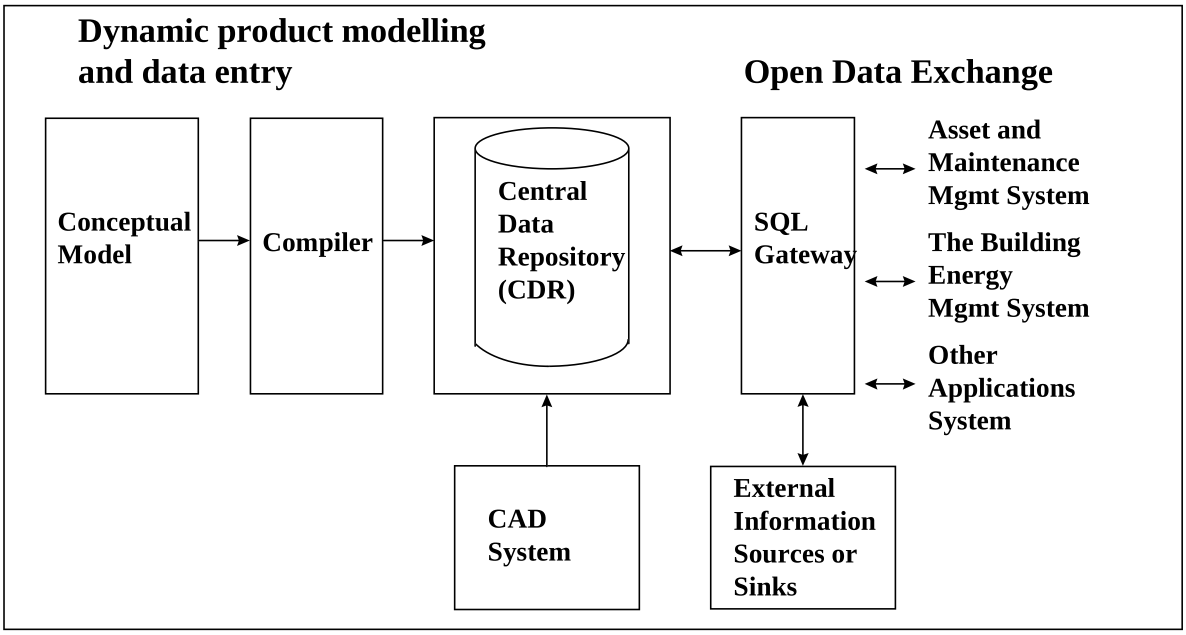

Figure 4:14 A schematic desription of an Integrated Facilities Management Information System based on STEP.

A CAD interface provides the possibility of initial data entry via an enhanced CAD system. The objects of the CAD system are mapped to the entities in the product data model via database tables generated by the SQL compiler. After compilation, the CDR may be populated via the enhanced CAD system. This enables entities within the CDR to be more or less automatically associated with objects in the CAD drawings.

The author of this text is not informed of to what degree the described system has come into regular usage.

Formalising Building Requirements Using an Activity/Space Model

The specification of the spatial requirements for a building is the basis for architectural design. *Maher et al*. [1997] present a model - the Activity/Space (A/S) Model - which is specifically developed to capture the characteristics of specifying buildings. This requires the representation of functions or activities and their associated space in a building. According to the authors, the model could become part of an integrated product model for buildings as well as the basis for automated spatial layout. It provides a representation of the building that is supposed to be applied before the building has been designed, when there are no spaces but many functional requirements. It should also have the potential to provide information on the management and redesign of existing facilities.

The A/S Model addresses the need to represent requirements corresponding to both the functionality of the spaces and the geometric or physical description of the building. The model provides the explicit representation and manipulation of activities and their associated spaces in a building. The representation and functionality of the activity and the space are provided by abstract objects which can be manipulated. The interactions and relationships between singular activities and their corresponding spatial envelopes are illustrated in figure 4:15.

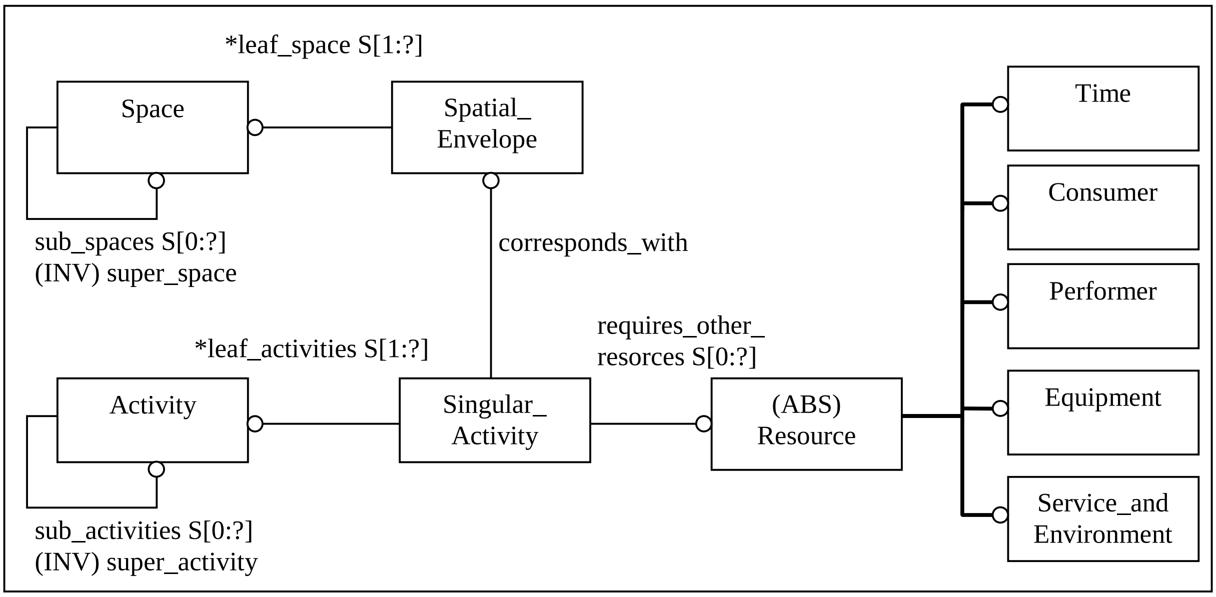

Figure 4:15 General outline of the A/S Model in the case of spatial singularity
After Maher et al.[1997]

Finally, the principles and functionality of the model are illustrated by applying it to the design of a health facility on two different levels of activity elaboration. The first level is providing space for looking after bed-ridden patients in an emergency room and the second level is providing space for a psycho-geriatric care and treatment unit. The model allows the transformation from activities to spatial envelopes in the design stage and in the other direction on the design feedback and on the usage/maintenance stage.

Concepts of Space in Building Classification Product Modelling and Design

Initially, the paper of *Ekholm and Fridqvist*, [1997] discusses the use of the concept 'space' in different contexts. Common to several different descriptions of the concept is that a space is something with some kind of spatial properties. It is necessary for spaces to be represented independently of other entities. It is necessary to distinguish between the organisation's spatial properties and the spatial properties of the built environment. From an ontological foundation this paper presents a framework for building space information. It also gives an account of some other scientific papers and standardisation efforts dealing with the concept 'space'.

A definition of space in the construction context proposed by *Ekholm* [1996] is: "….. an aggregate of construction works, their parts or other things with materially or experientially enclosing properties". With this as a starting point and based on scientific papers and standardisation efforts a schema of construction entity space is provided. This structure is described in figure 4:16.

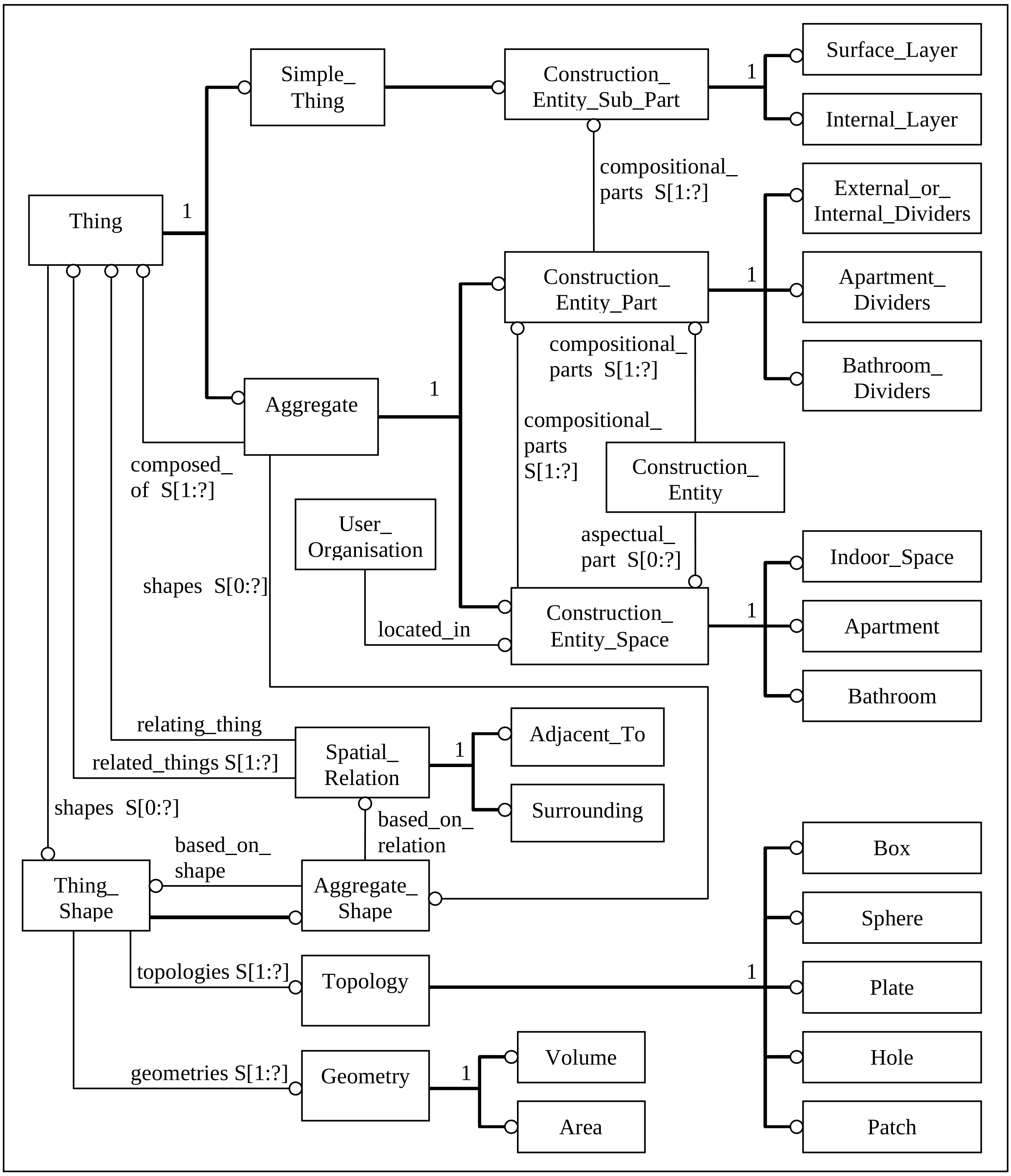

Figure 4:16 A schema of the construction entity space After Ekholm and Fridqvist *[1997]*

In the schema the ‘Construction Entity Space’ e.g. apartment or bathroom represents an aspectual part of a ‘Construction Entity’ e.g. apartment or bathroom divider. The ‘User Organisation’ is ‘located in’ the ‘Construction Entity Space’. The ‘Construction Entity Space’ is composed of ‘Construction Entity Parts’ which in their turn are composed of ‘Element Parts’ e.g. surface or internal layer. Both ‘Construction Entity Space’ and its parts have ‘Shape’ and ‘Spatial Relation’ to other entities of the same kind. The shape of the ‘Construction Entity Space’ is based on the shape of the ‘Construction Entity Parts’ and their spatial relations. The shape of the ‘Construction Entity Part is based on the shape of the ‘Element parts’ and their relations.

The conclusion of the paper is that “…. a space is an aspect view on things; depending on the view, it may be seen both as a property of things and as a thing in itself”.

4.9 Conclusions on the Technology

Several authors have discussed the effects of using object-oriented building product models as an integrating structure for construction related information, e.g. [*de Vries and van Zutphen*, 1992], [*Eastman*, 1992], [*Hannus et al.*, 1994], [*Galle*, 1995] and [*Augenbroe*, 1993b].

The probably two most important aspects of using building product models and product data technology are:

- the enabling of data exchange and data sharing
- the representation, exchange and access of product data without using documents as a mechanism.

Possible effects of this are different for different actors. Examples of possible advantageous effects according to the opinion of the author are mentioned below.

For the final user of the information systems, the building product model technology could:

- imply that the IT-systems have a closer correspondence with the end users perception of the building and the construction process;
- result in better integration of the life-cycle of buildings and thus provide better possibilities for life-cycle thinking in the construction sector;
- gives more functional and logical system architectures;

- result in more functional and logical data/information structures;
- give more functional and user-friendly user interfaces.

From the view point of the system developer, the BPM technology could:

- give a better possibility for modular development of systems;
- provide a good starting point for using object-oriented methodology in system development;
- make it possible to integrate data and methods;
- give better conditions to apply current information system technology, e.g. open systems, client-server network, and multimedia technology.

The most important technology used in the research of this thesis is the use of object-oriented building product modelling. The knowledge about and experience from this technology has increased enormously during the duration of the research process. The number of research and development activities increased considerably as well as the amount of general literature within this area.

Finally, almost all of the research results referenced and discussed in section 4.8 concerning current ideas on the use of building product models in information systems for FM, were published after the research of this thesis was carried out. They represent examples of research carried out in parallel with the writing of this thesis.

5 Functional Requirements for a Building Product Model for FM

Introduction

The research of this thesis was rather carried out using a series of structured assertions instead of a regular hypothesis. The assertions are structured as a chain of reasoning which is described in this chapter.

5.1 The Inefficiency of Current IT Applications for FM

Assertion 1: Current IT applications for FM are inefficient.

Several authors have described the current inefficiency of IT applications for facilities management [*Atkin* 1990], [*Teicholz*, 1992], [*Barrett*, 1995], [*Majahalme*, 1995] and [*Wikforss*, 1997]. Experience at the National Board of Public Building [*Svensson et al*., 1989] and [*Sandesten and Ahlkvist*, 1990] also highlighted the inefficiency of current IT systems. Information is often lacking altogether (i.e. as built information) or is available in the wrong format or the wrong place. The cost of creating or retrieving and reformatting the information is often too high to make such an effort worthwhile.

Inefficiency in handling the information is for instance manifested as follows.

- Either too little or too much information.
- Obsolete or inaccurate information.
- Incomplete and inconsistent information.
- Redundant information.
- Information is not relevant to the task at hand.

Consequences of this inefficiency are e.g. that decisions are taken without the right information support because information is lacking or that dependencies in information both over time and space are not analysed because it is too laborious or even impossible to do so. The results of this could be that the facilities are not utilised optimally or that the costs of operation and maintenance are not minimised.

Assertion 2: A main reason for the inefficient use of IT in FM is a lack of integration.

The lack of integration is technically manifested in a number of ways. One central feature is that downstream IT applications (occurring later in the process) cannot reuse the information produced by earlier applications in a digital format but that human operators need to interpret the information manually to input it again. Another related feature is that information produced by an earlier application is structured in the wrong way compared to a later application (for instance use different classification categories for building parts). One consequence of all this is that the cost of "recreating" the data which already exists digitally is high, another that due to these high costs the recreation is not considered worthwhile and decisions are made based on incomplete or obsolete information, which in turn may have negative consequences for the optimal use of the facilities.

This lack of integration has mainly historical reasons. Most IT applications within the FM domain have been developed from existing IT systems. They have often been created as a second application on top of an already existing system. This means that they have inherited a lot of specific features from the "mother" system. Also, those systems that are developed from scratch are often created on an ad hoc basis without a thorough investigation and co-ordinating phase at the beginning of the system development project to secure a solid foundation for appropriate functionality. IT development work within the FM domain has also normally been carried out within a local environment without any real ambition to work for standardisation and open systems. Finally, many of these system development efforts were carried out, or at least started, before modern open and standardised IT solutions existed.

The integration that should be pursued is mainly within the FM domain itself, but is also reaching outside of it.

The lack of integration can be sub-classified as follows:

- between different FM applications
- between applications used in different parts of an FM organisation
- between different types of information used in FM
- between different generations of FM applications
- between FM applications and applications for design and construction
- between FM applications and systems used in core business activities

In the following these categories are briefly discussed. The probably most evident lack of integration is between *different FM applications*. A way of illustrating this is through different systems using information about the areas inside buildings. Systems for space management, managing tenancy agreements, maintenance planning and energy management all use information about the spaces inside the building, but they seldom all use the same source for this information.

A second quite evident lack of integration between IT systems concerns different parts of an FM organisation. Two important categories are: information used for *different types of FM functions* (technical, administrative or economic) within an organisation and information used on *different levels of management* (strategic, tactical and operational) within an organisation.

A more scattered lack of integration is between the *different types of information* used in FM, for example:

- graphical and alpha-numerical information,
- paper-based (non-digital) information and information in digital format,
- information per document and structured in smaller pieces of information,
- information sorted according to construction classification classes (often used by engineers and technicians) and information sorted according to account classes (often used by accountants).

A significant current problem is the poor interoperability of new applications with existing ones, that is the lack of integration between *different generations of FM applications*. Ideally, the new IT systems for FM should co-exist flexibly and smoothly with older ones within the FM domain or other related domains. The existing discontinuity between different information systems creates costs to both building owners and the core business in the buildings.

The lack of integration between IT systems could also include areas outside the FM domain. When talking about FM two areas are of major interest. Firstly the lack of integration with *systems used during the design and construction phases of the life-cycle of the building*. Ideally, information from the design and construction of the building should be transferred in digital form into the FM systems. Vice versa, a lot of experience is gained during the FM processes and such information should be of interest when new buildings are planned and built. This means that information should go in both directions between FM and the design and construction processes.

Secondly the lack of integration *with certain systems used in the core business activities*. Typical examples of such systems are pre-production engineering systems or economic analysis systems.

Overall the lack of integration generates a number of problems such as:

- many different information systems must be operated in parallel,
- information redundancy (the same information stored in many places),
- it is hard to feed the IT systems with necessary information and even harder to keep information updated,
- it is often not possible to analyse the information and
- feedback does not function.

5.2 A Proposed Remedy for this Lack of Integration - Consistent and Appropriate Data Structures

Assertion 3: A Proposed Remedy for this Lack of Integration is the consistent use of Appropriate Data Structures

There a number of ways in which the integration problems discussed above could be solved. Present IT provides for instance good prerequisites for integration on account of developments such as:

- standardised hardware and systems software,
- local (LAN) and global (WAN) network technology,
- client-server technique,
- object-oriented system technology and
- standardised user interfaces.

These characteristics make it easier for end users of systems to take part in the development of new systems, to learn new systems and to use them. While these new technologies promise to simplify the design and implementation of software applications and simplify the man-machine interfaces for the end-user of the applications, they only provide part of the solution for data exchange and data sharing between applications, the key aspect of integration. To use an analogy mobile phone technology or the internet helps a long way in facilitating communication between people, but we still have to speak the same language (i.e. English) for the communication to function fully. Structuring and standardising information on the semantic level is thus essential.

The components of an information system are hardware, software, data/information and system users. The normal lifetime of the different components are given as life spans in table 5:1.

Table 5:1 Life span of the components of an information system

Component	***Life span (years)***
hardware	3-5
software	2-10
users (period of employment)	1-40
information	1-100

The table shows that the lifetime of information is by far the longest of the different components. This means that investments in good information structures ought to be very profitable in the long run for FM organisations, as compared to investments in the other three categories. There is furthermore an obvious tendency that the average lifetime of hardware, software and period of employment is decreasing. Finally, it is important to notice that the information handled in FM is to a large extent about infrastructure, which has a lifetime far above the average of most products.

Because of the reasons described above, there should be a focus on the information component of the system when trying to improve the integration of FM systems. The proposal made in this thesis is that the main remedy for this lack of integration could consequently be the use of *consistent data structures for information common to several applications in FM* (domain specific information).

Assertion 4: An appropriate standardised description of the building in digital form could be a backbone in organising the information utilised by different FM applications and would in particular facilitate the integration which is lacking today.

A wide range of functions are included in FM. The different FM functions have in common that they all exist to support the main (core) business of the organisation on both its operational, tactical and strategic levels. A red thread in the different functions describing the objective of FM is thus the building with its surroundings and its internal equipment and environment. FM includes planning, providing and managing facilities. This implies the following assertion:

Important reasons for proposing a standardised building description as a solution to the integration problems are:

- FM is primarily concerned with buildings, their surroundings and utilisation as a resource for the core process. Building parts of particular interest are spaces and the spatial systems these form such as flats or fire zones, technical systems e.g. ventilation systems or telecommunication installations and building parts such as doors, windows and columns.

- The FM process is linked with the design and construction processes of buildings and these processes also deal with the building parts above.

- The information used in FM is to a high degree of multi-media type with complex interrelationships (alphanumerical data, drawings, photographs, video etc.), and a standardised digital model of the building could act as a mechanism to integrate such heterogeneous data.

Assertion 5: The object-oriented methodology can favourably be applied to the definition of the standardised building description (i.e. a building product model is an appropriate solution)

The basic idea of object-orientation is that the world can be modelled as a collection of objects and this implies a data-centred view of the world (rather than a procedure or function-oriented view). Objects are relatively easy to define, design, implement and maintain. This means that the system development process becomes more intuitive and controllable. Object-orientation offers benefits not just to the system development process, but also to the utility and flexibility of the resulting software. Recent developments in building product modelling (cf. Review in chapter 4) indicates a broad consensus among researchers that applying an object-oriented methodology is the most promising way for defining standardised data structures supporting the exchange and sharing or building data. This view is also increasingly shared by practitioners and software developers.

One additional benefit of applying an object-oriented methodology is that the tradition within Sweden of classifying information in the construction industry and the design and construction processes could be used throughout the whole life-cycle of the buildings.

Assertion 6: A basis for the development of integrated FM information systems are suitable process descriptions.

The FM is carried out through processes, that is a series of activities that add value to the core business of the organisation using the premises in the buildings managed by the facilities manager. *Information requirements and constraints of the FM processes are favourably described through process modelling*. There exist many different techniques for modelling processes. Examples of techniques for analysing and describing processes are the data-flow diagram (DFD) and action diagram.

A possible solution to this has already been described in chapter 3.

5.3 End-User Requirements of a BPM-Based Information System for FM

A number of requirements can be defined for a building product model for FM purposes. Some of these can be derived from general requirements for any modern IT applications (e.g. graphical user interfaces and networking). Others are requirements which apply to any database system (for instance non-redundancy of data). A last category consists of requirements which are particular to the FM domain (for instance have to do with the fact that FM information needs to be usable several decades later on).

The list of requirements provided below originates in this author's own experiences from work within the National Board of Public Building. The list was further amended and refined through:

- literature studies and
- experiences in standardisation work in which the author has also participated, e.g. the STEP work.

The requirements for product models in general are studied and described by e.g. *Tolman* [1991], *Augenbroe* [1992], *Eastman* [1993], *Galle* [1995] and *Björk* [1995]. An example of a studie concerning FM specifically is the one done by *Bos* [1995]. A comparison could also be done with the lists of requirements on a BPM provided by *Hannus et al.* [1994] and *Tarandi* [1998].

A building product model for facilities management should be:
-flexible,
-stable,
-adaptable,
-comprehensible and
-cost-effective.

- ***Flexible** i.e. the model can be used in different situations or conforms to different requirements (as they occur).*

Information systems for FM require a considerable scope of flexibility so that the systems are useful under different conditions and requirements as they occur. IT in itself provides the perhaps most important resource and incentive for changing the organisation and processes of the FM work. On the other hand the IT systems must be relatively easy to adapt to continuous different changes.

The model should be able to match the FM requirements by the end-user of the system (the facilities manager with IT experience). The model should also be usable within different organisations/companies in spite of minor differences in company-specific requirements. Also the ability of the end-users to modify the models are of considerable importance in making the systems applicable to specific company requirements.

- ***Stable*** *i.e. the model is not likely to experience any sudden changes.*

To be able to build reliable systems based on the model, the changes in it over time should be limited.

It must be possible to use the model within different IT environments. Systems that are strongly tied to specific hardware or a particular operating system are not acceptable. The model should also survive both the software and the hardware on which it was created and which quickly become obsolete. Also, it should be possible to use the information stored in systems based on the model for many years.

The type of requirements described above are to a high degree met by standardisation of the model and other parts of the information systems. By using an information infrastructure of models adherent to relevant standards it should be easier to transfer information from one system to an other.

- ***Adaptable*** *i.e. the model can be changed, when felt necessary, in order to deal with a new situation or purpose*.

The FM process is changing rapidly and it is necessary to have methods/processes and systems that can easily be changed in order to make them suitable for a new usage or situation. Clearly defined product (and process) models can contribute to the adaptability by not being on a too detailed level and by providing hierarchical structures.

The model must not prevent the application from taking advantage of future unknown but innovative changes within the FM domain and within the IT evolution. This means that changes of the model should be possible to a reasonable degree and it should be possible to manage additional information changes in the system.

- ***Comprehensible*** *i.e. the model can easily be understood and used by the system users (and system developers).*

The requirement on comprehensibility is in FM emphasised by the fact that the IT systems in FM are normally used more by generalists than by specialists. The IT systems need to be accessible to users with minimal IT experience. Comprehensibility means here the ability of the systems to be understood and used properly. The FM systems used must less than in the design and construction phases mirror the technical aspects of the building and more the usage and spatial aspects of the buildings.

The requirement of comprehensibility means also to some extent a limited model and to some extent a model that to a high degree reflects the logic of the system domain.

Another general aspect of comprehensibility is the need for simplicity. Quite a number of existing IT systems for FM have failed due to complexity and impracticality.

- ***Cost-effective*** *i.e. the resources spent on developing the model should be kept low and reasonable in comparison with its benefits*.

The IT systems used in FM need to be cost-effective that is give enough profit, benefit, etc. compared with the money spent on them. The requirement of cost-effectiveness leads to trend towards simplicity and this more often appears as requirements even from technologically advanced facilities managers.

The requirement of a cost-effective model means e. g.:

- It should if possible reuse already existing concepts and sometimes e.g. models or classifications.
- The model should not be unnecessarily large or it should have a well-designed modular structure.
- It should permit the FM system to handle existing FM information both in paper-based and digital formats.

The major cost when developing and implementing new IT applications in FM are related to information gathering and information feeding into the systems. Due to that it is important for the cost effectiveness to be able to use and redistribute the data stored by the models as far as possible.

Two types of requirements specifically discussed in this project

Two other important requirements for a building product model for FM (and partly also other applications) are described below under the headings: “Proceed from existing domain concepts and domain classification” and “Support compound documents”. These two requirements were taken into specific consideration during the research project.

The first of the additional requirements is a consequence of the need for a comprehensible and cost-effective model and system, while the second is mainly a consequence of the need for a flexible model and system. The model must be able to function as an infrastructure for information structured both as documents and as data in tables.

Proceed from existing domain concepts and domain classification
Industry-specific concepts should be used as far as possible when developing the model. In the Swedish situation, in which this research was conducted, this means in particular that the object classes of the building product data model should coincide as far as possible with the classification categories of the national building element table (BSAB). Close correspondence makes it easier to adapt existing applications and easier for users to understand product model based applications.

Support compound documents
A (standardised) BPM should act as a tool to organise the wealth of heterogeneous information used in FM. The first generation of BPM proposals was based on the paradigm of complete semantic modelling of all information describing a building (including geometry), from which all conceivable documents could be derived automatically. This implies a situation where all the information describing the building is structured from the beginning according to a BPM. This is not the case with FM today and will not be the normal situation for the near future, when we have to deal with existing buildings described using paper-based documentation or even photographs and videos. For FM purposes, a less comprehensive approach based on clustering of information and documents around building elements, is often sufficient and also technically easier to achieve.

5.4 Conclusions

This chapter provides a description of the causal process of coming to particular ideas and suggestions that provided a basis for the research reported in this thesis. The following gives a summary of this chain of reasoning.

The problem - section 5.1. A state of affairs that causes problems to people using IT in FM work is that current IT applications for FM are inefficient. A possible way to deal with this problem is to improve the integration of information used in different parts of the FM organisation and in adjacent organisations. The point of issue of the theory consists of two statements:

Lack of efficiency - a major problem
A primary cause - lack of integration

The proposed solution - section 5.2. A way of dealing with the point of issue is to create a stable and standardised infrastructure for basic information used in the FM processes. A proposed backbone of this infrastructure is an applicable building product model. A basis for the FM information systems is also a generic process description. A suitable method for the information handling in FM is the object-oriented technology. Thus, major constituents of the proposed solution are the following:

A remedy - consistent data structures and
satisfactory data management
An appropriate backbone - a building product model
A basis for the information system - a process description
A suitable method - O-O technology

Requirements for a suitable solution - section 5.3. To be a suitable infrastructure for the information handled in the FM work a building product model should fulfil certain requirements should be fulfilled. Most of these requirements are general i.e. they are not specialised in the FM subject matter while others more refer to the FM area. The requirements could be summarised as follows:

General requirements:

- *flexible,*
- *stable,*
- *adaptable,*
- *comprehensible and*
- *cost effective.*

Specific requirements:

- *proceed from existing domain classification and other domain concepts and*
- *support compound documents.*

6 The KBS Model - A Proposed BPM Structure

Introduction

In this chapter a conceptual schema - the KBS Model - which tries to fulfil the requirements defined in chapter 5 is described and explained. A main concern was to try to integrate existing national construction classification tables (the BSAB/SfB-system) into the model structure.

6.1 Context and Scope of the Model

The context of the KBS Model is the life cycle of ordinary buildings, and its scope is frequent information about such buildings handled by the actors within the Swedish construction sector.

After having identified the context and scope of a model the next stage is to identify classes of objects. “The identification of classes and objects is the hardest part of object-oriented design” [*Booch*, 1991]. There are different suggestions how to discover these objects and classes. *Coad and Yourdon* [1991a], for example, suggest the following object-sources:

- The UoD itself and any description of it.
- External systems and “terminators” interacting with the system.
- Physical devices interacting with the system.
- Events occurring in or around the system.
- Roles played by different actors in the system.
- Physical or geographical locations and sites relevant to the system.
- Organisational units relevant to the system.

An additional method is to utilise already existing application-specific class libraries. This implies that somebody has already done an OO analysis.

The analysis process is normally both an incremental and an iterative process. The model gradually grows and/or changes and the work may be done over and over again.

Instead of trying to identify new objects and classes (entities) based on some of the methods above, there was a decision in the KBS project to utilise the existing classes within the national classification tables of the BSAB System [*SB-Rekommendationer,* 1987] as a starting point for identifying the entities. The BSAB classification tables are already in use in the industry today. The relationship between the context and scope of the KBS Model on one hand and the BSAB System on the other is described in figure 6:1.

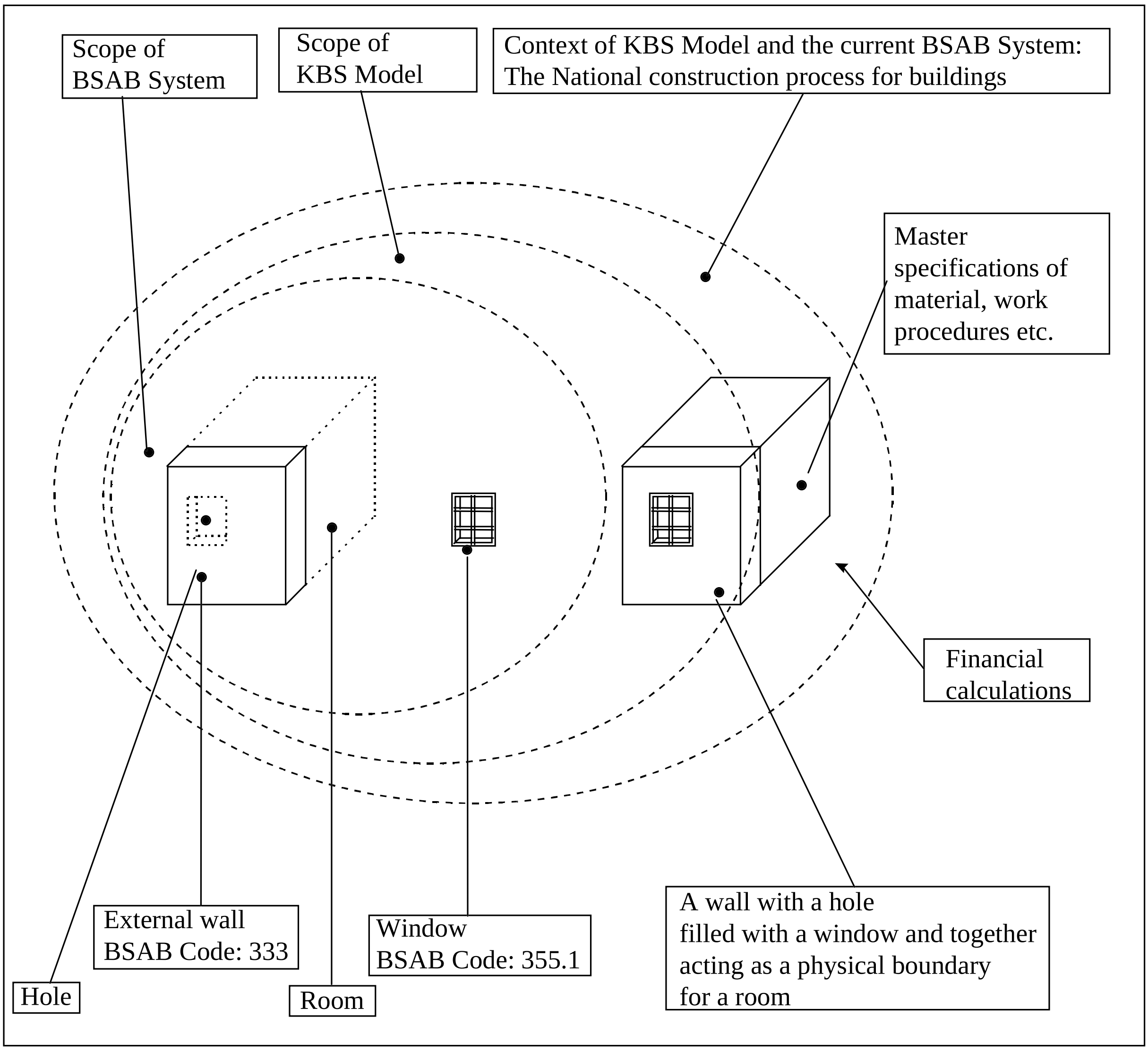

Figure 6:1 Context and scope of the BSAB System and the KBS Model respectively

The BSAB System contains product classification tables describing ordinary buildings. These tables are tools for the arrangement of technical and financial information in documents and databases. The figure 6:1 gives examples of objects and type of information included and excluded respectively in the context and scope of the BSAB System and the KBS Model. Taking a wall and a window as a concrete example the BSAB System identifies and assigns codes to these two building elements. The KBS Model should in addition model the relationships existing between the window and the wall and provide information about material used.

6.2 Using the BSAB System as a Starting Point

The present BSAB System contains two product classification tables, Product Table 1 and Product Table 2. In Product Table 1, the work sections of earthworks, buildings and building services are classified mainly with regard to their material content, but partly with regard to the type of labour required to produce them. Product Table 1 has 26 primary principal groups (A, B, C,.......Z) which are further subdivided. Most of the classification concepts are associated with product resources. The structure of Product Table 1 is a one-dimensional list and examples, translated into English, are given in figure 6:2a.

F	**Brickwork and blockwork**
F4	**Brickwork**
F4.2	**Brick walls**
F4.22	**Walls of facing brick**
I	**Pipes and tubes, ducts etc.**
I1	**Pipelines, single**
I1.1	**Cast-iron pipelines**
I1.11	**Grey cast-iron pipelines**
I1.111	**Pressurised grey cast-iron pipelines**
I1.1111	**Grey cast-iron pressure pipelines**
V	**Apparatus, machinery etc. in electrical systems**
V3	**Lighting fittings, lampholders etc.**
V3.1	**Lighting fittings**
V3.11	**Fixed lighting fittings for general lighting**

Figure 6:2a Examples of classification from Product Table 1 of the BSAB System

In Product Table 2, elements of earthworks, buildings and building services are classified with regard to their technical function. There are ten principal groups, but at the moment only six of them are further subdivided into tables. The structure of these tables is an orthogonal grid. Subdivision along the vertical grid is principally based on technical function (systems). Subdivision along the horizontal axis is principally based on a space-related subdivision of the construction elements. The subdivision along the horizontal axis is the same in the four principal groups describing building services systems (no 5, 6, 7 and 8), while the principal group of earthworks, etc. (no 1) and buildings (no 3) each have unique subdivisions. In figure 6:2b examples of tables, translated into English, are provided.

5 Heating, refrigeration, water supply and sanitation systems

	/0/ Complex	/1/	/2/ Central equipment	/3/	/4/ Ductwork	/5/ Pipework	/6/	/7/	/8/ Local equipment	/9/ Others
50 Complex										
51										
52 Tapwater and drainage systems										
53 Sprinkler systems										
54 Gas and compressed air systems										
55 Refrigeration and heat pump systems										
56 Heating systems										
57 Air handling systems										
58										
59 Other heating, refrigeration, water supply and sanitation systems										

Two examples are:
57/ 2/ Air handling systems/ Central equipment
52/ 5/ Tapwater and drainage systems/ Pipe work/

Figure 6:2b Examples of the classification in Product Table 2 of the BSAB System

Using the BSAB System as a point of departure, a complete set of classes for the KBS Model was defined in a uniform and standardised manner. As the classes were enumerated in close relationship with a decomposition hierarchy described in the following section, the extension or domain of classes on different levels of decomposition is also described there.

6.3 Decomposition (Whole-Part) Hierarchies

An important analysis activity is to organise the entities of the UoD into hierarchies. The BPM must be a logical description of the generic product of buildings on different levels of decomposition. If the BPM is to act as an integrating mechanism, it is essential to establish a sufficient decomposition hierarchy that can function during the entire life-cycle of the building product model entities. Thus, a general decomposition hierarchy relevant to the construction sector, was defined. This hierarchy has seven levels of decomposition and is described in figure 6:3 .

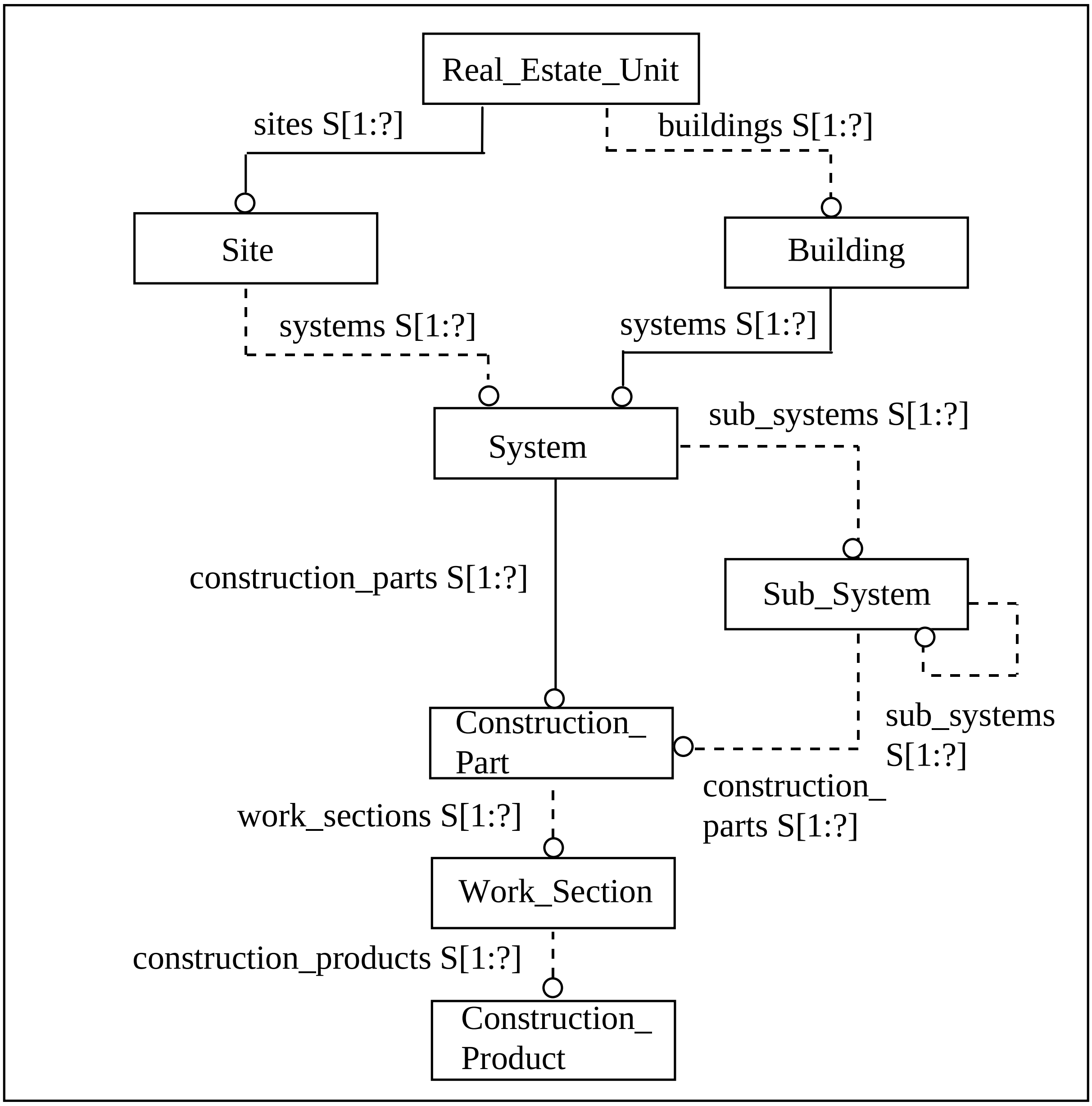

Figure 6:3 Technological decomposition hierarchy of the KBS Model

Important sources of inspiration were the decomposition hierarchies used in the RATAS Model [*Björk*, 1989] and the AEC Building Systems Model [*Turner*, 1989]. In the original RATAS work five levels were defined, compared with the seven levels in the KBS Model.

The most important point of departure when defining this general decomposition hierarchy, was the structure of the BSAB System. These levels can be defined and filled with adequate objects by defining each level on the basis of concepts in the BSAB System according to table 6:1.The table shows how the different aggregation levels of the KBS Model are related to concepts in the BSAB System.

Table 6:1 Decomposition levels of a facility in the KBS Model

Decompo-sition Level	***Name of Decompo-sition Level***	***Related Concept in BSAB System***	***Example of Entity with BSAB System Code***
1	Real Estate Unit	All P2 grids (1,3,5,6,7 and 8) together	
2	Site -------------- Building	Part of P2 grid 1 ----------------------------- Remainder of P2 grid 1 and almost all of P2 grids 3,5,6,7 and 8	
3	System	Subdivision of each prin-cipal group of P2 along vertical axis	35 Facades 6210 Electrical distribution net-works
4	Sub System	Subdivision of each sys-tem along horizontal axis of P2 grid	355 Secondary elements in open-ings 62102 Central equipment in elec-trical distribution networks
5	Construction Part	Subdivision of subsys-tems of P2-table or ag-gregation of work sections of P1-table (results by method of construction)	355.1 Window X2.11 Window, French window etc. 62102.V1.1 Switching equipment in electrical distribution networks V1.1 Switching equipment
6	Work Section	P1 heading	M6.521 Window sheet of zinc plate V1.11 High voltage switchgear
7	Construction Product	SfB table (is related to the BSAB System)	

Ekholm [1987] have also examined the decomposition levels of the BSAB System and the relationship between the classes of Product Table 1 and 2. A comparison of Ekholm’s results with the description above indicates a considerable similarity. The two analyses were done independently of each other.

During the construction process the building is often considered from a spatial viewpoint. Also from a spatial viewpoint, different levels of granulation are needed and in figure 6:4 a spatial decomposition hierarchy with seven levels is described.

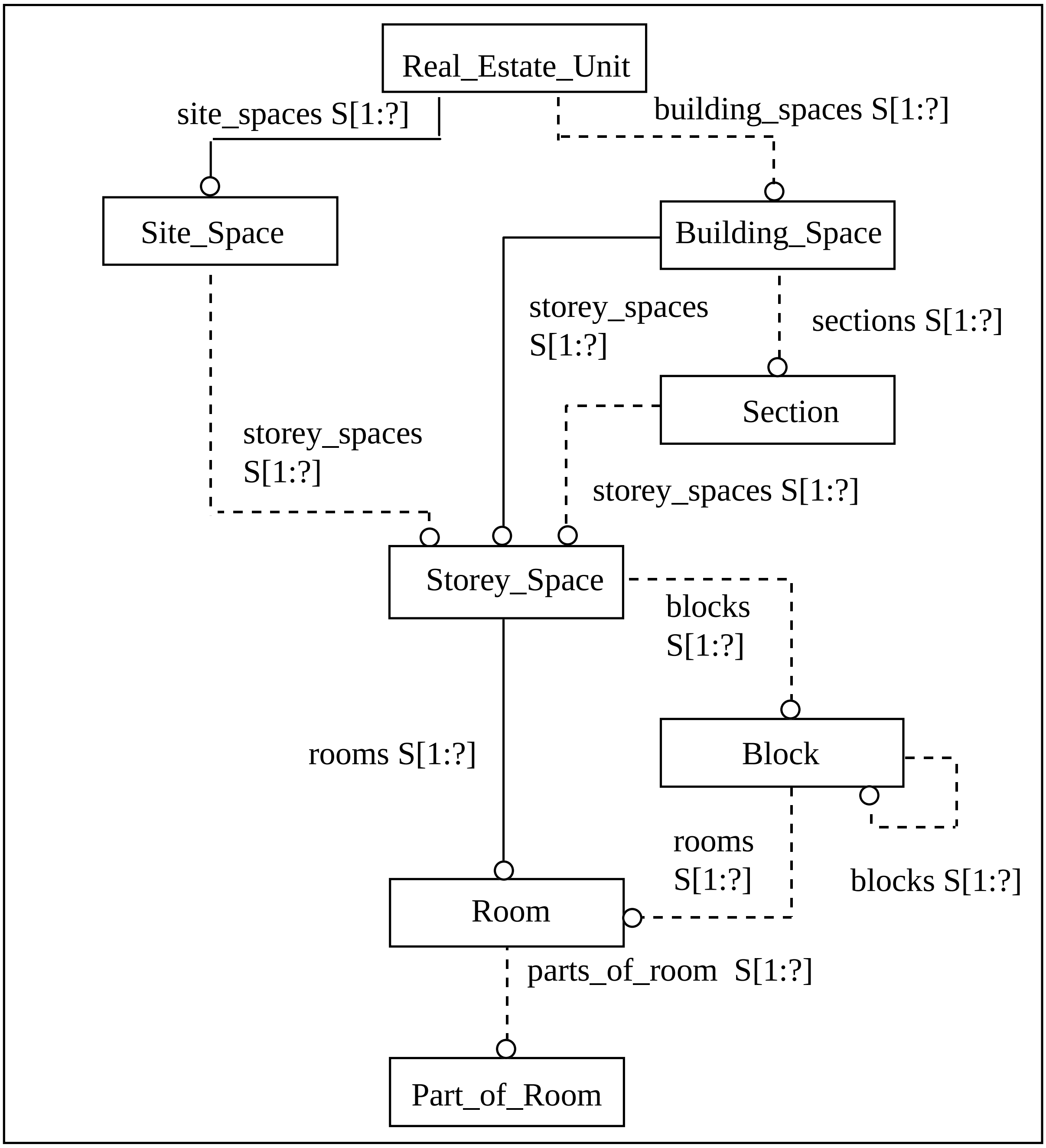

Figure 6:4 Spatial decomposition hierarchy of the KBS Model

In the spatial decomposition hierarchy it is mainly the entities building space, floor plan and room that are handled. The spatial decomposition levels of section and block could be seen as spatial systems and subsystems and are basically aggregations of rooms.

It is reasonably easy to use the classes of the present BSAB System during a large proportion of the design and construction phases of the building's life-cycle. Its structure and content suits the method of working during these phases. In technical specifications in the early stages of the design phase, Product Table 2 of the BSAB System is primarily used, and during the outline and detail design stages, Product Table 1 or a combination of Tables 1 and 2. During the construction phase, Product Table 1 is predominantly used. However, one obvious shortcoming when the P2-tables are to be used is that they do not provide full coverage, particularly as regards the ‘building’s services’ principal groups. Another shortcoming with the current BSAB System from 1983 is its lack of spatial element classes.

At present a third generation of the BSAB System (BSAB 96) is on its way into the national Swedish construction industry [*SB-Rekommendationer*, 1997]. It is a revised and extended version of the current BSAB System (BSAB 83). Some of the shortcomings of the earlier tables, from the viewpoint of the KBS Model project, have been amended in BSAB 96.

It is evident from the above that two important additions are required to the present BSAB System (BSAB 83) in order to allow it to be used as the basis for an object structure that is valid for the whole of the design and construction processes. In the KBS Model the following two additions were made:

- The system was augmented so that it comprises all the elements and work sections in a modern building.
- The system was augmented by a totally new classification of spatial entities of different granulation including the whole building.

The first addition is done as an alteration of the grids of the present Product Table 2. Only alterations that are considered very important were made. In certain areas the existing classification is too narrow, i.e. it does not include all parts of the UoD. In other areas the existing classification is too shallow, i. e. it lacks required sub-classes. The alterations were made in accordance with the following principles:

- In the first instance they were introduced as additions to the existing system divisions (along the vertical axis of the tables).
- In a few isolated cases, deletions were made in the existing system as a consequence of alterations.
- In yet other cases, alterations were made to tables.

All the alterations were discussed with the Swedish Building Centre (Svensk Byggtjänst) which is responsible for administering the BSAB System and for continually making adjustments to the BSAB-tables which are in the interests of the Swedish construction sector. The expanded P2-tables are illustrated in Appendix 3.

The second addition consisted of the development of a grid for the classification of spaces. In the classification of spaces, there are two principal parameters, type of building and type of room. The proposed new grid is based on two existing classifications of these parameters. The type of building is sorted and classified in accordance with the code of the Universal Decimal Classification System (UDC) for library management [*CIB*, 1966] for sorting buildings and civil engineering installations. This classification is often applied in the construction sector. The types of room are classified in accordance with the activity code for rooms (BAF 1633) [*BAF*, 1985] developed at the National Board of Public Building. In this, rooms are classified on the basis of the principal activity in them. The new grid for spatial classification is illustrated in figure 6:5.

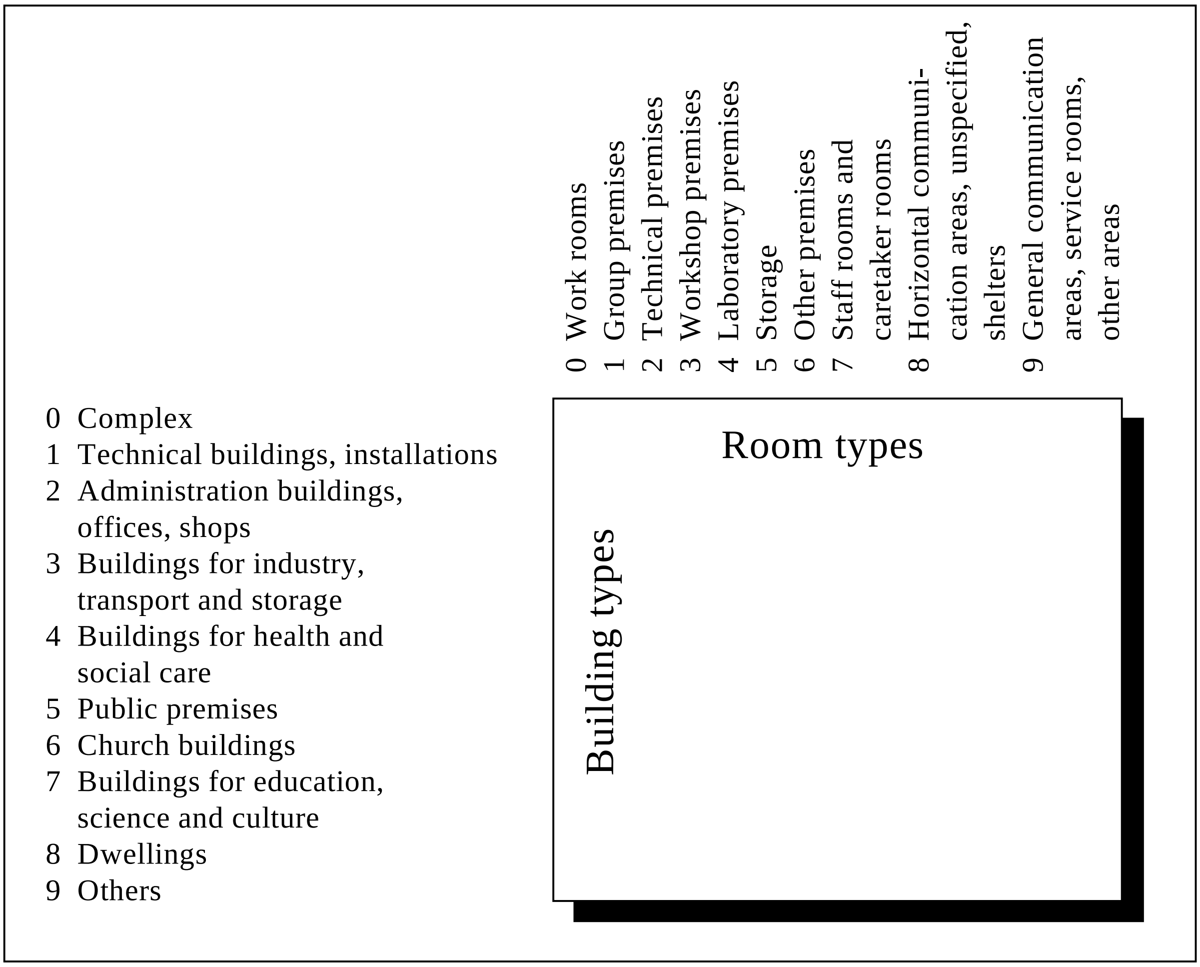

Figure 6:5 Grid for the spatial classification within the KBS Model

In *Svensson et al*., [1990] the complete set of BPM classes on different levels in the decomposition hierarchies is described. This description includes the following:

- **Building classes**. A proposal for a complete classification of buildings according to the so-called UDC code is introduced. The proposal contains about 50 classes.
- **Room classes**. A proposal of an almost complete classification of spaces is accounted for. The classification is based on the main use of the rooms and the description contains about 50 different classes.
- **Spatial system classes**. Spatial systems are defined as a collection of spaces (rooms), or as areas or volumes which are linked to each other in a functional way. Only examples of spatial systems like houses, floors, flats, fire-cell, local area and net volume are described in *Svensson and Falk* [1994].

In the technological decomposition area a complete set of classes is defined according to the following:

- **System classes**. Technical systems are defined as subdivisions along the vertical axis of the cardinal group of matrices in Product Table 2 of the BSAB System. Ground systems, building systems and installation systems are defined in this table. In the current version of BSAB (from 1983), however, this division is incomplete. A proposal for an almost complete division into system classes is given in [*Svensson et al*., 1990] and [*Svensson and Falk*, 1994]. It contains about 100 classes and covers the need of normal buildings. This system list has also been adapted by the so called NICK-project [*Tarandi et al*., 1994]. An example from the proposal is given in Appendix 3.

- **Subsystem classes**. A subsystem is defined as a complex part of a system. In *Svensson et al*., [1990] subsystems are described as a subdivision of the systems along the horizontal axis of the P2-matrices. The subdivision of the systems is hardly enough, however, to define subsystems. Types of subsystems which are interesting for instance in the management phase, are such complex parts of installation systems which have a special function and can be tested separately, for instance in connection with preventive maintenance. Examples of such functional entities are the heat-recovery entity and the air-cooling entity.

- **Construction part classes**. These classes are defined as a geometrical or functional classification of building parts. In *Svensson et al.,* [1990] a table per main group is described in which systems, subsystems and so-called type components are accounted for. Type components are equivalent to construction parts. An example of this classification of construction parts is described in Appendix 3. The list of construction part classes has also been adopted by the NICK-project [*Tarandi et al*., 1994].

- **Work section classes**. These classes are given in *Svensson et al.*, [1990] as headings in the P1-tables of the BSAB System.

- **Construction product classes**. These classes are not handled at all.

Using the concepts of the general decomposition hierarchies of the KBS Model together with some other fundamental concepts commonly used in the construction industry, the construction process could be described schematically as in figure 6:6.

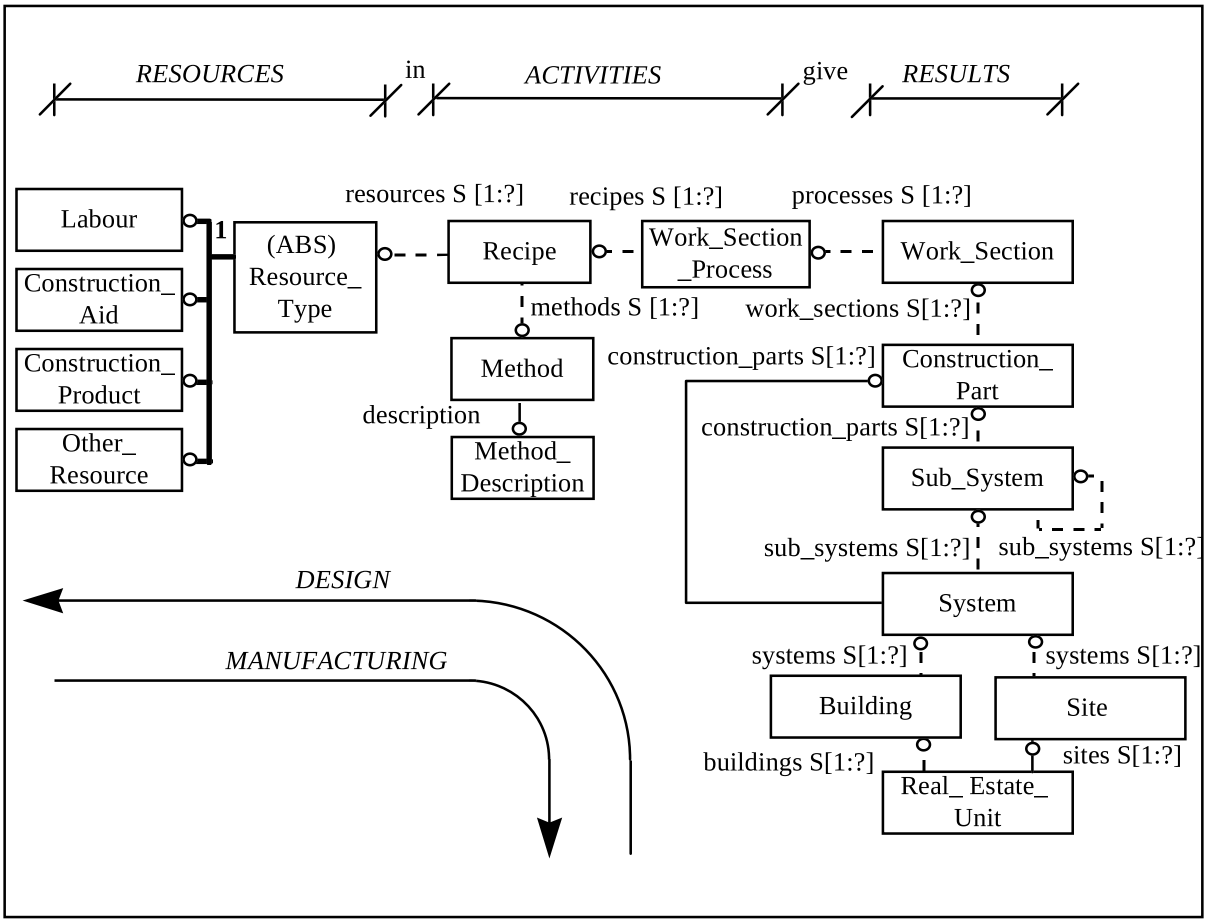

Figure 6:6 Schematic description of the concepts used during the design and construction processes

From this picture it can be recognised how the whole-part hierarchy is run through both during the design phase and, in the other direction, during the construction phase of the facility's life-cycle. During the initial design phase, objects on a high level of granulation are mainly used. These objects are then gradually transformed into smaller objects, during the continuing design work, according to the whole-part hierarchy above.

6.4 Specification Hierarchy

Different degrees of abstraction are commonly used when describing building components during their life-cycle. A hierarchy of different degrees of specification is important during the work to define, compare and select building components. Especially during the early stages of the design phase of the building product life-cycle, there is a need to work on a low degree of specification (high degree of abstraction) in the design description. But different levels of specification are also considered during other phases of the building product life cycle.

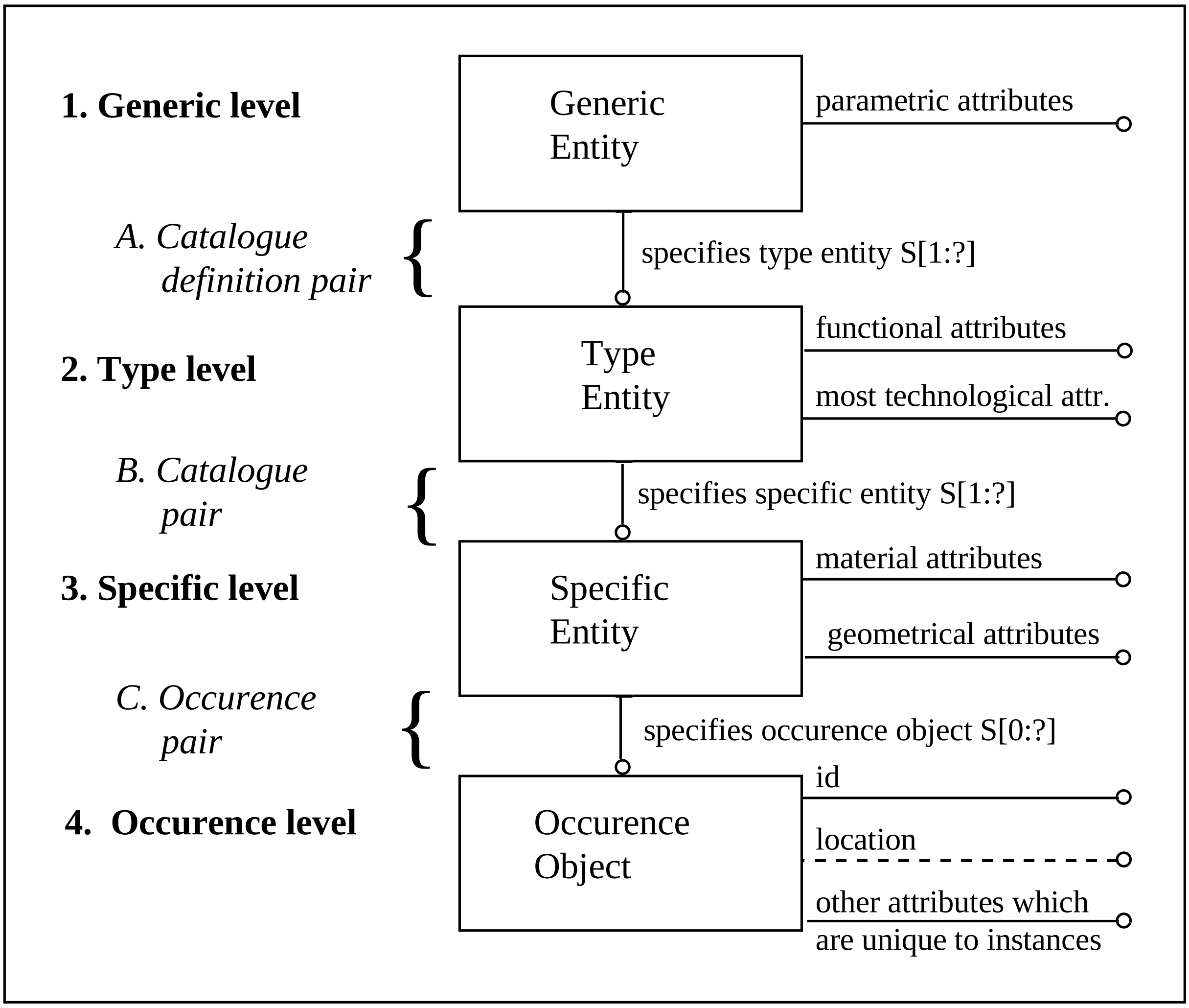

Figure 6:7 The four different specification levels of the KBS Model

In the KBS Model, a general specification hierarchy, with four levels of specification, is defined. This hierarchy is generally applicable to information handling in the construction sector. The specification levels of the hierarchy are described in figure 6:7 above.

To reduce the size of the instances, as much as possible of the information ought to be put on the first three layers (in the catalogue information, described later). At e.g. the instantiation of a wall object, the thickness and layer information of the wall are stored in the catalogue with a type specification, while the information which is unique to the instance, e.g. the position, height and length of the wall, is stored in the core part of the model.

In figure 6:8 the four specification levels of the KBS Model are applied to a typical construction part - a wall.

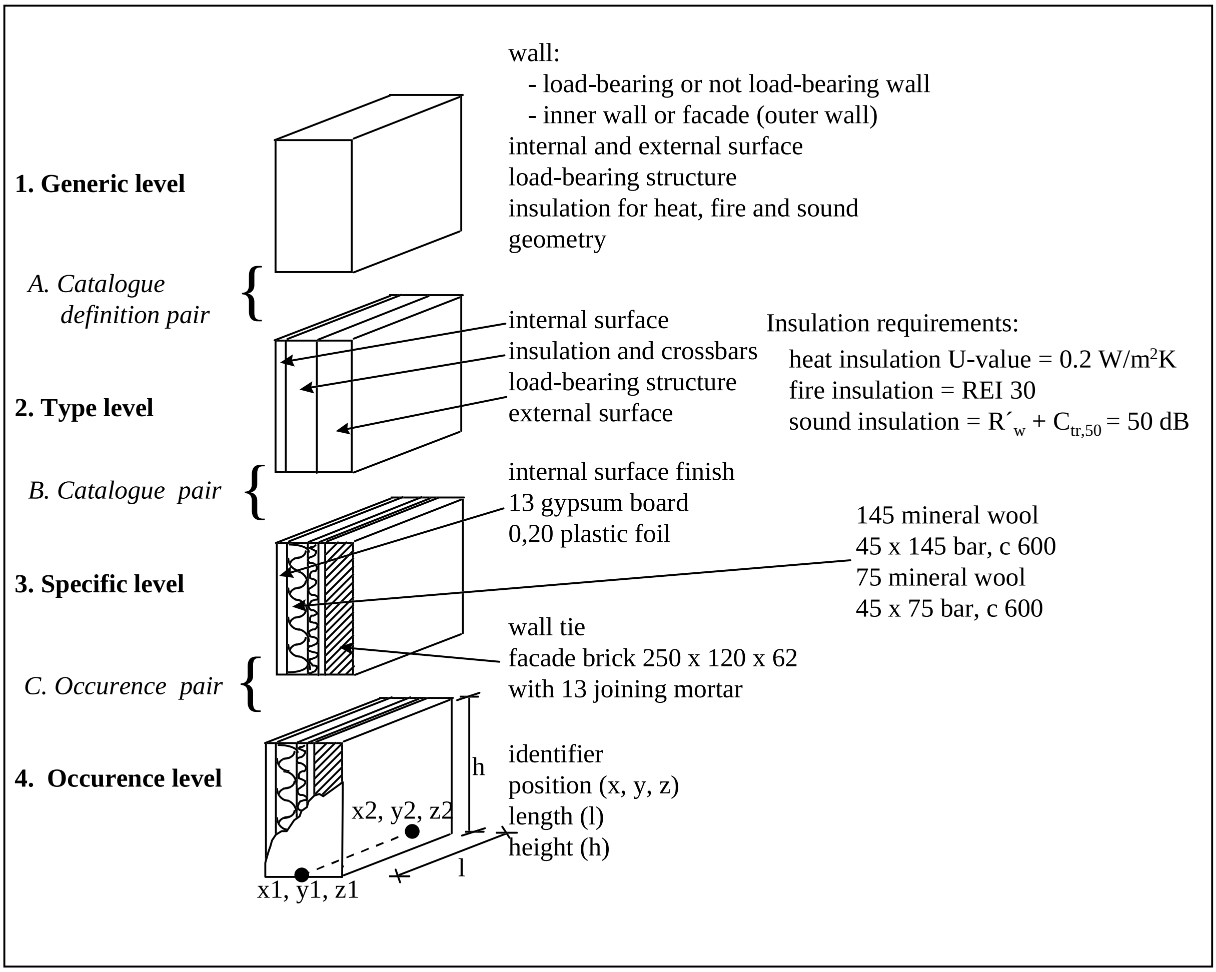

Figure 6:8 The four level hierarchy applied to the entity wall

Table 6:2 shows examples of entities on each specification level. It gives them on different levels of detail.

Table 6:2 Examples of entities on different specification levels

Level of decomposition	***Level of specification***	***Content described with explicit text***	***Content described with BSAB code***
Building	Generic Type Specific Occurrence	Building Office building Police station The main building in block Blandaren	0 02 (E0049001)
Technical System	Generic Type Specific Occurrence	HVAC system Supply air system Turbulent ventilation with back edge inlet The supply air system in the main building in block Blandaren	5 571 (TA 02)
Room	Generic Type Specific Occurrence	Room Work room Work room with a certain design Room No. XX in Blandaren	 0 01
Construction Part	Generic Type Specific Occurrence	Wall Inner wall Wall with gypsum board on steel A particular wall in a specific room in block Blandaren	 363

6.5 Relationships between Entities

The structure of the KBS Model described on three levels

The KBS Model is described below. Its starting points have been the class lists and general basic structures described in sections 6.2, 6.3 and 6.4. The description is divided into three levels. On level one, the model is described schematically and general principles behind its structure are clarified. On level two, the most important class types and their relations are described. The complete KBS Model is described on level three.

A schematic description of the KBS Model (level 1)

In this level one description, five main parts can be recognised according to figure 6:9. The core part of the KBS Model (1) handles information about specific and occurrence entities (according to the generic specification hierarchy described in section 6.3) which are above the work section level (according to the generic decomposition hierarchy described in section 6.4). The core part has relationships with three catalogue parts (2, 3 and 4) managing information about systems, spaces and construction parts respectively on the generic and type levels. Finally, the fifth part (5), manages information about the entities of the BPM on the work section level. Within this fifth part, there could be catalogue parts also handling common information about work sections or resources.

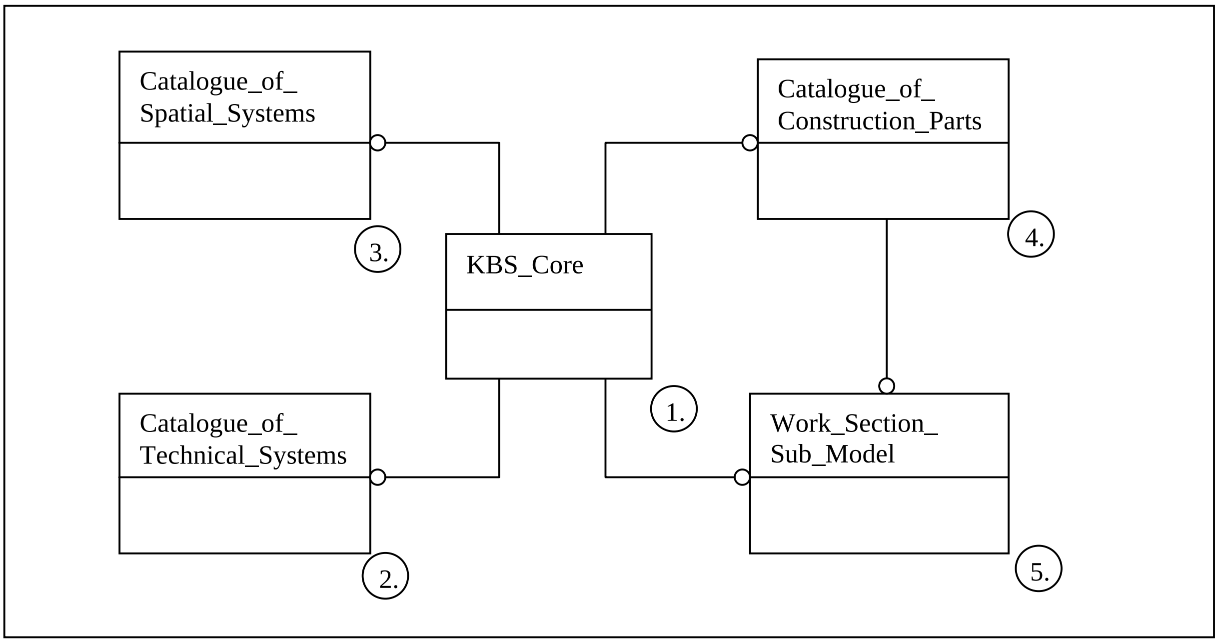

Figure 6:9 The schematic structure of the KBS Model

Using the terminology of section 6.6 (describing different types of attributes defined in the KBS Model), the general principles for the structure can be described as follows. Individual attributes and connections between occurrences are handled primarily by the core part (1) of the model and at times by its work section part (5). Group attributes (explored later in section 6.6) and class connections are handled primarily by catalogue parts (2, 3 and 4) and the catalogues embedded within the work section part (5).

The basic entities of the KBS Model (level 2)

In figure 6:10 , the most important entities of the KBS Model and their relations are described using EXPRESS-G.

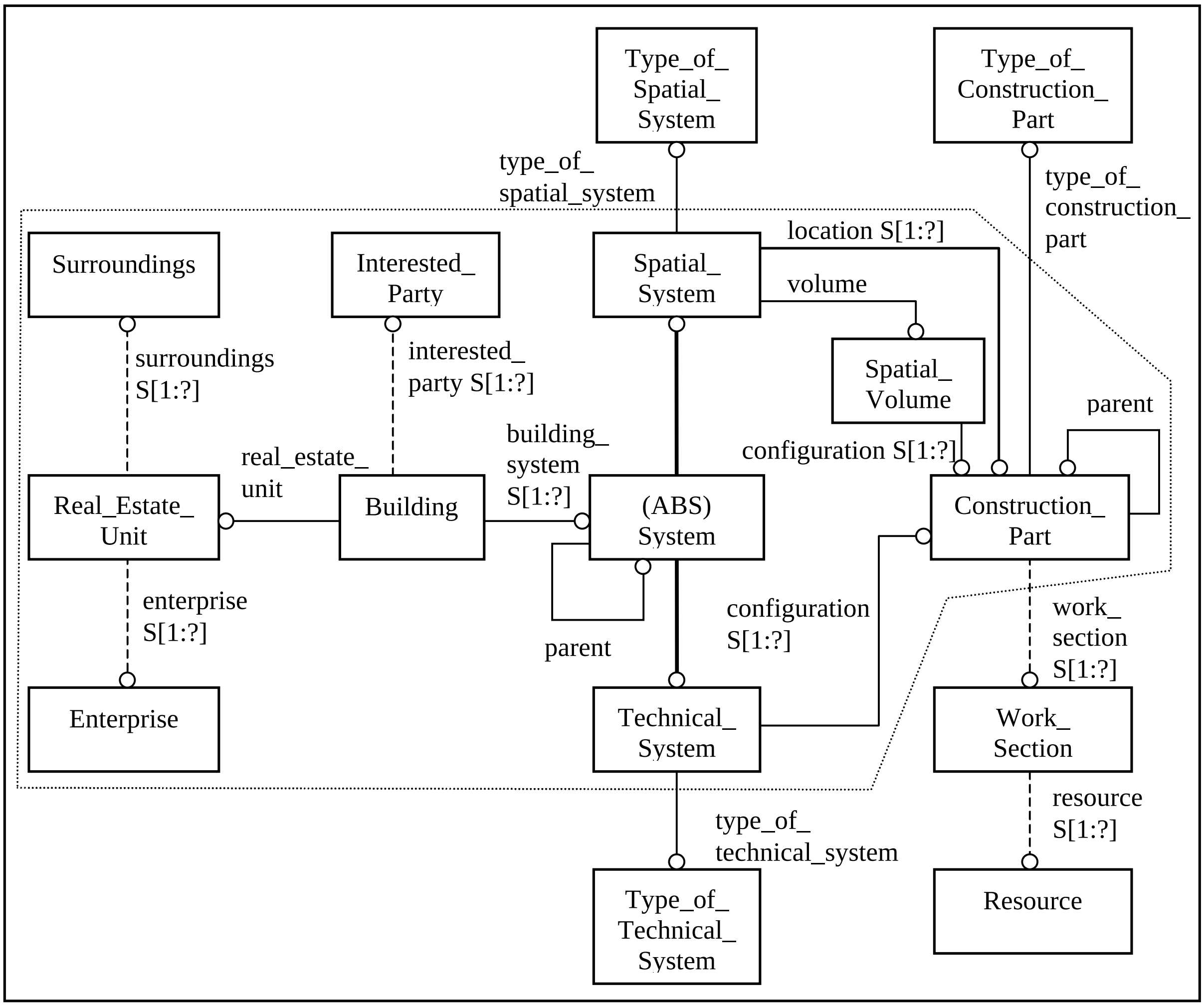

Figure 6:10 Level 2 description of the KBS Model

The relationships 'configuration', 'parent' and 'location' are, to keep the description simple, described/modelled very schematically on this level-two description of the KBS Model. The relationships are elaborated furthermore in the level-three description further below. This level-two description of the KBS Model mainly describes the core part of the model in greater detail while, the catalogue parts and the work section part are still kept similar to the schematic description in stage 1. The core part of the model is delimited by a dotted line in figure 6:10 above.

The entities of the core part of the KBS Model are:

- **Building**, the main body of the building including the foundations but excluding earthworks. All the systems must belong to one building.
- **System**, a super-class for technical and spatial systems.
- **Technical system,** a collection of construction parts which together carry out a characteristic function and can be, for instance, a structural, a HVAC, or an electrical system.

- **Spatial system**, a space with a certain function, normally related to the user of the building. As with technical systems, the spatial systems can have a structure i.e. one space can be connected to other spaces and spaces can consist of spaces. The spatial system has a spatial volume.
- **Spatial volume**, a defined space of any kind inside the building. The objectives of this class are to relate the specific space to the space-configuring construction parts, to keep track of the creation of physical parts and to handle the volume of the space.
- **Construction part**, a classification of physical parts of the building from a functional viewpoint. The construction parts of the KBS Model correspond to a subdivision of subsystems in the P2-table of the BSAB System or a grouping of work section results from the P1-table of the BSAB System.
- **Real estate unit**, a legal concept denoting the union of the site and building(s) on the site.
- **Interested party**, a physical person or a legal entity who is linked to the building as for instance landlord, administrator or tenant.
- **Surroundings**, parts connected to the building but not belonging to it, for instance municipal networks or roads.
- **Enterprise**, different (business) firms involved in the design, construction or usage of the building.

The model reflects some important aspects of the building as a product:
- The model describes both the user's view of the building as a collection of spaces or rooms and the engineer's view of it as a collection of technical components and systems.
- Both the spatial and the technical systems are built up by construction parts.
- The spatial systems, technical systems and construction parts are mainly described in the separate catalogue parts of the model.
- The building is a product with external connections. The building belongs to the real estate unit placed in geographical surroundings and the real estate unit has an owner. There are several persons or firms, too, directly linked to the building or the real estate unit.
- The construction parts are put together from different types of resources by different methods.

A complete description of the KBS Model (level 3)

This level-three description is a more detailed one of the entities in the KBS Model and the connections between them. The model is described with EXPRESS-G in figures from 6:11a to 6:11e.

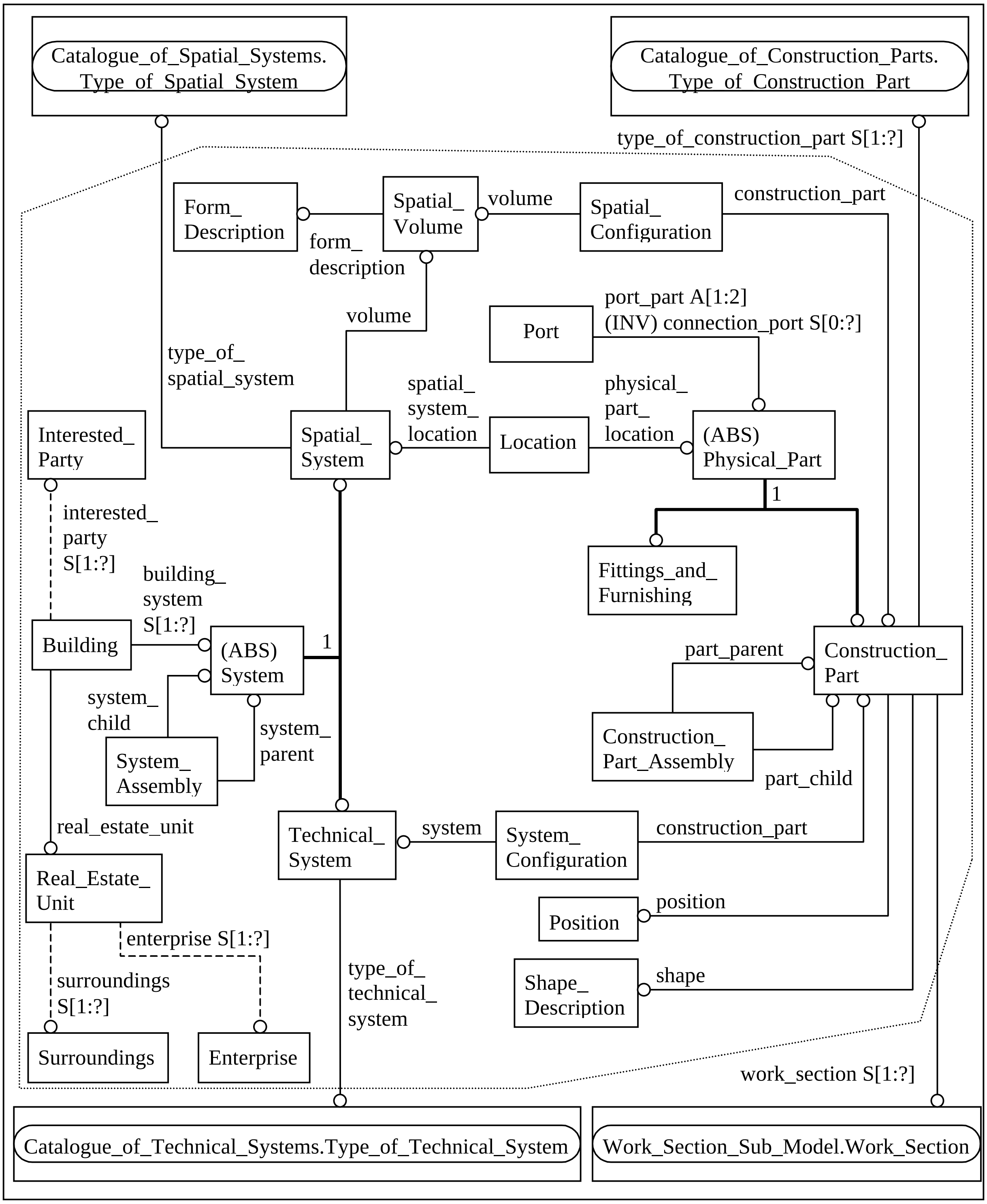

Figure 6:11a The KBS-Core schema

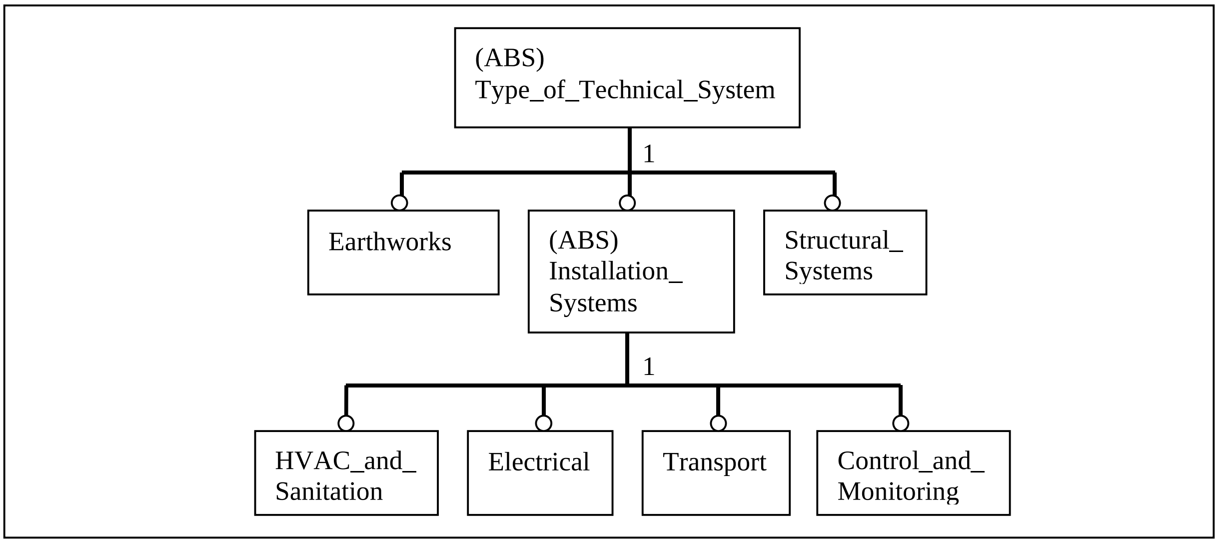

Figure 6:11b The Catalogue-of-Technical-Systems schema

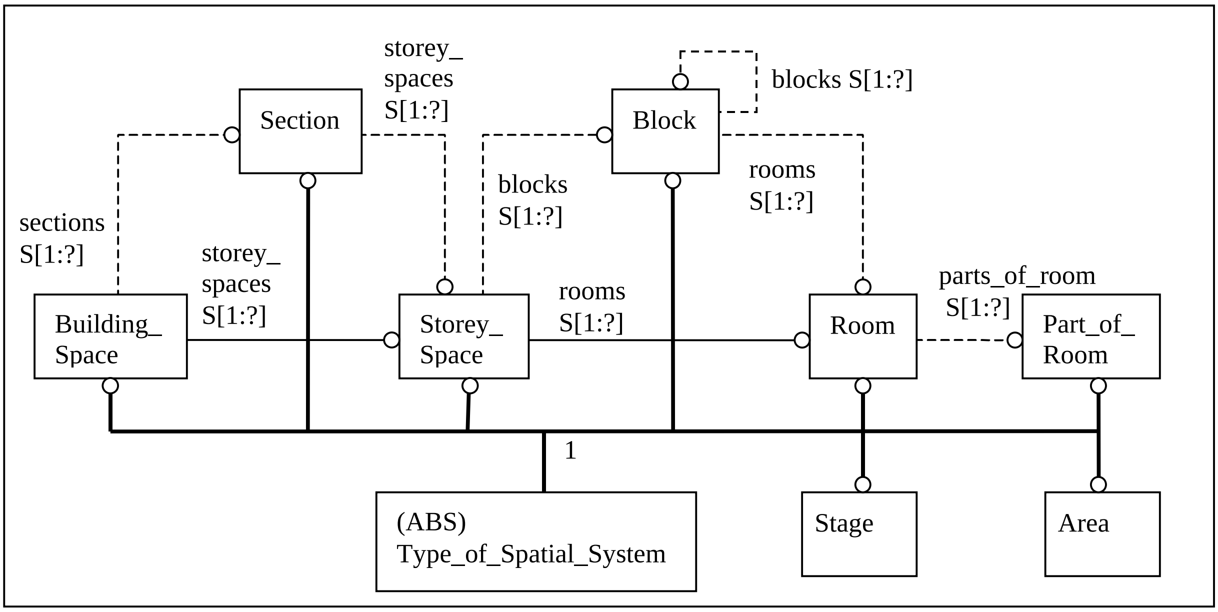

Figure 6:11c The Catalogue-of-Spatial-Systems schema

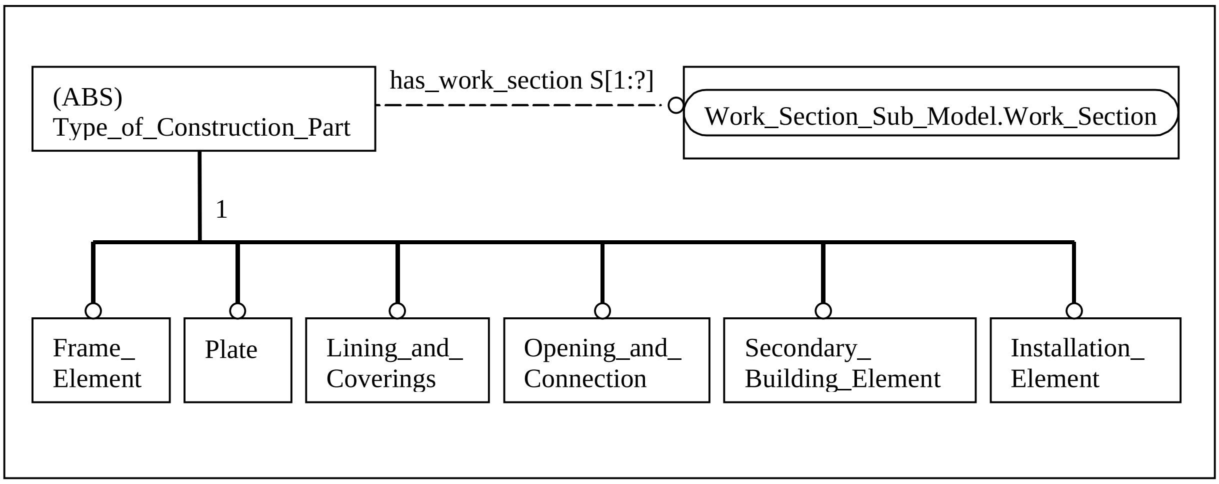

Figure 6:11d The Catalogue-of-Construction- Parts schema

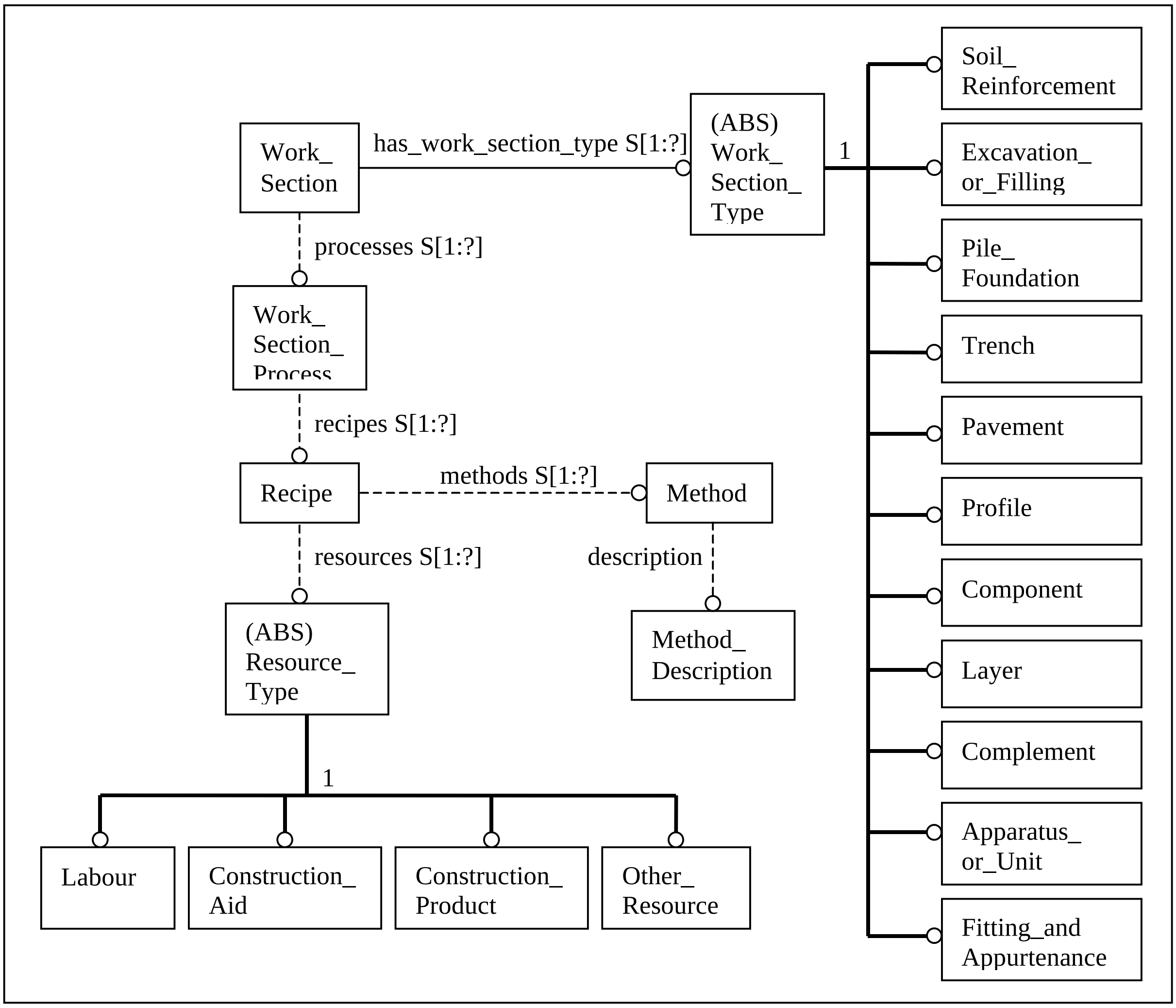

Figure 6:11e The Work-Section-Sub-Model schema

Compared with the level-two description of the KBS Model in figure 6:10, the different catalogue parts are specified in more detail with subclasses for the different catalogue parts. The core part of the model is also described in more detail with a number of relationships entities. A number of classes have been added compared to those described in the schematic version of the model. These are:

KBS Core

- **System assembly** is used to create structures of the type 'contains' or 'is-part-of' for different system classes, for instance subsystems in technical systems or rooms which are part of a floor plan.
- **Form description** handles the implicit geometry description of spaces.
- **Spatial configuration** shows the construction parts e.g. walls, columns and slabs which configure a space.
- **Physical part** is a superclass for construction parts and fittings and furnishing.

- **Fittings and furnishing** means objects in the building that are not part of the building e.g. furniture and computers.
- **Port** handles the connection between different physical parts e.g. a connection between two walls or between a computer and a network.
- **Shape description** handles the implicit geometry description of construction parts.
- **Position** handles the position of the construction parts with X-, Y- and Z-co-ordinates.
- **Construction part assembly** handles structures of the form 'consists of' or 'part of' for different construction parts e. g. a door in a wall.
- **Location** describes in what space a physical part is to be found.
- **System configuration** builds up systems from construction parts.

Catalogue of Technical Systems

- **Type of technical system** is a superclass of the different types in the catalogue of technical systems.
- **Earthworks** is the technical system for earthworks.
- **Installation systems** is an abstract superclass for different types of building services systems.
- **HVAC and sanitation** is a subtype of services systems.
- **Electrical** is a subtype of services systems.
- **Transport** is a subtype of services systems.
- **Control and monitoring** is a subtype of services systems.
- **Structural systems** is the structural and/or enclosing technical systems of a building.

Catalogue of Spatial Systems

- **Type of spatial system** is a superclass for different types of spaces in the catalogue of spaces.
- **Building space** is the collection of all spaces in a building.
- **Section** is the collection of spaces of a mainly vertical subdivision of a building.
- **Storey space** is the collection of all spaces on a floor.
- **Block** is a collection of spaces, for instance the rooms in a flat.
- **Room** is an area or volume within or around buildings (and other facilities), bounded physically and virtually. It normally has a certain function, form and position.
- **Part of room** is some part of a room intended for a certain type of activity or function.
- **Area** is a space/area concept representing a volume/area defined according to a certain rule of measurement, for instance gross area, utility area etc.

- **Stage** is a dynamic geographical position concept which is a temporary spatial system entity e.g. cast section.

Catalogue of Construction Parts

- **Type of construction part** is a superclass of different types of construction parts found in the catalogue of construction parts.
- **Frame element** is a load bearing part both above and below the earth surface, for instance pillars and beams.
- **Plate** is a plane-shaped vertical or horizontal construction, load-bearing as well as non-load-bearing, e.g. interior wall, exterior wall, floor or ceiling.
- **Lining and covering** concerns interior and exterior surface layers on e.g. a wall, ceiling or floor.
- **Opening and connection** concern doors, windows, flaps etc.
- **Secondary building element** is used for complementing foundation, house, room or interior equipment.
- **Installation element** is parts of the building services systems e.g. sanitation units, certain types of white goods and cupboards.

Work Section Sub Model

- **Work section**, one or many physical parts of a facility and the result of a work-section process where resources are put together. Cf. *ISO* [1994]. The work section of the KBS Model corresponds to classes in the P1-table of the BSAB System.
- **Work section type** is a superclass for different types of work sections.
- **Soil reinforcement** is improvement of the ground under the building.
- **Excavation or filling** is the removal of soil or the filling with soil.
- **Pile foundation** is for example sheet piles for the foundation of the building.
- **Trench** is ditch dug in the ground for construction purposes.
- **Pavement** is the hard surface of road, parking place etc.
- **Profile** is a profiled rod normally of metal.
- **Component** is equipment within interior fittings.
- **Layer** is a layer with different purposes e.g. isolating, covering or load bearing.
- **Complement** is complementary equipment inside or outside of building.
- **Apparatus or unit** is an instrument or suchlike.
- **Fitting and appurtenance** is a fixture or suchlike.
- **Work section process** is the activities to create work sections with the help of a method and resources according to a recipe. Compare with “production activity” in *ISO* [1994].
- **Recipe** lists the resources used/needed by a method.
- **Method** lists the different methods useful for a certain work section process.

- **Method description** describes how an activity is carried out.
- **Resources type** is a superclass to the classes labour, construction aid, construction product and other resources. Resource is an item provided to assist in the construction process.
- **Labour** includes both manual and intellectual work.
- **Construction aid** means different objects used as aids in the construction/erection work.
- **Construction product** is something used in the construction/erection work which is incorporated in the construction.
- **Other resource** could be e.g. energy and information.

In the schema above the modelling of geometry is not really described in detail. A method was chosen in the major prototype implementation of the KBS Model - the Blandaren prototype - and is described in connection with the presentation of the prototype in chapter 7.

Finally, it should be emphasised that the descriptions of the KBS Model on levels 1, 2 and 3 are not exactly the same in the sense of the earlier ones being direct subsets of the third level schema. The differences are a result of the fact that the two lower are abstractions of the final description on the third level.

6.6 Attributes of the Entities in the KBS Model

Attribute types

Three types of attributes are defined in the KBS Model; individual, group and index attributes. They are defined as follows:

- **Individual attribute** - is one whose value must be defined or enumerated separately for every instance of the entity.
- **Group attribute -** is one whose value is the same for two or more instances of the same entity, and which is described somewhere outside these instances, for example in a catalogue.
- **Index attribute** - is one containing the address of an attribute list where these attributes can in turn either be individual or group attributes. The address of this list constitutes the value of the index attribute. Among the group attributes too, there may be index attributes which point further to an attribute list etc. See also figure 6:12. The index attribute may point to sets of attributes describing geometry, the AMA-recipe, surface treatment etc. The names of the index attributes vary and depend on how they are used in the actual project.

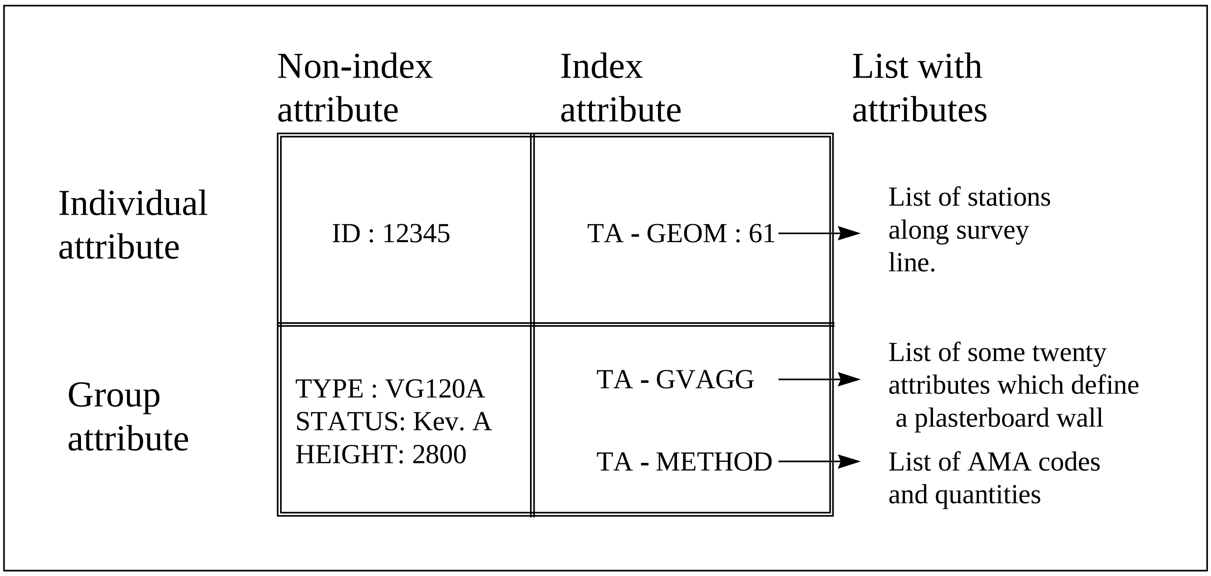

Figure 6:12 Relationship between the attribute types of the KBS Model

The individual attributes are related to the occurrence level of the specification hierarchy described in section 6.4 above. The group attributes can be found on all four levels (occurrence, specific, type and generic) of the specification hierarchy.

Classification of attributes

The individual, group and index attributes can be sorted into different classes depending on their information content. In figure 6:13 such a grouping is described schematically.

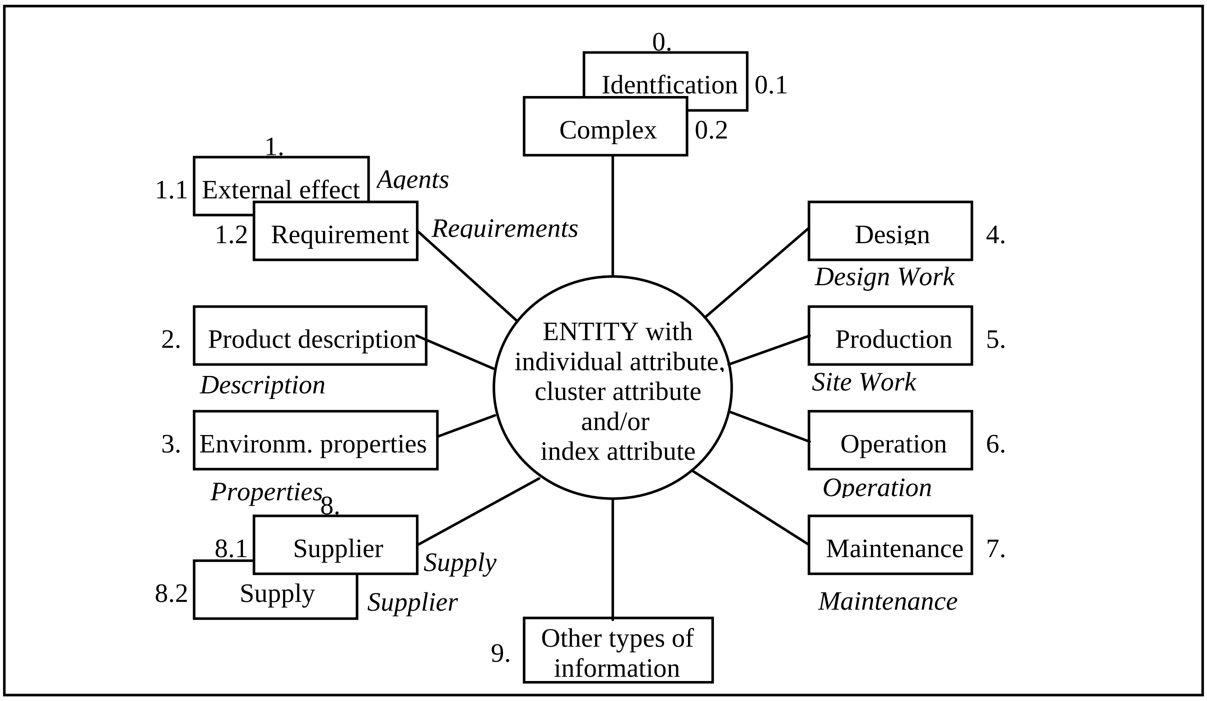

Figure 6:13 Attribute classification according to the CIB Master List. The headings of the CIB Master list are shown in italics.

The principal headings in the classification have mainly been taken from 1983 CIB Master List [*CIB*, 1983]. The classification of attributes according to figure 6:13 was used in the KBS Model project. The main classes were supplemented by subheadings. A more detailed description of the type of attributes found under each of the main classes of figure 6:13 is given in a table in Appendix 4a. The classes proposed in the CIB Master List are written in brackets.

Attributes for a given building product model entity were in the KBS Model project [*Svensson et al.* 1990] to some extent set out in tables structured according to figure 6:14.

In the layout schematically described in the figure above, the management of different attributes can be described during the whole life-cycle of a given building product entity. A similar type of accounting of attributes is also described in *Karhu* [1997]. An example of an attribute table for the entity "French window" (with BSAB code 355.2) is given in Appendix 4b, structured in accordance with the layout in figure 6:14.

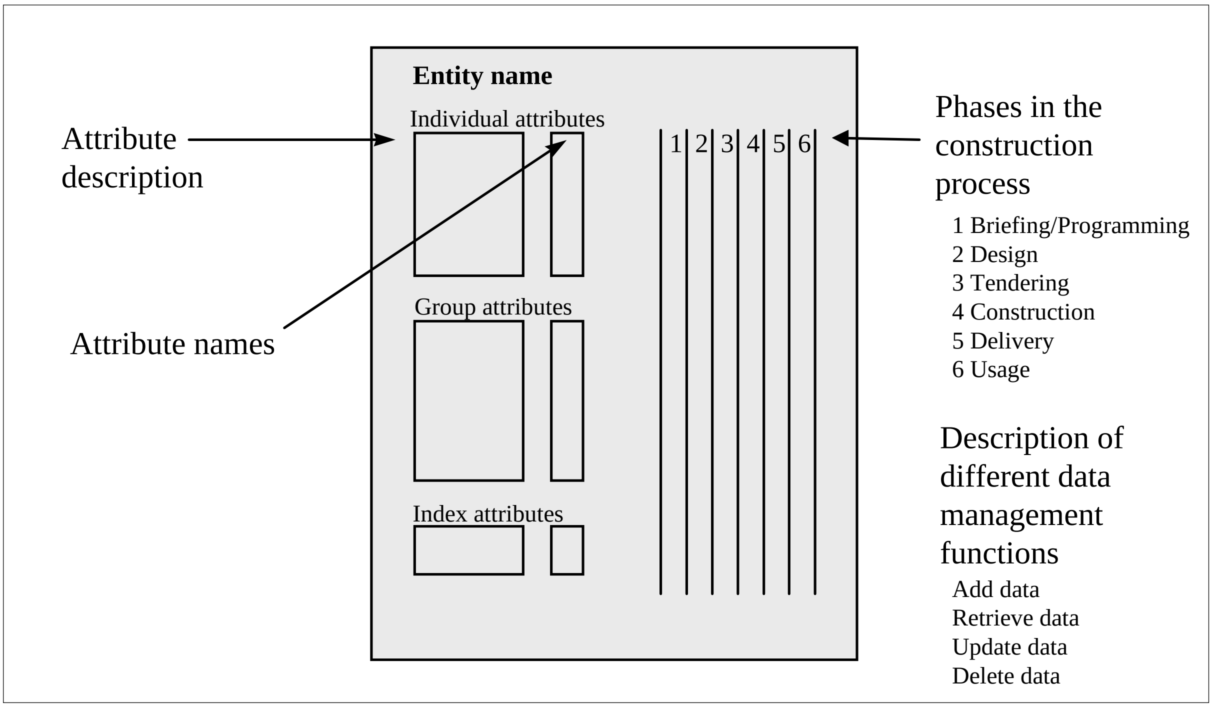

*Figure 6:14 Layout used for the presentation of attributes concerning a specific entity of the KBS Model [*Svensson et al.*, 1990]*

7 The Three Prototypes

Introduction

The information structures of the KBS Model were to a varying degree tested in three separate prototypes. Initially, this chapter gives an overall description of the scope, objective, and context of each of the prototype projects. In the following parts of the chapter, each prototype is subsequently described. This description and associated discussion will mostly be restricted to one aspect of the prototype work only, as to what parts of the KBS Model were tested in the different prototypes and to the results and conclusion of this testing. The three prototype projects were all carried out at the National Board of Public Building henceforth just called the Board.

7.1 Scope, Objective and Context of each Prototype

The **scope** of the prototype is defined as the area or range of FM-activities being supported. The scope is normally very much echoed by the title of the work. The **objective** of the prototype describes what the prototyping specifically aimed at achieving. It is important to remember that each of prototypes in addition to testing the KBS model had other individual objectives. The **context** includes a description of other aspects of the prototype work such as the participants in the prototype work, available software platforms, use of external programmers, the case material used, timetable, location of the work etc.

The Klara prototype

Scope

The scope of the Klara prototype was *operation and maintenance* of facilities. It handles the different types of operation and maintenance functions carried out in a typical FM district. Examples of functions are management of energy-, electricity- and water-consumption, operation, and preventive as well as repair maintenance. The system handles information about tenants, spaces and technical systems.

Objective

One objective of the Klara prototype system was to develop *an object-oriented system structure utilising entities of the KBS Model*. Another objective was to *fulfil a number of strategic requirements* emanating from observed shortcomings in earlier systems for similar purposes. Examples of such shortcomings were:

- weak co-ordination in FM work with the tenants,

- focusing on the preservation of condition of the services systems rather than securing their functioning,
- lack of computer support for different sorts of analysis in the information systems for FM and
- weak integration in and between different systems.

Another objective with the system was to, as far as possible, *utilise existing hardware platforms* and *information from existing database tables*.

Context
The prototype was developed in close co-operation with the people working at the property management district called Klara. This district is situated in central Stockholm and consisted at the time of the prototype work of 20 buildings, mainly office buildings for the Swedish government. The prototype project begun in the autumn of 1990 and consisted of a prestudy and three stages, as described in figure 7:1.

The hardware platform was the existing local area client server network with Macintosh PCs and complemented with a more powerful fileserver. The main software used in the prototype project was the database development and management system called 4th Dimension. Most of the implementation work was done by a consultant while the other project work was carried out by the members in the project team coming from the National Board of Public Building.

The Blandaren prototype

Scope
The scope of the Blandaren prototype consisted of central *management of FM information* and information retrieval *for* five different downstream *applications needing information from the central repository*. These were:

- indoor-climate calculation
- management of a tenancy agreement
- a small refurbishment typical for the usage phase of a building
- creating an operation card
- scheduling of maintenance

Objectives
The major objective was to *concretise* and *test the information structure* of the KBS Model. An additional objective was to *evaluate the use of the BSAB classification system as a starting point for a national BPM development*. The prototype also aimed at *demonstrating some basic ideas of BPM-based information*

systems both for the construction sector (the end-user of this type of information systems) and the system developers (the IT industry). In order to achieve this one additional objective was to develop a general purpose user interface to building product models.

Context

Information about an existing office building in Linköping (kv Blandaren) was used as a test case for this prototype. The initial prototype was implemented on a workstation using the UNIX operating system. The intention was originally to move the system into a PC-based environment, but due to lack of resources this was never done.

The system design was carried out jointly by the members of the project team consisting of people from mainly two consultant companies and persons from the National Board of Public Building. The system implementation was done by the Digital Equipment subsidiary in Sweden.

The Kronoberg prototype

Scope

The scope of the Kronoberg prototype was all sorts of *information used in daily work by FM managers*. The prototype aimed at *integrating a number of existing software applications, utilising existing databases, combining information from existing drawings and non-graphical documents*.

Objectives

The most important objective of the Kronoberg prototype was to create *a fully integrated* information system that could be *easily used by facilities managers*, and *even outside their office*. In order to achieve this one of the objectives was to make use and test the structure of the KBS Model. A particular objective of this prototype was to implement the system *in a PC environment* (at that time a novelty for the organisation in question).

Context

The Kronoberg prototype was implemented at the property management district called Kronoberg. An inventory was made of the information needed for the every day management of one specific building (a factory building rebuilt into an office block). The information was mainly paper-based and was converted into a digital format before being processed by the computer-based prototype system.

The IT platform used was a PC, or actually a pen-computer, to make the system easier to handle in the field. The system had an MS Windows-based software platform supplemented with three program modules:

- an editor of raster and vector graphics (“RasterEdit”)
- a tool for integrating scanned drawings with relational databases and measuring tools (“InfoRaster”)
- a hyper media tool for connecting documents with each other and with information in underlying relational databases (“HyperDoc”)

The implementation work was done by same company that had developed the three program modules mentioned above. The requirement of the system was set by facilities management professionals at the National Board of Public Building.

7.2 Timetables, Comparison and Descriptions of the Three Prototypes

The prototype work was done during a period of roughly five years. Most of it was done in parallel with the development of the KBS Model itself. The three prototypes were started and finished at different times. Figure 7:1 shows the duration of the three prototype projects as well as of the theoretical work involved in developing the KBS Model.

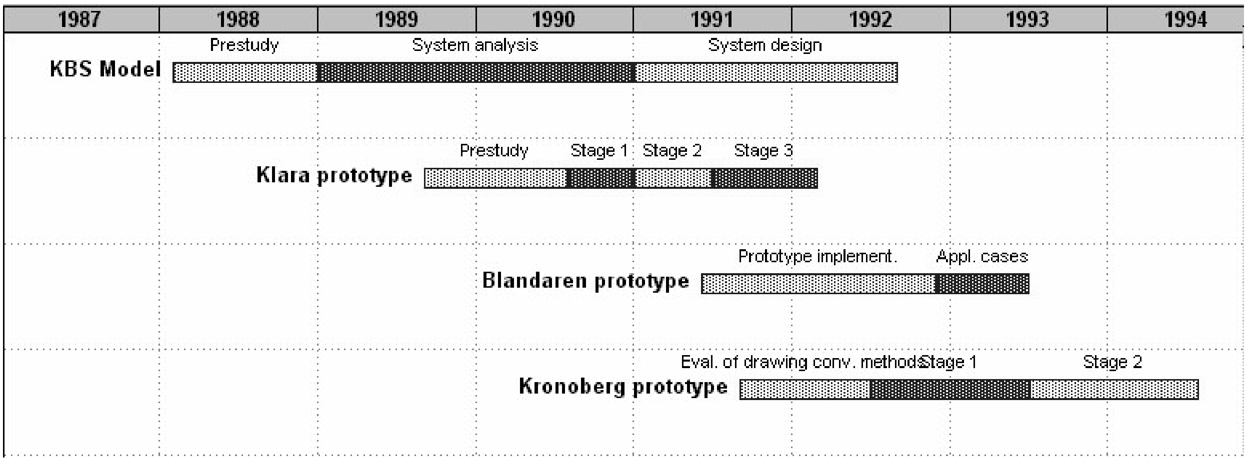

Figure 7:1 Overview timetable of the conceptual modelling and the prototype work

A way of describing the three prototypes is by comparing their information scope which is done in the matrix in figure 7:2. On the Y-axis is the degree of granulation (degree of detail) of the information and on the X-axis the extent of the information. The degree of granulation corresponds roughly to the number of object classes implemented in a particular prototype. The extent is interpreted as narrow if the information is only concerned with the building definition and wide if also other types of FM information (rental contracts, fault announcements etc.) are included. The result is that each of the three prototypes is quite different concerning the information scope.

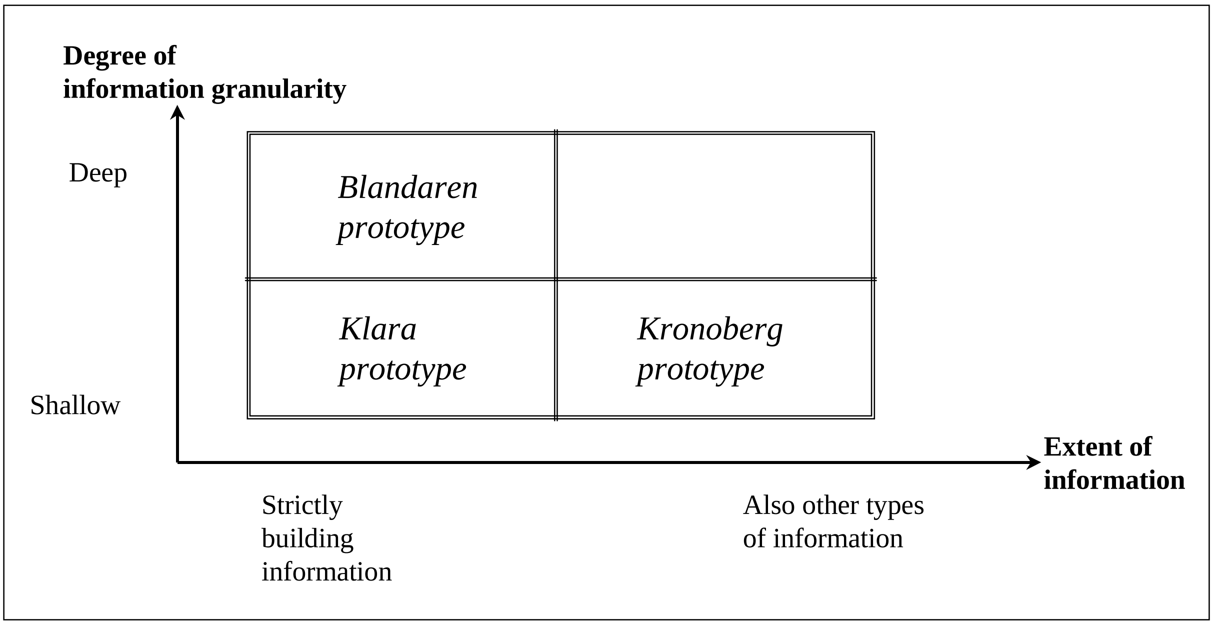

Figure 7:2 An overview of the differences in information scope of the three prototypes

The prototype work was carried out as detached projects, where a number of persons from industry were involved. Different existing reports (mainly in Swedish) describing the prototype work were utilised as a basis when writing this chapter. These sources are acknowledged in Appendix 1, as are the persons primarily involved in the prototype projects.

In the following the discussion will mainly be restricted to one aspect of the prototype work only, to what parts of the KBS-model were tested in the different prototypes and to the results and conclusions of this testing.

The prototype descriptions are illustrated partly through screen dumps. Unfortunately, most of the text in the screen dumps is in Swedish, but translated versions of some of these are to be found in Appendix 7.

7.3 Testing of the KBS Model in the Klara Prototype

The prototype work

The main objective of this prototype system was to develop a system for operations and maintenance that uses the entity lists of the KBS Model. This meant that almost all of the information handled should be tied to entities taken from the entity lists in the KBS Model. An important type of entity in the prototype system is functional unit. It denotes a building entity which performs a specific function that it is possible to control. Most of these functional units could be found in the KBS lists.

The prototype system was linked to certain existing FM systems already in use such as ones for control and regulation, lease management and budget/cost accounting. These were not previously integrated. As far as possible, the prototype system aimed at including existing database tables. The integration aimed at is schematically described in figure 7:3.

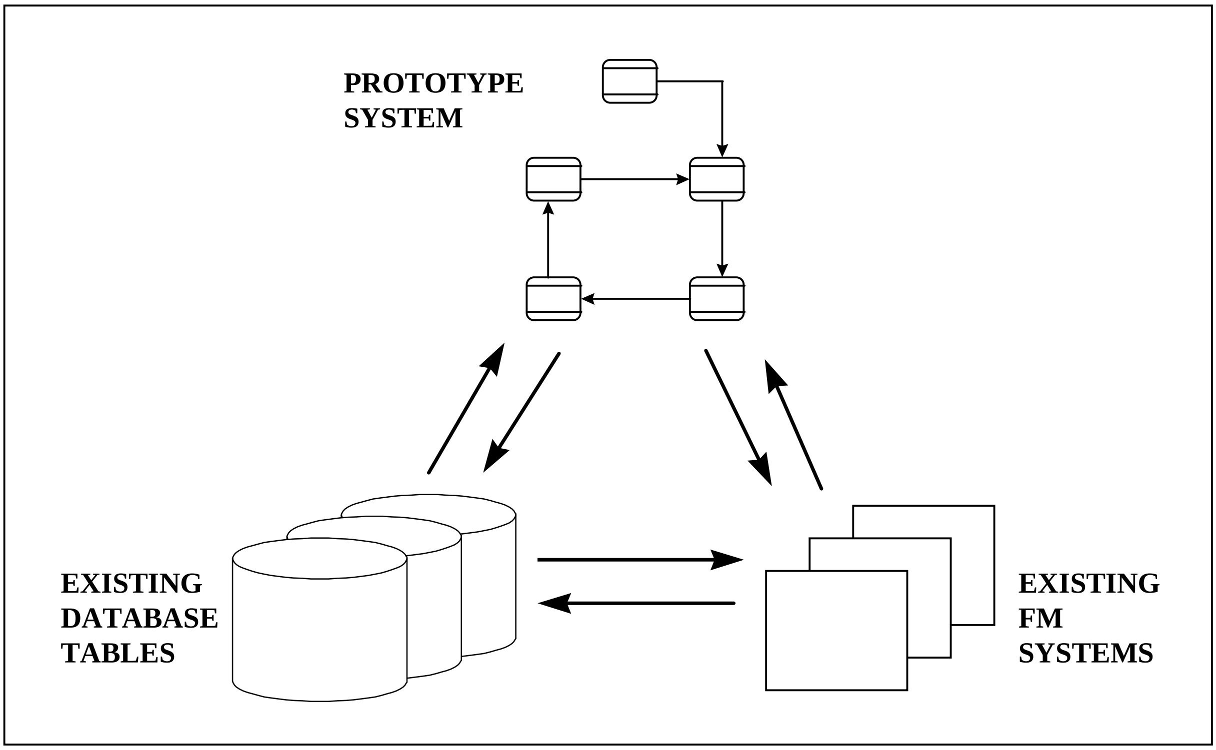

Figure 7:3 The overall context of the Klara prototype system

An overview of the Klara prototype project is probably best provided by the process model for the operation and maintenance work developed and used in the prototype system. This process is described in the schematic data flow diagram (DFD) in figure 7:4. A description of the DFD technique is given in [*Avison and Fitzgerald*, 1988].

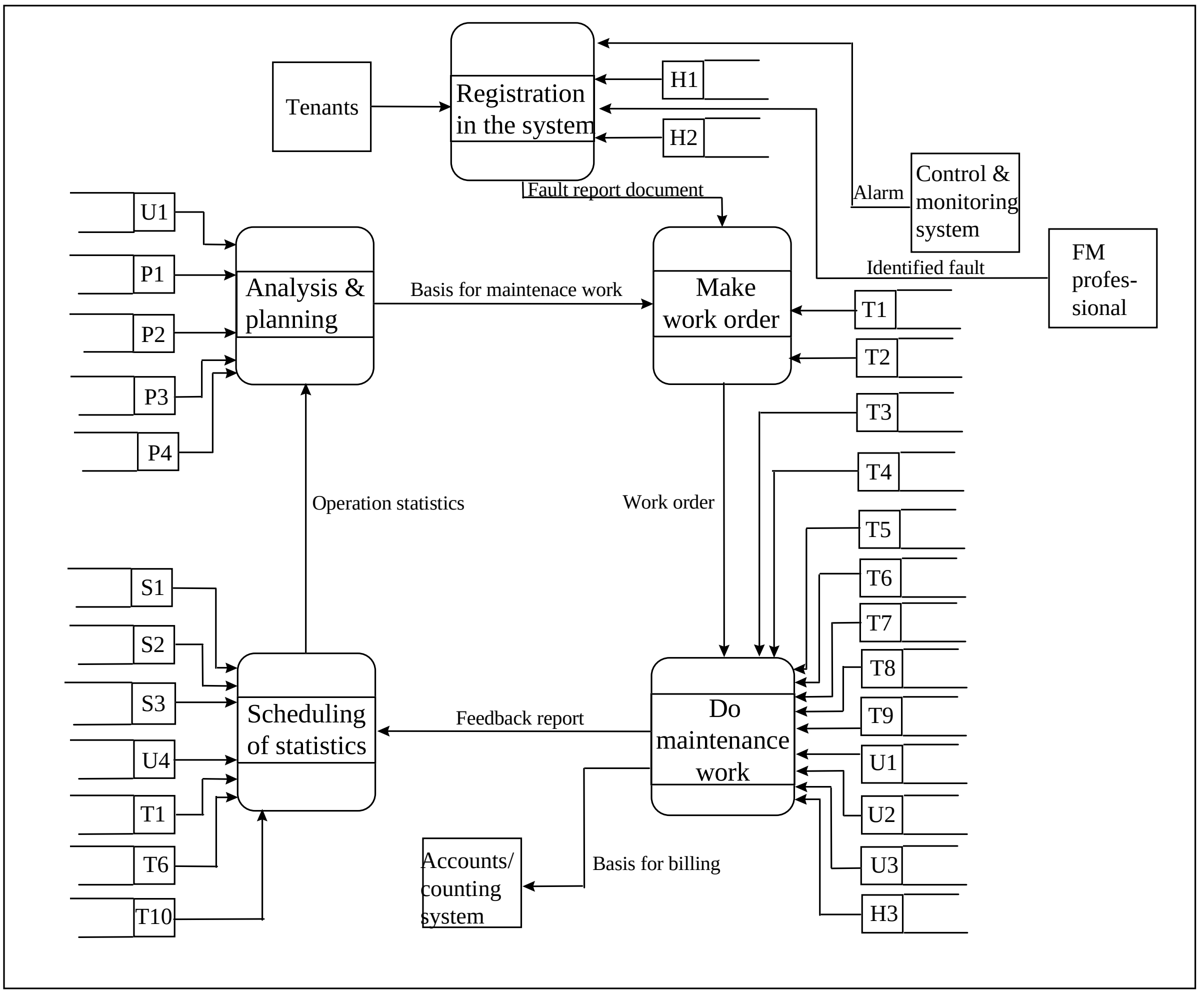

Figure 7:4 Data flow diagram for the operation and maintenance process of the Klara prototype

The DFD is composed of four elements. The data flow which is represented by an arrow, depicts the fact that some data is moving from one process to another. The processes or tasks, represented by soft boxes in figure 7:4 above, transform the data flow either by changing the structure of the data or by generating new information from the data. A process must have at least one data flow coming into it and at least one leaving it. Except for another process, there are two more possibilities where the incoming data flows come from or end. The first is a data store and the second a sink or a source. The data store is a data repository (computerised or manual) and the symbol of this is a pair of parallel lines with one end closed and a compartment for a reference code plus a compartment for the name of the store. Sinks and sources are often termed external entities and normally they represent entities outside the system. Sinks and sources are both represented by the same symbol, a rectangle.

The data stores that are indicated by reference codes in the data flow diagram above, are listed in table 7:1.

Table 7:1 Important information in the Klara prototype

Product information	Technical information	T1 Room - service system
		T2 Technical system
		T3 Site layout
		T4 Key process chart
		T5 Adjusted operation card
		T6 Room/space
		T7 BSAB code
		T8 Function
		T9 Functional unit
		T10 Enthalpy
	Statistical information	S1 Tenant enquiry
		S2 Energy consumption
		S3 Operation statistics
	Tenant information	H1 Tenant
		H2 Contacting person
		H3 Rental agreement
Process information	Planning information	P1 Aim and requirement
		P2 Operation budget
		P3 Status record
		P4 Energy budget
	Maintenance information	U1 Working instruction for preventive maintenance
		U2 Checklist for preventive maintenance
		U3 Fault code
		U4 Measures code

At the time when the Klara prototype work started the KBS Model was not yet fully specified. The database structure was consequently developed in parallel with the KBS Model. The hierarchies described in section 5.3 and the lists of entities partly described in Appendix 2 were however available and were used as a starting point. Another starting point for the database structure was, as mentioned above, existing database tables and their data structures. The development of the schema was facilitated by the fact that the existing database tables were structured according to the classes of the BSAB tables which also have provided the backbone of the entity list in the KBS Model.

The main structure of the database implemented in the Klara prototype is schematically described in figure 7:5.

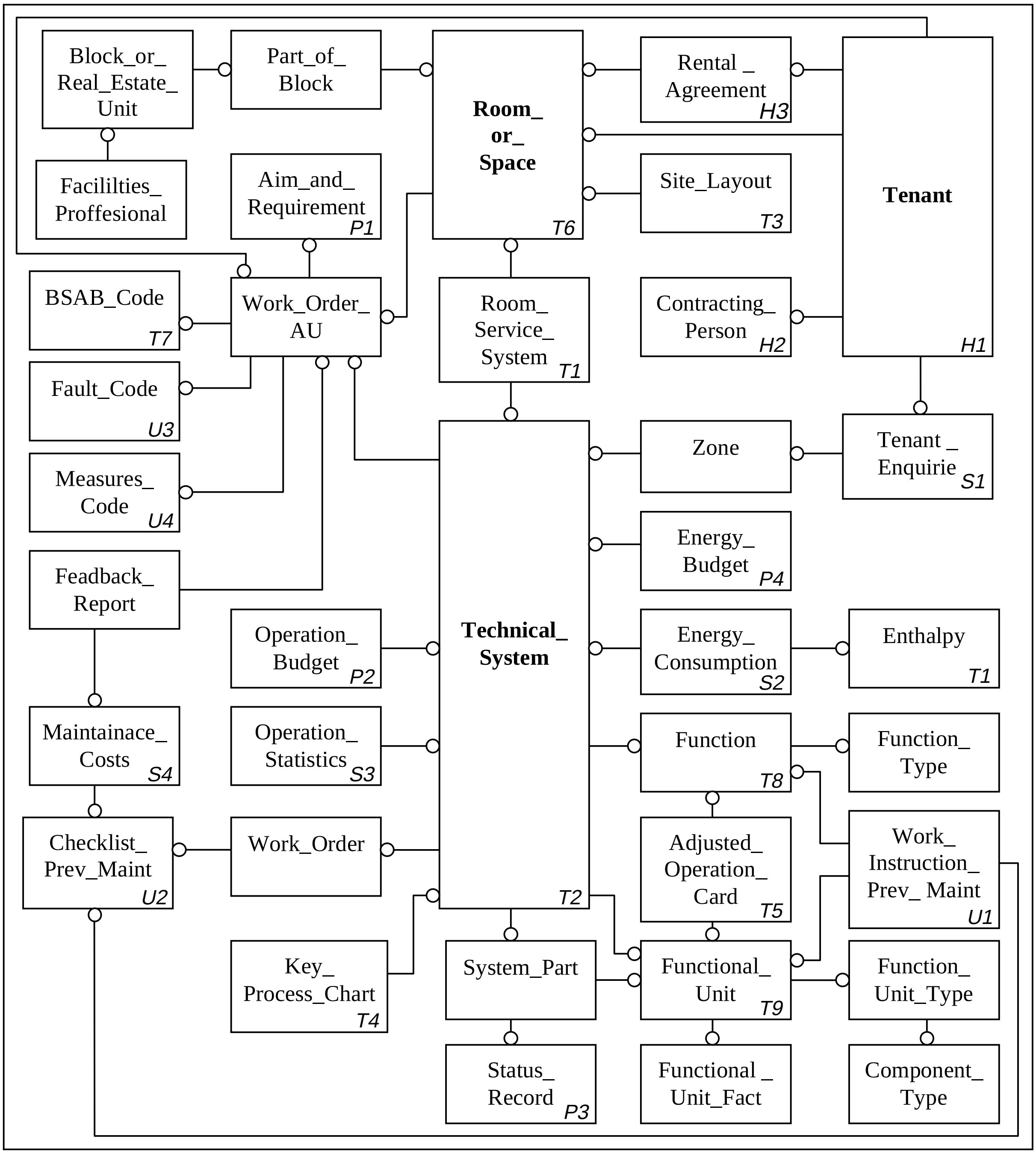

Figure 7:5. Description of the schema of the implemented database in the Klara project

Attribute names and cardinalities are omitted from the model description which means that the figure mainly shows the major entities used in the database structure and their relationships. The three most important entities of the model are ‘technical_system’, ‘room_or_space’ and ‘tenant’ and they together form a core of the model/structure. The ‘technical_system’ represents the technical view of the building while the ‘room_or_space’ entity represents the spatial view of the building.

The feeding of information into the system was done in a semi-automatic manner. Information already stored in the existing database tables was transferred into the database system of the prototype automatically. Examples of such information are the attributes room area, room height and room code. An example of additional room information which did not exist in any data bases is the type of room (taken from the classification developed in the KBS model project) and which sort of installation system was serving the specific room. This additional information had to be fed into the system manually. The total number of data items stored in the data base of the prototype system could be estimated to be roughly 150000.

The system was implemented on existing hardware - a network with Macintosh PCs. The prototype system was implemented on the following technical platform (table 7:2):

Table 7:2 The technical platform of the Klara prototype

Type of system component	***System component description***
Hardware	Macintosh PCs with minimum 2MB internal memory, connected in a network.
Operating system	System 7 for Macintosh PCs
Software	Database manager: 4th Dimension, ver. 2 Spreadsheet: 4D Calc Word processing: Write Diagram presentation: Graph 3D OO drawing editor: 4D Draw

The discussions/prestudy of the prototype project started in the early autumn of 1989 and in the late autumn a project team within the National Board of Public Building was established. During the spring of 1990 a project description was gradually developed together with a time schedule. The actual prototype work was divided into three stages:

- Stage 1 established the infrastructure of the system and the ‘registration of fault announcements’ and ‘make work order’ parts implemented.
- Stage 2 meant that the bulk part of the system was developed and established.
- In stage 3 the relationship with working instructions for operation and maintenance was incorporated into the system.

Each stage was followed by evaluation and reporting of the work carried out in the stage. The prototype work was carried out partly by internal personal and partly by consultants. The major part of the programming work was done by the consulting company Malus System AB while the bulk of the feeding of data into the system was done by staff from the Board. The system analysis work was done in co-operation between staff from the Board and the consultant.

The system review and testing was done by letting the ordinary staff use the system in their ordinary daily work. First the system was used in parallel with the existing solutions but later and gradually it was used without back-up from earlier established solutions. After evaluation of stage 1, all fault announcements as from 1st of January of the year in question were registered in the system, as a full scale test of the system.

One of the stages of the work flow in the application is the generation of a work feedback report after some measures have been performed based on a fault report. This report is very important because it is central for providing later feedback information which can be utilised for a more thorough analysis of the operation and maintenance work and for cost optimisation. The common information structure for the generation and long-term storage of the report is provided by a number of object classes of the KBS Model.

The following data is recorded for feedback. Those posts marked with an asterisk are saved as statistical data, see the paragraph below.

Data always recorded:

- code for tenants*
- category of maintenance work*
- system code, type and class according to the KBS Model*
- cost of materials*
- measurement text (later completed with measurement code).

Remaining data transferred in relevant cases:

- time and date of notification of defect
- time and date of data feedback*
- organisation unit
- block and block part*
- cost of work for own employees or contractors*
- text about measurement taken (later supplemented with measurement code).

An example of a complete work report is shown in figure 7:6 below.

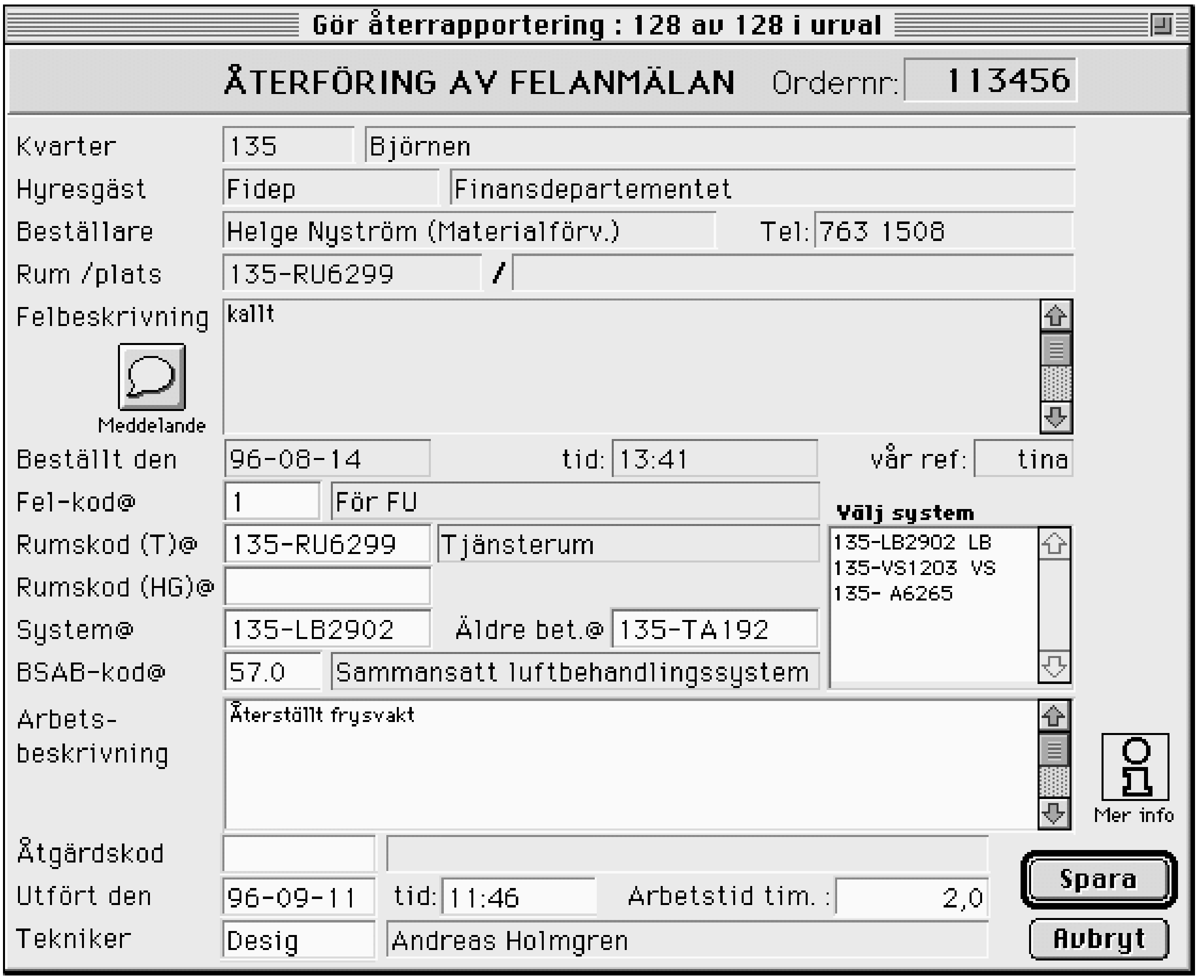

Figure 7:6 A work report generated by the Klara system

Later on data from the work order is transferred to a specific statistical file for follow-up and analysis. The costs for work done can be totalled for alternative periods (year, season, month and week). The statistics also include figures showing media consumption cost per system class and per class type according to the KBS Model.

The costs of breakdown maintenance, preventive maintenance and media consumption (water and energy of different sorts) can be analysed by dividing them among different buildings, different system classes and system types in the specific building. The costs can be related to rooms served and room volumes and to climate values for the specific period. This makes it possible to calculate different key values automatically. The results of the analysis are presented as tables or in graphical form (curves or staple diagrams) in analysis reports, as in figure 7:7.

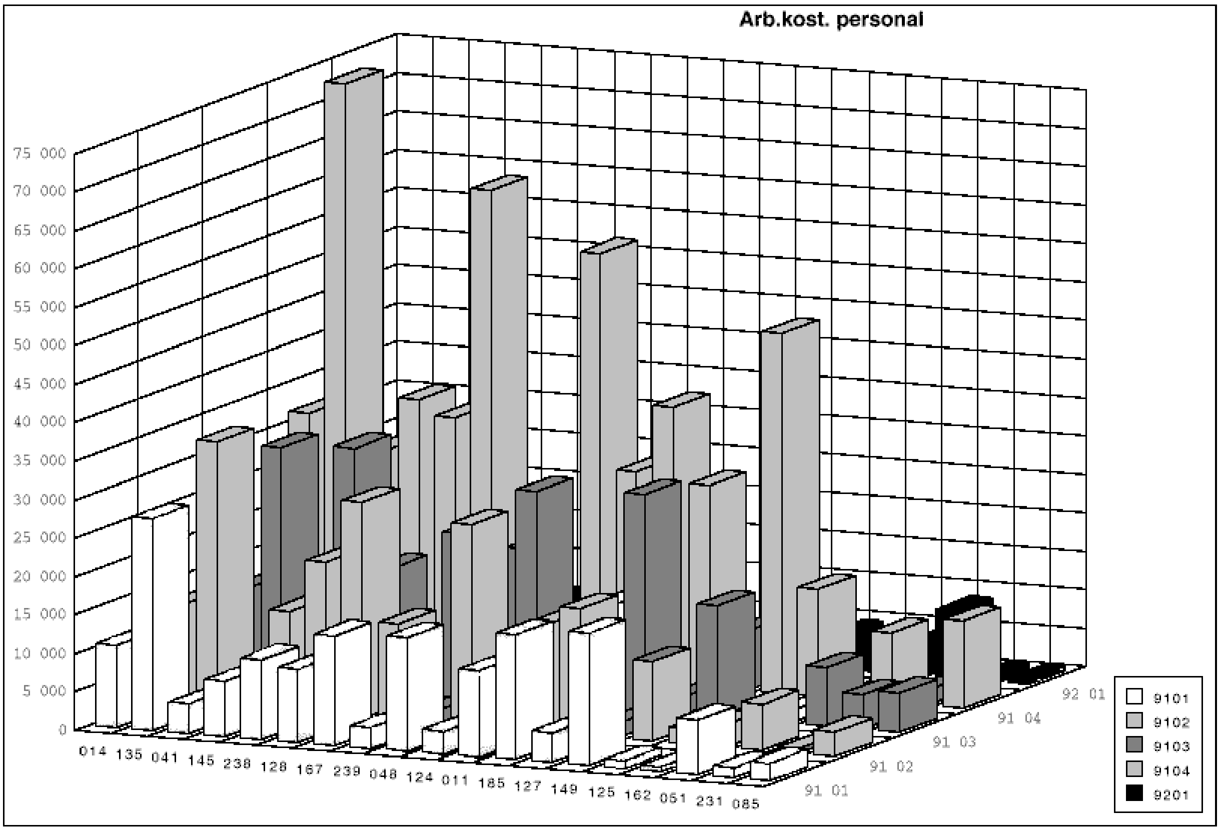

Figure 7:7 Example of analysis presentation in graphical form

Conclusions from the Klara prototype

- The overall conclusion from this prototype was that a number of central classes in the KBS Model provided the necessary support for integrating applications for day-to-day management and long-term planning of operation and maintenance.
- It also provided evidence that the process model for this type of work, discussed in chapter 3, offers support for better work flow management.
- It was possible to base the object-oriented information structure of the system more or less totally on the classes of the KBS Model.
- It was possible to integrate existing database tables into the system due to the fact that the backbone of both the existing tables and the information structure of the prototype system were the classes of the BSAB System.
- Working, existing FM systems could be linked to the prototype system.
- As-built drawings and other important FM documents could constitute integrated parts of the prototype system.
- Graphical elements/construction parts in the drawings were directly linked to information in the database of the prototype system.
- The prototype system contains tools and methodologies for generating feedback on the tenant's core business and on operation and maintenance cost. This feedback is fundamental for the analysis and evaluation of the FM work.

7.4 Testing of the KBS Model in the Blandaren Prototype

The prototype work

The overall aim of the prototype project was to develop a database system structured according to the KBS Model. Objectives were to concretise and test the structure of the model and demonstrate both to the construction sector (the end-users of these information systems) and the system developers (the IT industry) the idea of a neutral building product model.

The original intention was that the prototype system should include a central building product model implemented in a data base system and integrated with five applications using data from the building product model as input (figure 7:8). Five cases were chosen so that together they could give a representative illustration of how the building product model information could be used specifically in facilities management work. The aim was to study the following five applications:

- indoor-climate calculation
- management of a tenancy agreement
- computer-aided design of a small refurbishment
- creation of an operation card
- scheduling of maintenance

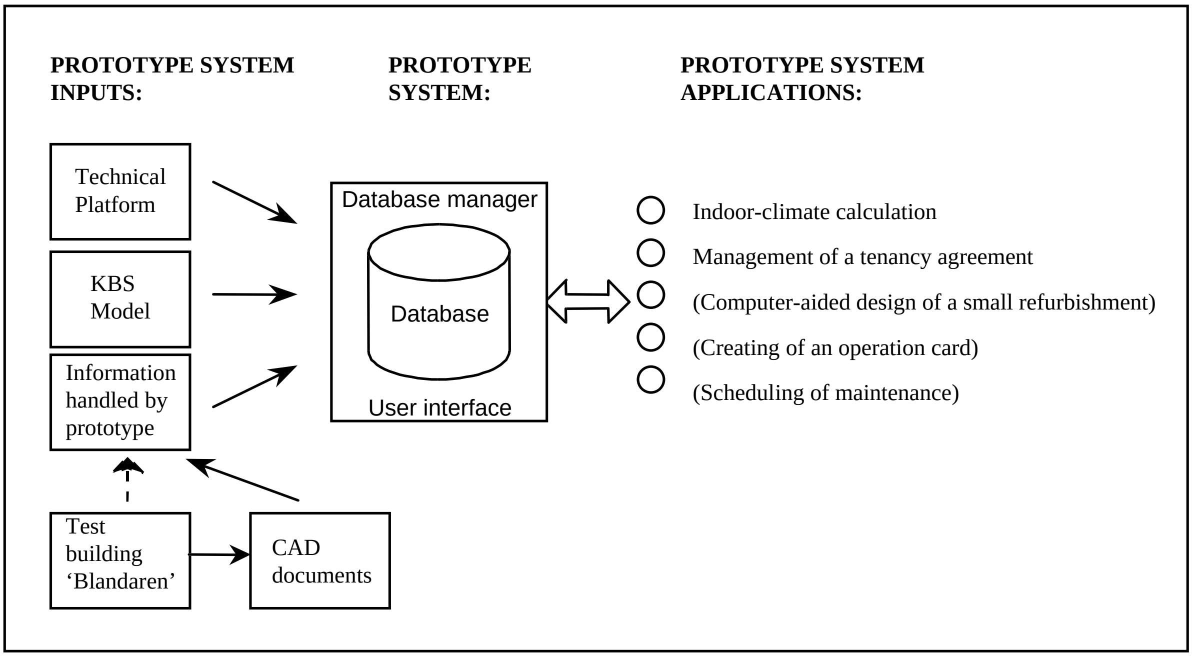

Figure 7:8 Overall description of the Blandaren prototype

A general user interface suitable for handling the information in the database was developed. Application models and specific user interfaces were developed for two applications: ‘indoor-climate calculation’ and ‘management of a tenancy agreement’. For the application ‘small refurbishment’ the redesign was done using the CAD-systems MEDUSA-Build and Installation-MEDUSA.

In implementing the prototype, a partial model of the KBS Model was used. A planned second implementation which would have extended the implemented schema could not be carried out due to lack of resources. The schema is described in figures 7:9a and 7:9b below.

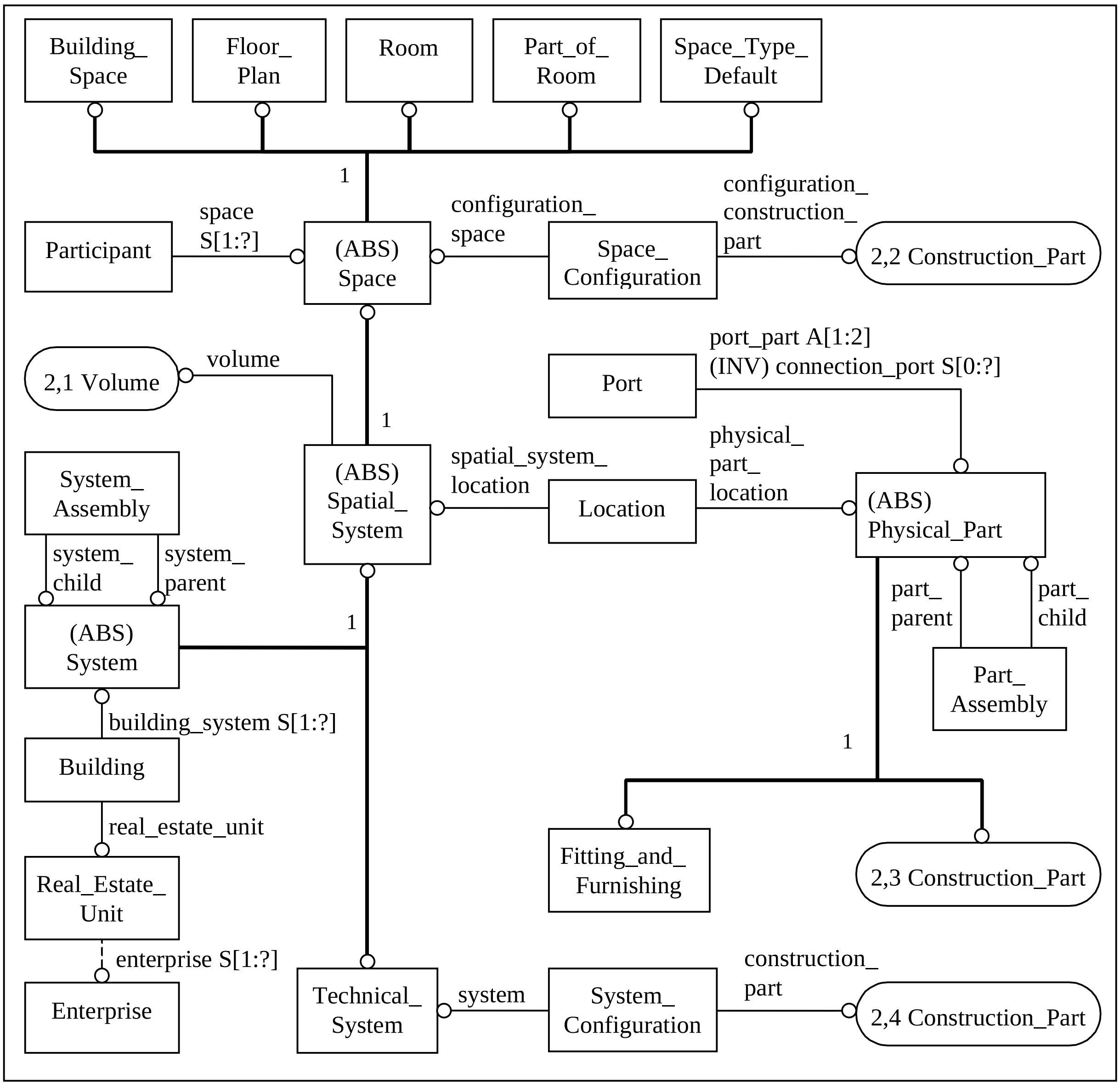

Figure 7:9a Schema implemented in the Blandaren prototype, diagram 1

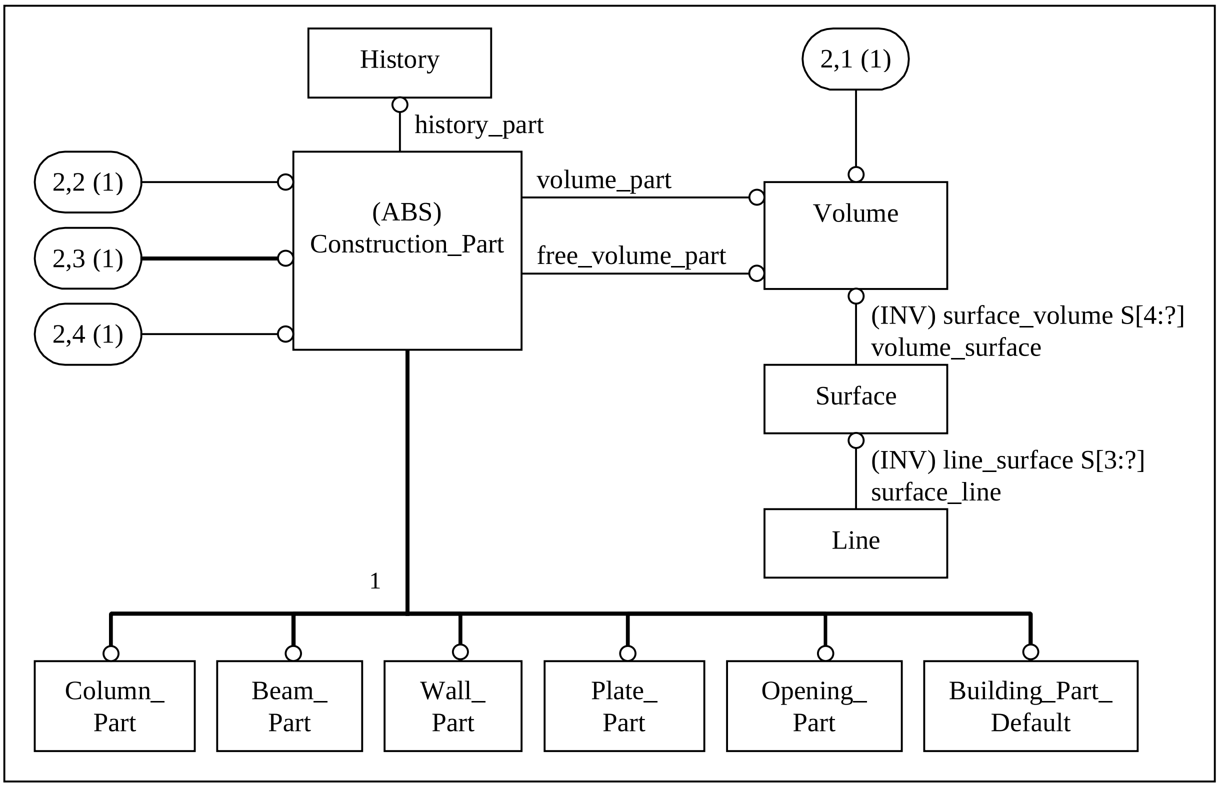

Figure 7:9b Schema implemented in the Blandaren prototype, diagram 2

There are minor differences between the partial model implemented and the corresponding part of the complete KBS Model described in chapter 5. Two examples of these minor differences are different subtyping of spaces and construction parts. The reason for this is that the way to model this was still discussed when the implementation work started.

Additional entities compared with the KBS Model described in figures 6:11a to 6:11e of chapter 6, are described below.

- **Participant** is a physical or legal person linked to a space.
- **Catalogue Reference** is an abstract class containing data and methods that are common to all catalogue classes. The catalogue reference also constitutes a connection between the catalogue description of a building part and its instantiation.
- **History** is a class handling information from the creation of an entity, e.g. the reference line of a wall or the reference point of a symbol.

An explicit geometry-modelling part is provided in the implemented model. Basically, this submodel contains three classes; **volume**, **surface** and **line**. The model means that a surface delimits a volume and that a line delimits one or two surfaces and, in the other direction, that a surface is described by three (a triangle) or more (other types of plane surfaces) lines and a volume consists of four (a tetrahedron) or more (other types of volumes that consists of plane surface elements) surfaces.

In an application the methods of the object classes of the BPM must be described in a programming language. These methods are not directly specified in the EXPRESS-schema of the KBS Model, which thus only gives a part of what is to be implemented. Neither is it clear from the EXPRESS-schema , what level of ambition the implementation must contain. Information required because of this was added to the model through C++ programming at the time of implementation.

All development was carried out in an UNIX-environment consisting of workstations with a central disc server and an object-oriented database supplied by Digital. All program code was written in the programming language C++. User interfaces were generated by the CASE tool Visual Basic. The developed user interfaces did not have any automatic connection with the database of the prototype system. In summary, the Blandaren prototype system was implemented on the following technical platform (table 7:3):

Table 7:3 The technical platform of the Blandaren platform

Type of system component	***System component description***	
Hardware	Workstations DEC 2100 and DEC 3100 with a central disc server	
Operating system	UNIX-environment	
Software	Database manager: Standard tools: CASE-tool:	DECOODB from Objectivity Inc Make and Imake Visual Basic (on PC)

The aim of the data import was to fill up the database with appropriate data about the test building in the prototype project. An office building in Linköping (pictured in figure 7:10 below) was chosen, among other reasons because it had been designed throughout with CAD. The architects, constructors, electric system designers and HVAC designers all used different CAD system applications founded on the general CAD system MEDUSA.

Figure 7:10 The test building of the Blandaren prototype

In the prototype project, the data was imported using a physical file structure according to the STEP standard Part 21. This requires a conceptual model described with EXPRESS.

Importing data would be relatively straightforward if the originating system would have the same schema as the BPM. This is, however, usually not the case if the data comes from a CAD-system. In particular spaces will be missing altogether and will have to be generated either by automated algoritms or manually.

The schema used for data input is described with EXPRESS-G in figure 7:11 below. The schema was gradually developed in earlier projects carried out before and outside the research work of this thesis. The two most important projects for this development was the MCAD project [*Paulsson et al.*, 1990] and the CAD/OPEN project [*Svensson et al*., 1990]. The schema is also quite similar to the NICC model [*Tarandi et al.*, 1994], developed in the NICC project carried out at the same time as the KBS Model development work and partly with the same people involved.

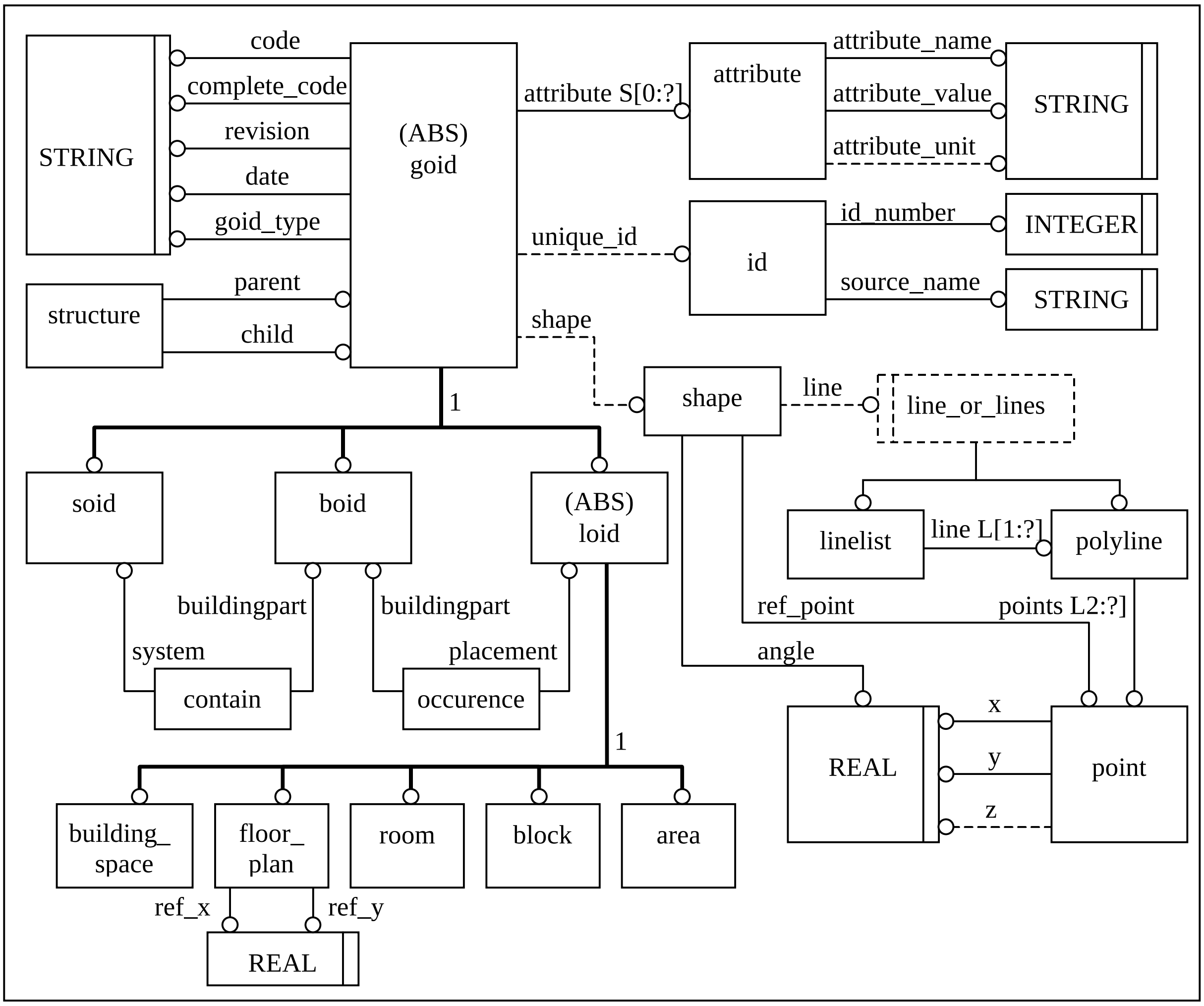

Figure 7:11 Data import schema used in the Blandaren prototype

The classes of the import schema are described as follows:

- **Boid** (construction part entity) handles both building construction entities and service systems entities on the construction part level.
- **Loid** (spatial entity) represents both spaces and locations.
- **Soid** (system entity) represents building construction entities and service systems entities on the system level.
- **Goid** (generic building entity) is an abstract super class for boid, loid and soid and handles common data of the three subclasses.
- **Occurrence** (space configuration) relates boids (construction parts) to loids (spatial entities).
- **Contain** (system configuration) relates boids (construction parts) to soids (systems).
- **Structure** handles structures of goids (boids, loids and/or soids).
- **Attribute** is a class that handles the generic description of an attribute with name, value and optionally with unit.
- **Point** handles the x-, y- and z-co-ordinates of a point. The z-co-ordinate is optional.

- **Shape** handles, on the one hand, the implicit description of certain building entities with a line with at least two points, and on the other hand, the description of the position of certain building entities with one point and a rotation.
- **Id** handles the identification of boids, loids and soids with an integer and a character string. The character string could represent a drawing number or a layer number.
- **Polyline** handles a polyline described by points.
- **Linelist** is a number of polylines.

The schema above implies that construction parts are classified according to the BSAB system and are described with positions in space and dimensions for certain parts. From the CAD files, information could be transferred for the following BSAB-classes:

BSAB Code:	**Class Name:**
Building elements:	
3310	load-bearing internal wall
3320	column
3330	load-bearing external wall
3510	infill panel (not load-bearing external wall)
3551	window
3630	not load-bearing internal wall
3651	internal window
3652	door
HVAC elements:	
5700	central equipment
5740	ductwork
5750	pipework
5780	local HVAC equipment
Electrical elements:	
6050	wiring system
6080	local electrical equipment

The attributes transferred are differed for each class. As an example the construction class door has the following attributes:

Attribute:	**Meaning:**
type	BSAB-class name
height	height of the door
width	width of the door
surfdist	distance from wall rib to the door
level	height over reference level of door
framethick	frame thickness of door
hanging	hanging of door
with-a	partial width of double door

Figure 7:12 below shows an example of a physical file (structured according to the STEP physical file syntax) used in the prototype project.

The exchange model gives possibilities of transferring room descriptions, but this was not possible in the prototype project because of the properties of the CAD system (MEDUSA) used. This system does not handle room objects. Neither is there any data about how walls are connected with one another. The information transferred essentially described a number of building entities. In order to make the information complete the receiving system consequently generated the rooms from a number of construction parts that together constitute the room.

```
STEP;
HEADER;
FILE_NAME('151.step',
'19930413',
('falk'),
('Cascade'),
'STEP VERSION2');
ENDSEC;
DATA;
#1 = building('D100', 'Förvaltningsbyggnad'.', n, ', '19930413', $, $, $, $);
#2 = plane('0200', 'Del 3', '.n.', '19930413', $, $, $, $, 18800., 3600.);
#3 = structure(#1, #2);
#4 = attribute('height', '3200.', $);
#5 = attribute('thickness', '120', 5);
#6 = goid('3630', '363.99', '.n.', '            ', $, (#4, #5));
#7 = point(27950., 13690., 0. );
#8 = point(28210, , 13690., 0.);
#9 = point(28210., 13430., 0.);
#10 = polyline((#7, #8, #9));
#11 = shape(#10, #7, 0.0);
#12 = id(35297, 's.151');
#13 = boid(#6, #12, #11);
#14 = occurrence(#13, #2);
#15 = attribute('height', '3200.', $);
#16 = attribute('thickness', '320', $);
#17 = goid('3630', '363.99', '.n.', '            ', $, (#15, #16));
#18 = point(33450., 33490., 0.);
#19 = point(28270., 13490., 0.);
#20 = polyline((#18, #19));
#21 = shape(#20, #18, 0.0);
#22 = id(35275, 's.151');
#23 = boid(#17, #22, #21);
#24 = occurrence(#23, #2);
#25 = attribute('surfdist', '0', $);
#26 = attribute('width', '910', $);
#27 = attribute('level', '0', $);
#28 = attribute('height', '2300', $);
#29 = attribute(framethick' , '120', $);
#30 = attribute('hanging', 'R', $);
#31 = goid('3652', '365.201', '.n.', '            ', (#25, #26, #27, #28, #29, #30));
#32 = point(28640., 13430., 0.);
#33 = shape($, #32, 0.0);
#34 = id(35281, 's.151');
#35 = boid(#31, #34,  #33);
#36 = structure(#23, #35);
#37 = occurrence(#35, #2);
```

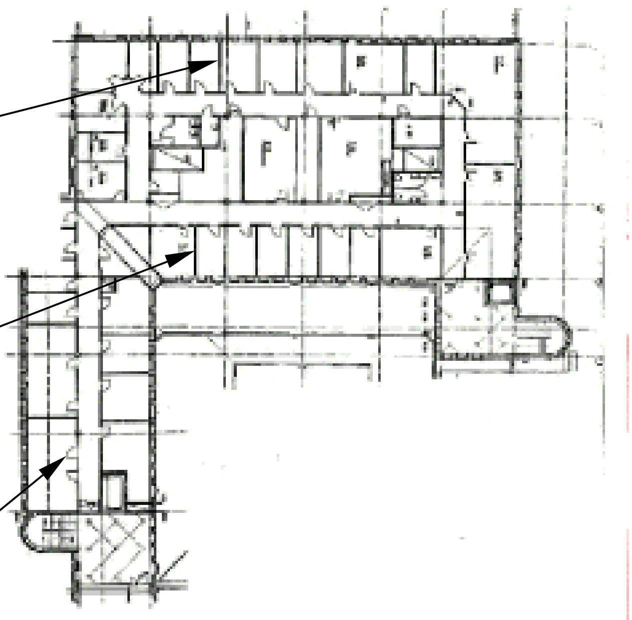

Figure 7:12 Part of a physical file used in the prototype project

In the Blandaren prototype each application consists of a model (the part actually manipulating data) and a user interface, as can be seen in figure 7:13. The user interface is the end-user's tool to handle the information in the database system. Via the interface, the end-user can navigate in the model, change it, activate methods and applications and store information in the model. Changes in the model can be made by the user on several different levels: attributes, objects, catalogues and applications.

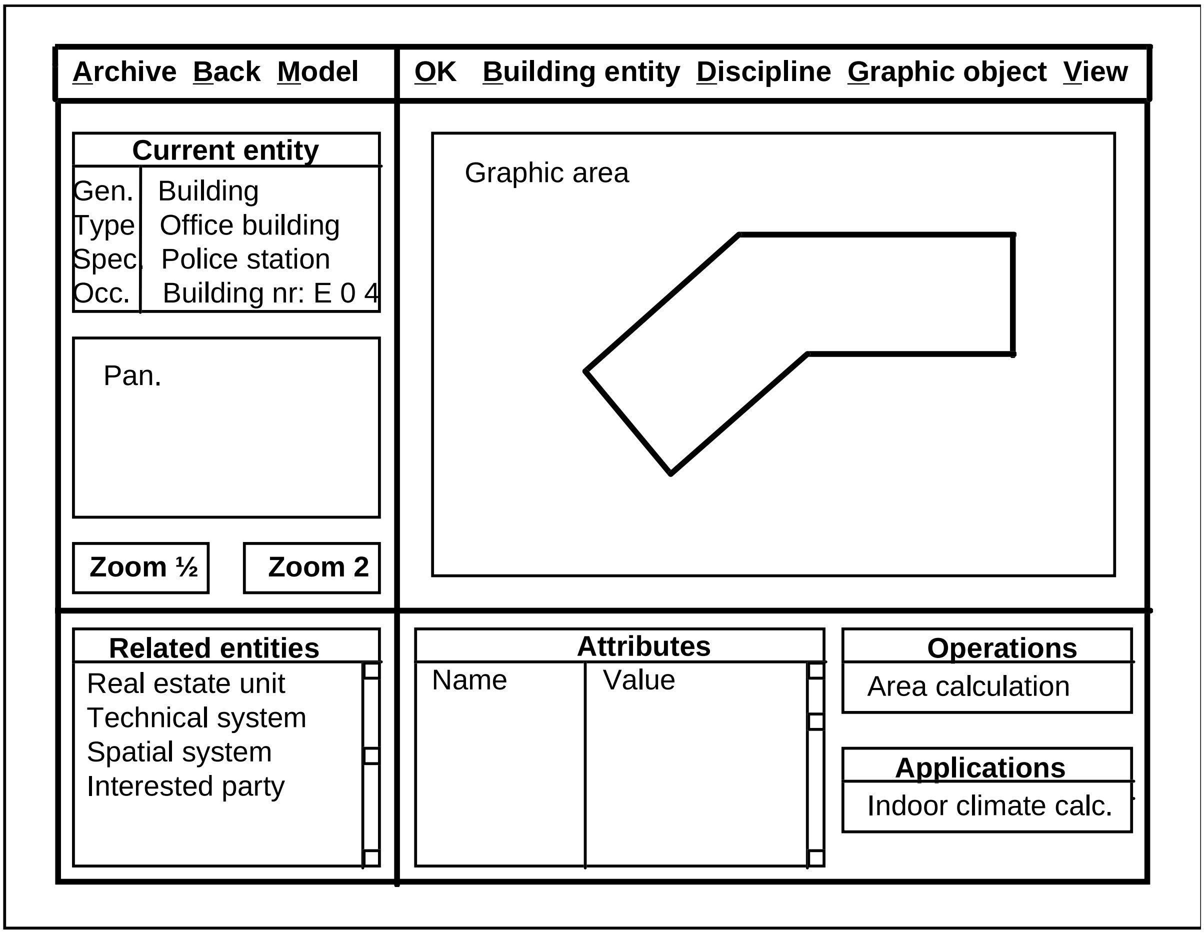

Figure7:13 The principal layout of the user interface in the Blandaren prototype

Navigation in the model is done by transfer between different objects, in a way which resembles hyperlinks in web pages. Every object class has relationships with several other object classes. Thus there are several possibilities of going from one object to several other objects in the model. From a certain given object it is possible to navigate further either with the help of the list of related objects, or by establishing an object type and marking it in the graphic area.

From the user interface it is possible to view different entities in the database. Important components of the interface are lists of entities, attributes and related objects, a graphical area for drawings and pull-down menus allowing selections of what information is shown (i.e. by discipline, drawing view, types of building elements). An example of a particular user-interface is shown in figure 7:14.

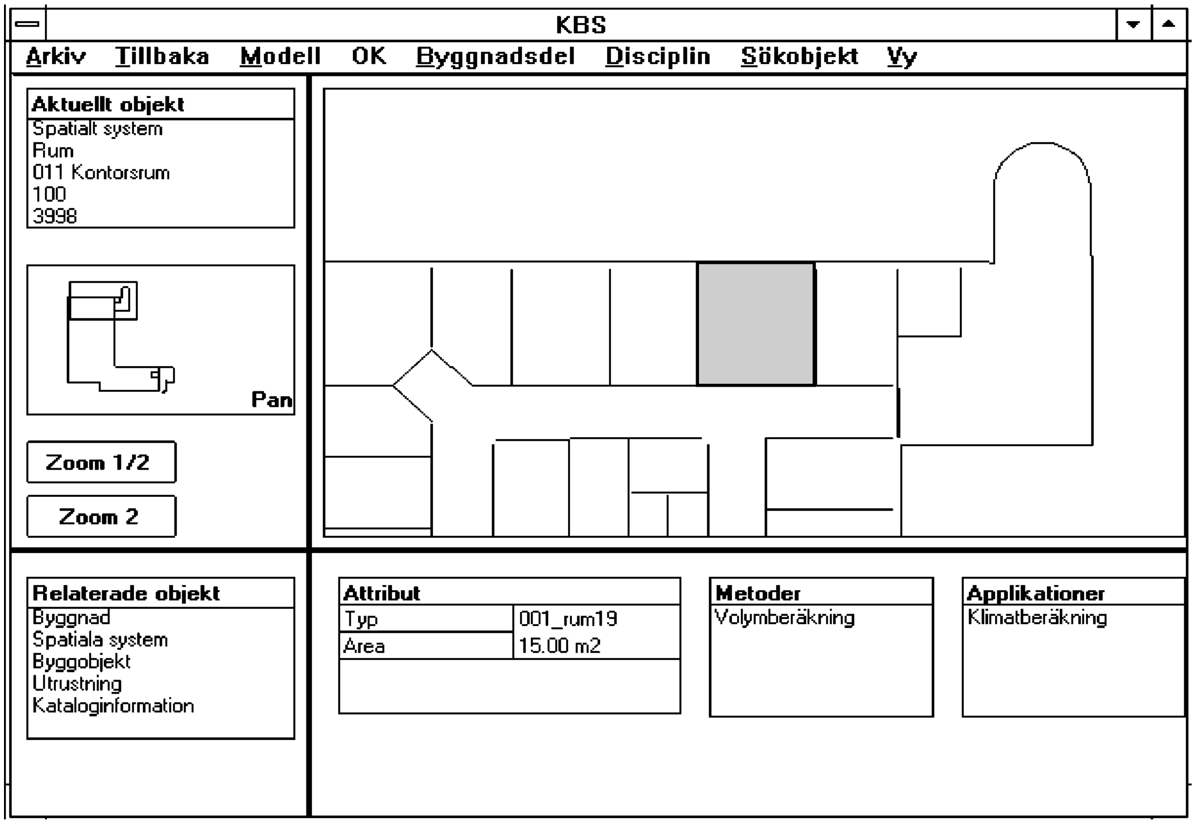

Figure 7:14 The screen display for the entity room, including related entities

Three-dimensional viewing of entities

Figure 7:15 shows an example from the prototype of a three-dimensional description of floor-level 5 in the middle of the specific building.

Of the planned five applications the 'indoor-climate calculation' was the only one that was fully completed. The 'management of tenancy agreement' and 'small refurbishment' were partly implemented. That not all of the five cases were completely implemented was mainly due not to technical problems but lack of financial resources and disturbing organisational changes in the organisations involved in the prototype work.[11]

[11] The National Board of Public Building was reorganised, which meant that it was divided into a number of smaller organisations, most of which became companies. The company involved in the prototype implementations (Digital Equipment) was also reorganised during the same period and a number of persons involved in the prototype work left and founded a new company (EuroSTEP).

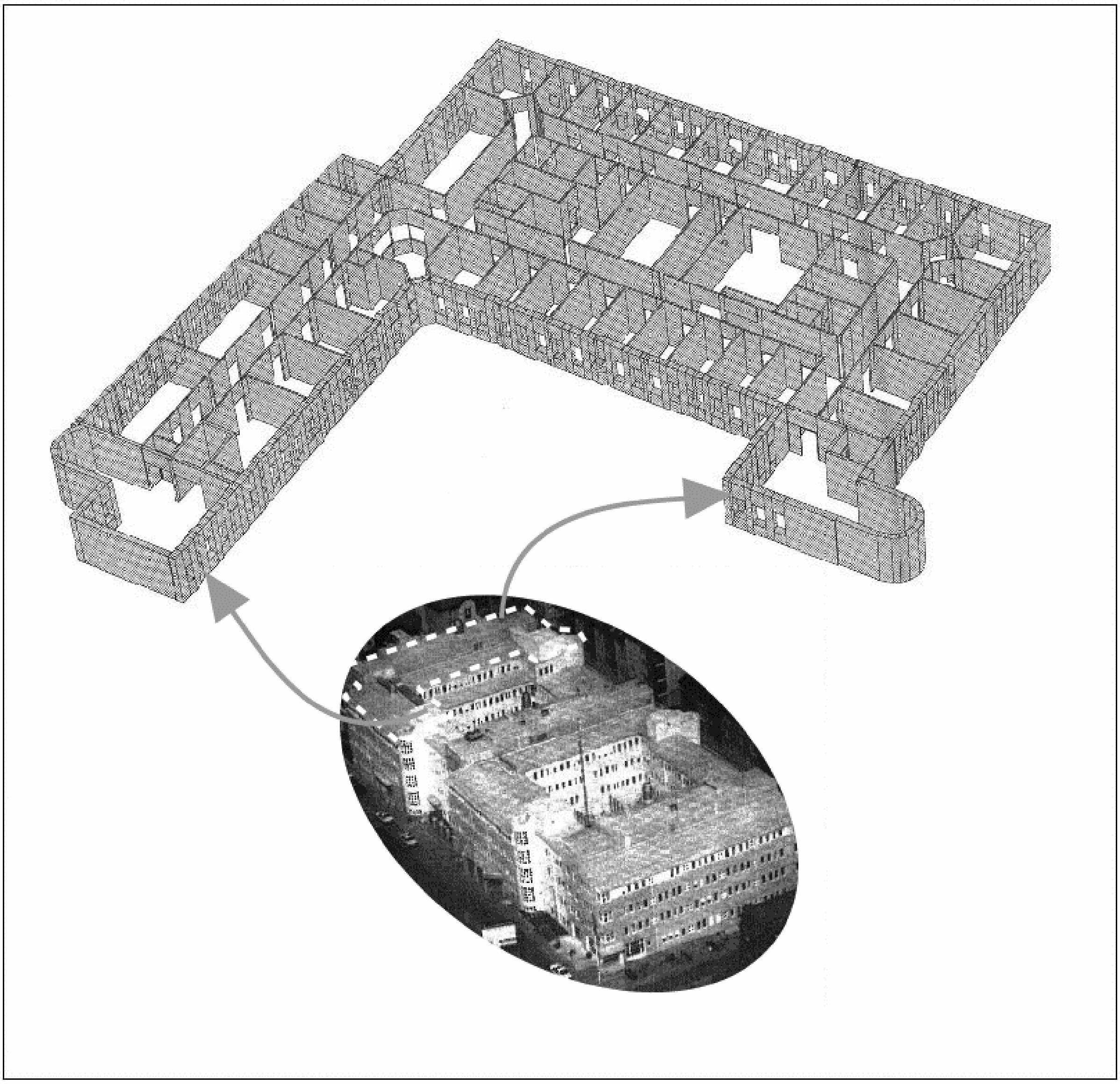

Figure 7:15 Three-dimensional description of specific floor plan of the case building 'kv Blandaren'

Figure 7:16 shows the application schema developed for the indoor-climate calculation and simulation. This schema is the basis for calculating the required exchange of air in a room in order to achieve a comfortable indoor climate. In the schema the room is a central entity because the climate calculation is for a certain room in the building. A number of entities with different quantitative and qualitative attributes, e.g. roof, floor, walls, are connected to the room. In the room, there are equipment and persons influencing the indoor climate. To be able to do the calculation one must also have data on the building in which the room is located e.g. its location and the climatic conditions there.

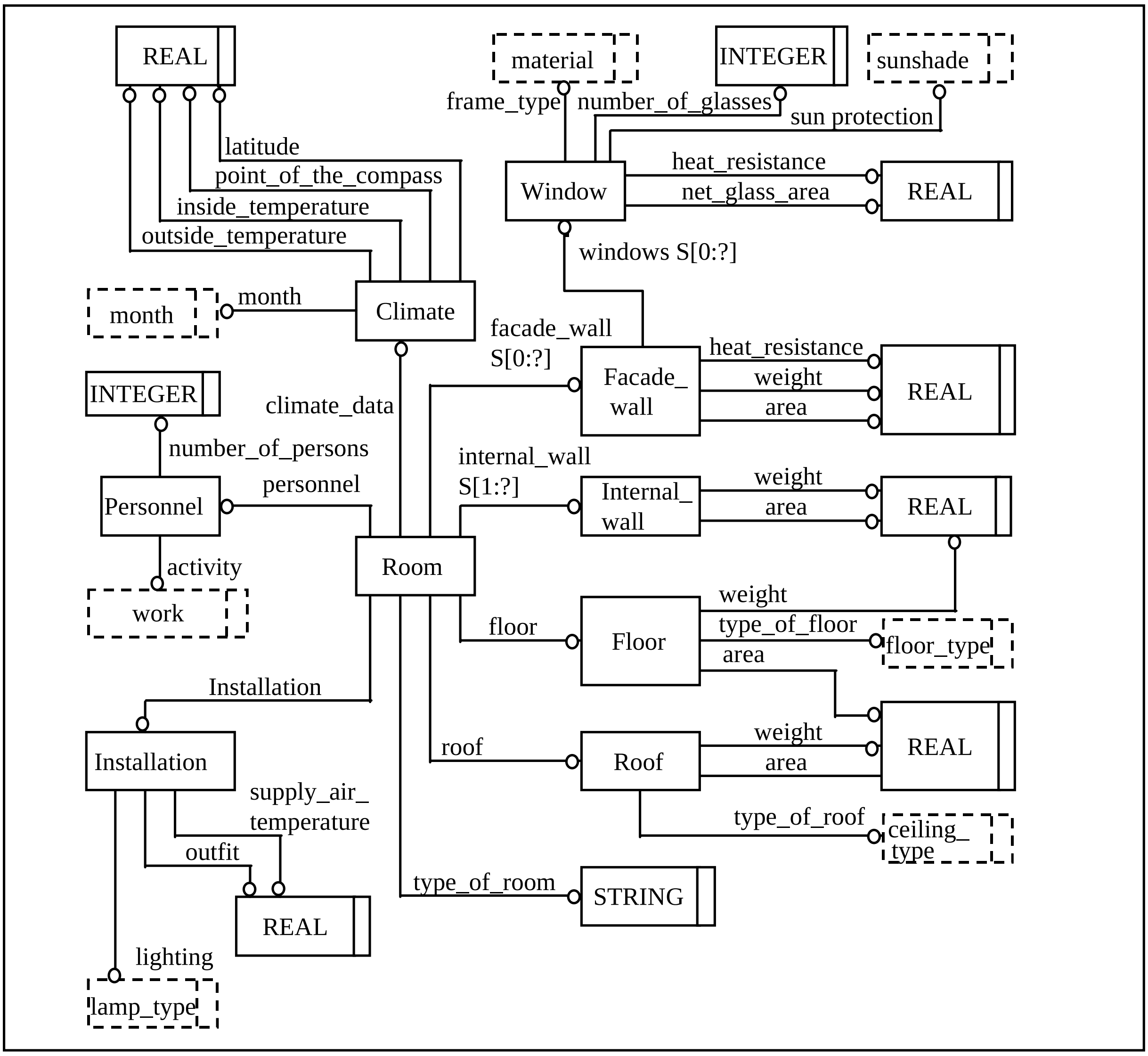

Figure 7:16 The application schema for the indoor-climate calculation application

During the calculation a great amount of information is required about facts influencing the heat balance of the room and this can come from different sources. Data about e.g. the geometry of the room is available in the building product model, while other data is given by the user or stored specifically together with the application as default values.

The calculation gives the ventilation flow required to obtain the stipulated indoor-climate. Changes of both numeric input data and discreet (textual) input data are made via the screen in a similar way. The user states the input data in connection with the execution and in most instances there is a default value which is valid if no other value is stated. Chosen values are stored in the database so that when the calculation is repeated, the latest given values will be valid as default.

The schema for the tenancy agreement application is shown in figure 7:17.

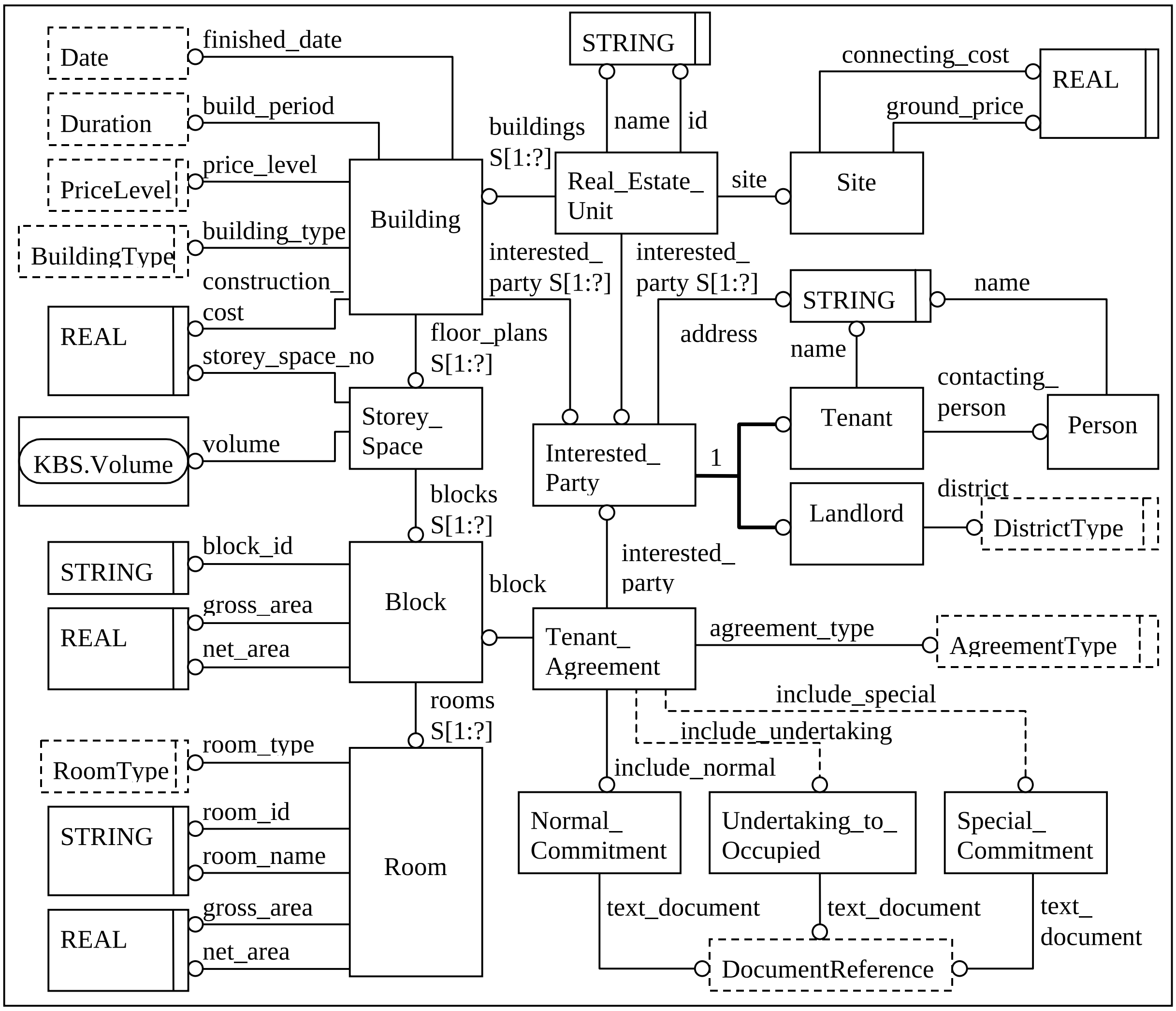

Figure 7:17 The application schema for the management of tenancy agreement application

In the schema, the entity ‘tenant agreement’ is essential. It ties two types of ‘interested party’ (tenant and landlord) together with a block, i.e. a number of rooms in a floor plan. One or many blocks could be related to each agreement. The main purpose of the application is to generate a tenant agreement.

Figure 7:18 shows a screen dump from the initiation phase. The current rental object is displayed and from the description, it could be modified until it is accepted. After acceptance, a tenant agreement would automatically be generated by the system.

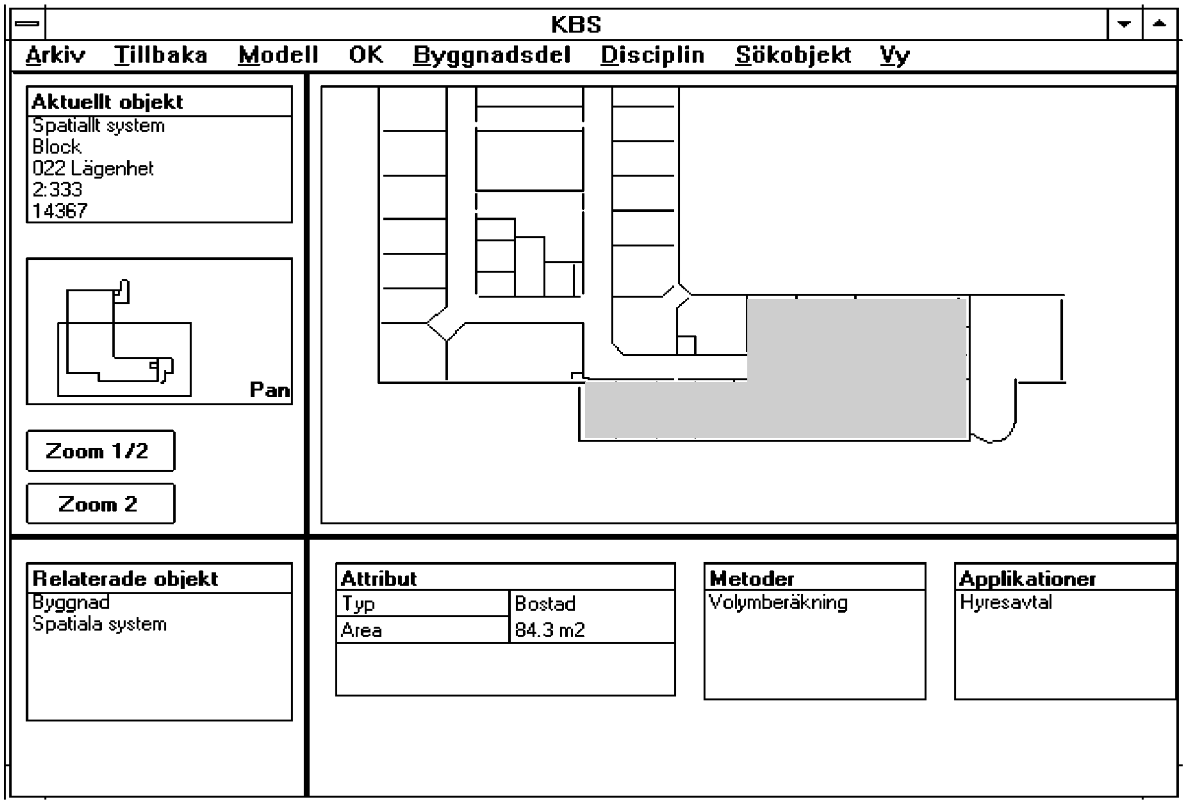

Figure 7:18 Screen dump from initiation phase of the tenancy agreement application

Conclusions from the Blandaren prototype

- The prototype demonstrated that it is possible to generate an object-oriented database with a structure based on a subset (including some slight changes) of the KBS Model.
- It also demonstrated that it was possible to partially fill this database by importing data from a CAD-system using a reduced schema and STEP physical files.
- It showed that two down-stream applications could get a part of the input data they needed from the building product model.
- The prototype demonstrated a user interface to the product model based on object navigation.
- The prototype gave some indications that the model structure with a 'core part' and 'catalogue parts' is a workable solution. Due to the very limited testing this cannot really be put forward as a proof of concept.
- The prototype high-lighted that the generation of information about spaces is problematic if existing CAD files are used to provide the input information. Spaces are only defined by surrounding physical building elements and it will be extremely difficult to build totally automated space generation procedures.
- Due to problems with space formation in particular the prototype demonstrated the importance of a facility for manual checking and correction of the building product model.

- The prototype implementation pointed out the difficulty of checking whether data fed into the system was valid. This happened when an occurrence model was built up from construction parts received one at a time. This meant that after each construction part is received a check was to be performed to see whether a room could be created or not. This made feeding information into the system considerably more difficult.

7.5 Testing of the KBS-model in the Kronoberg prototype

The prototype work

Drawings are the most important representation for exchanging information in the construction industry. Facilities managers use drawings in their daily work. Existing drawings and documents are normally in paper-based format. One of the main reasons for trying to transfer paper-based drawings and documents to digital formats is to apply modern information processing techniques equally to the creation and management of both drawings and other documents.

A considerable amount of FM information is today already stored in relational databases. Many facilities administrations depend on database applications in their daily work. In order to be accepted in FM organisations, proposed building product modelling systems must thus provide a way of using existing databases.

The Kronoberg prototype aimed in particular at demonstrating how PC-based tools can be provided for creating and using active connections between drawings, text based documents and database records. Figure 7:19 illustrates this.

The staff of the National Board of Public Building provided the information requirements and supplied the paper copies of all information put into the BPM database. The information handled by the prototype system concerned one specific building, a six storey office building in the block Kungliga Myntet situated in the centre of Stockholm. The building has a total floor area of approximately 3500 sq. m.

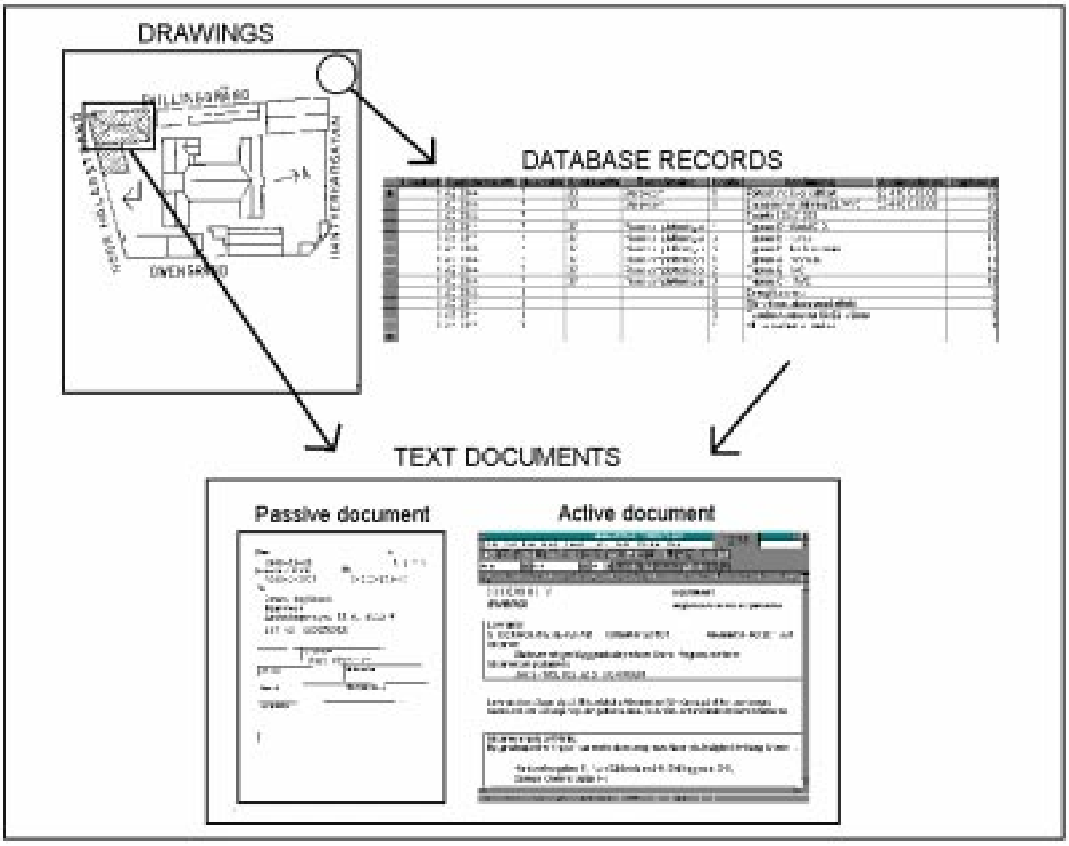

Figure 7:19 Required information links in the Kronoberg prototype system

Access to information in the form of database facts, drawings and other documents is provided in a way that is similar to the natural way of performing a facilities manager’s work. Scanned drawings and documents were integrated with the database structure. Also, external databases (database servers) were used as existing information resources.

In order to achieve these aims the use of an object-oriented information structure based on the KBS Model and the classification tables of the BSAB system, as a backbone to the system, was to be tested.

More concretely the prototype was aimed at integrating a number of already existing standard software applications. These included:

- existing text database resources with applications
- software tools to integrate (scanned) paper drawings and documents with a structured database
- viewing and editing tools

The prototype system was implemented on the following technical platform (table 7:4):

Table 7:4 The technical platform of the Kronoberg prototype

Type of system component	***System component description***	
Hardware	PC (pen computer)	
Operating system	MS Windows version	
Software	Database manager:	Access
	Spreadsheet:	Excel
	Word processing:	Word
	Graphical presentation:	Paintbrush

The work of the Kronoberg prototype project was divided into three stages:

- Pre-stage which meant evaluation of different methods for converting paper based drawings into documents in digital form.
- Stage 1 which meant the establishment of the infrastructure of the system (described within figure 10:6 above) and the system design.
- Stage 2 which meant system implementation and information feeding into the system.

The prototype system was developed and implemented in co-operation between the National Board of Public Building and Tessel Systems Inc. It consists of the different components illustrated in figure 7:20.

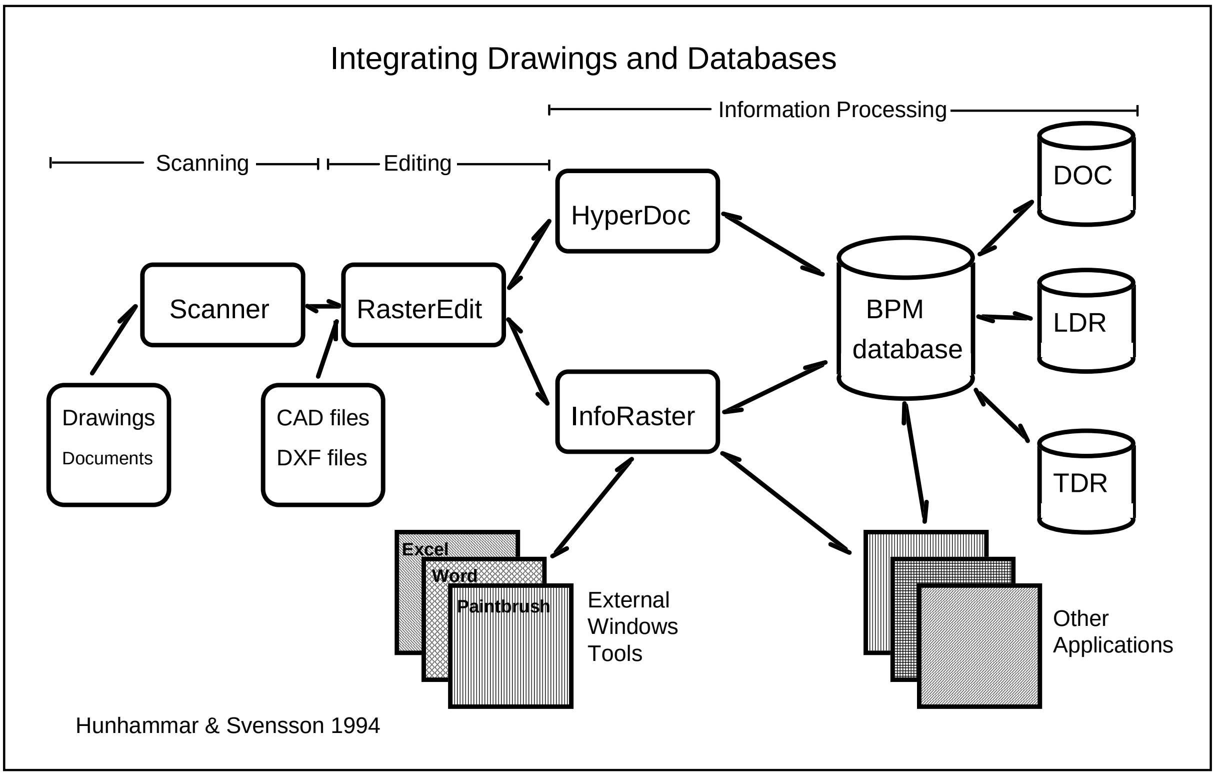

Figure 7:20 Components and structure of the Kronoberg prototype system

The main information source is the “BPM database”. It provides object-oriented organisation of data (information). Two existing (external) database servers are included in the system: the Technical Document Register (TDR) and Space Data Register (LDR). DOC is the storage for scanned and rasterised documents.

Figure 7:21 shows the conceptual schema implemented in the “BPM database”.

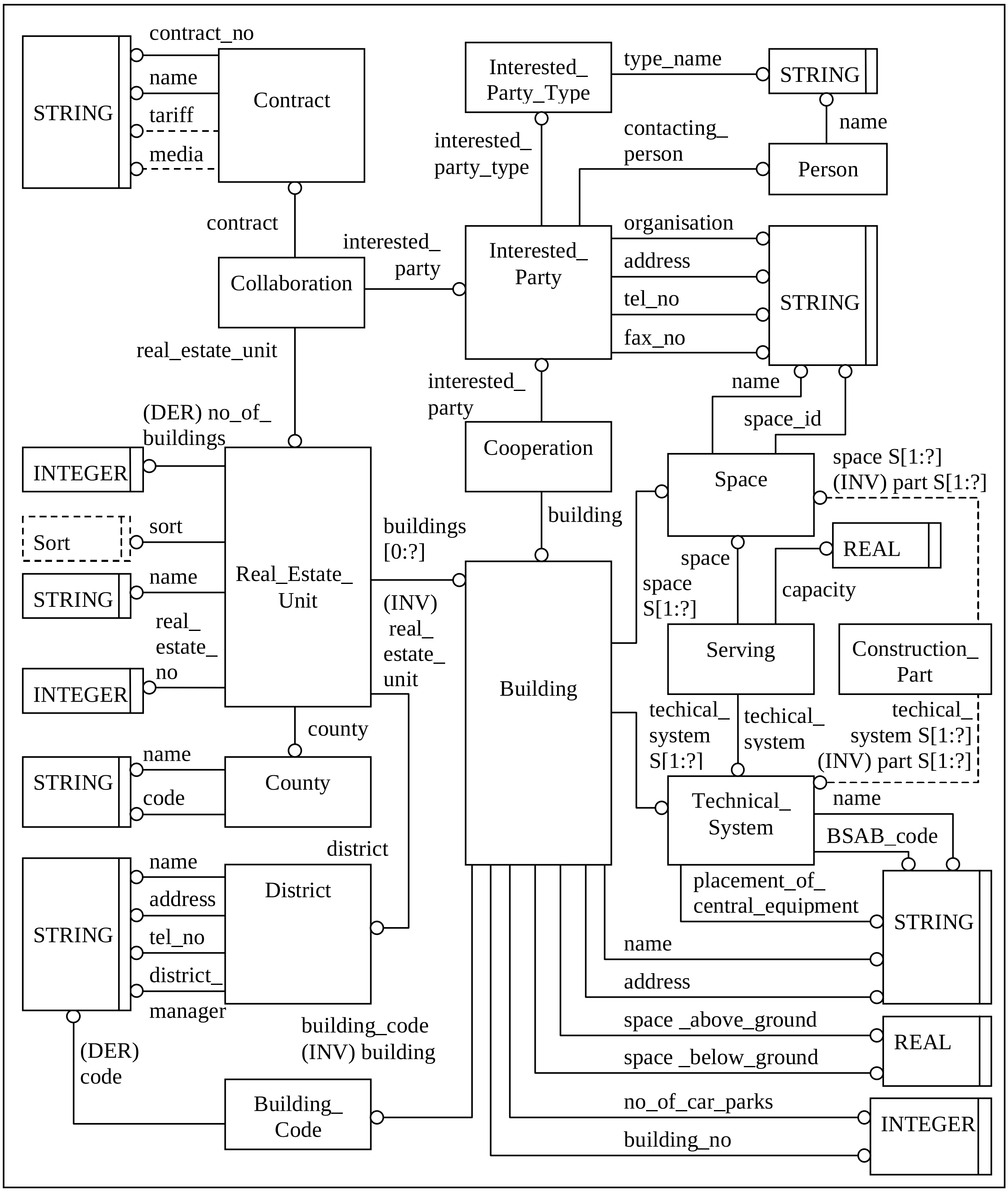

Figure 7:21 Description of the schema implemented in the Kronoberg prototype

The main structure of this schema is basically the high level structure of the KBS Model (described in chapter 6). The possibility of adding information at a construction part level was planned, but not implemented.

Figures 7:22 and 7:23 show the conceptual schemas of the two external databases which were integrated with the prototype system. The LDR database ("Lokal Data Register", Swedish for Space Data Register) contains information about the different spaces in the building and how they are used. It is basically a tool for planning and administration of the space usage.

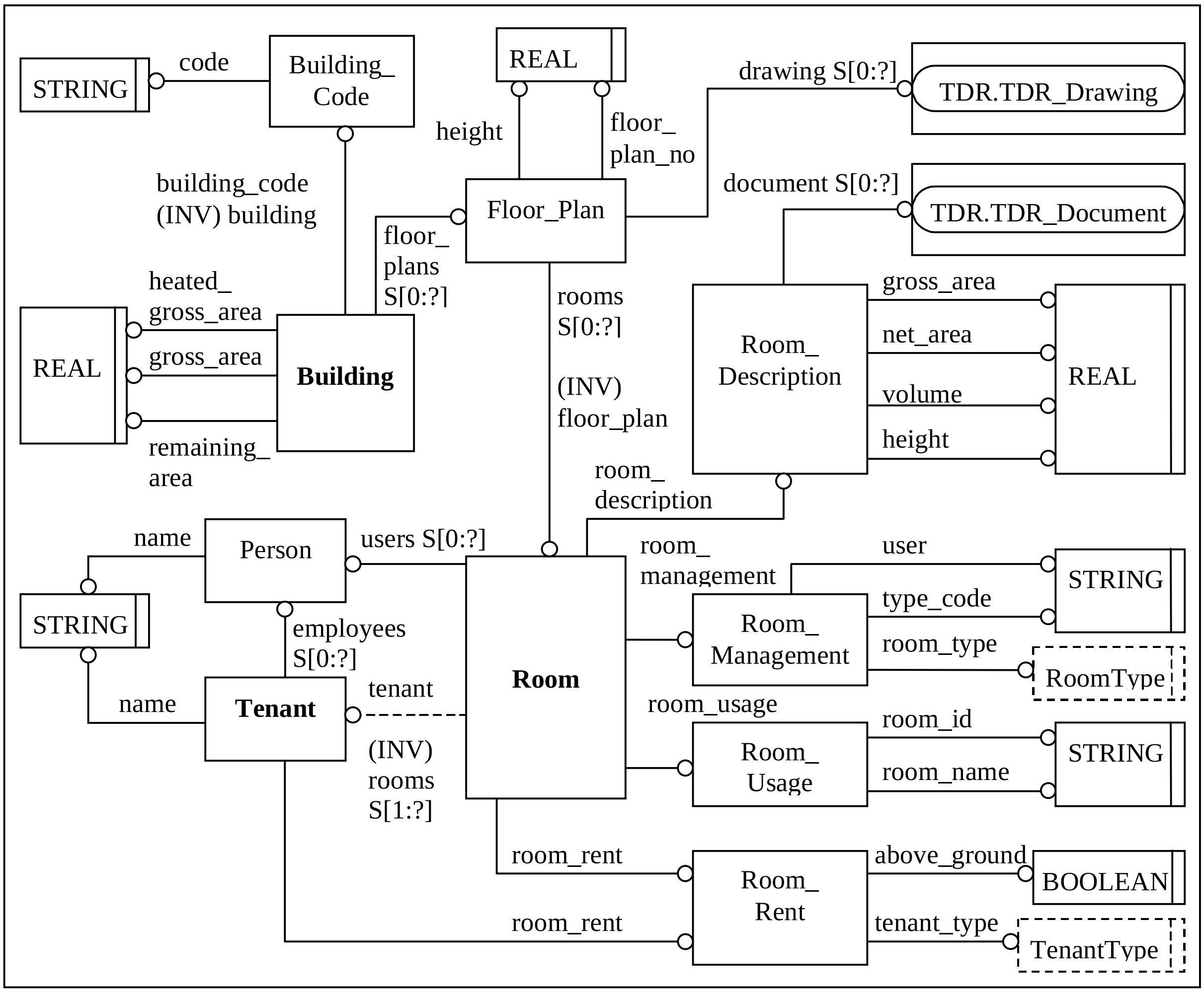

Figure 7:22 The conceptual schema of the LDR database in the Kronoberg prototype

The TDR database ("Tekniska Dokument Register", Swedish for Technical Document Register) contains information (meta data) about all drawings and written documents concerning the building.

All three conceptual schemas were in the project described with other graphical notations but have for this thesis been transformed into EXPRESS-G notation.

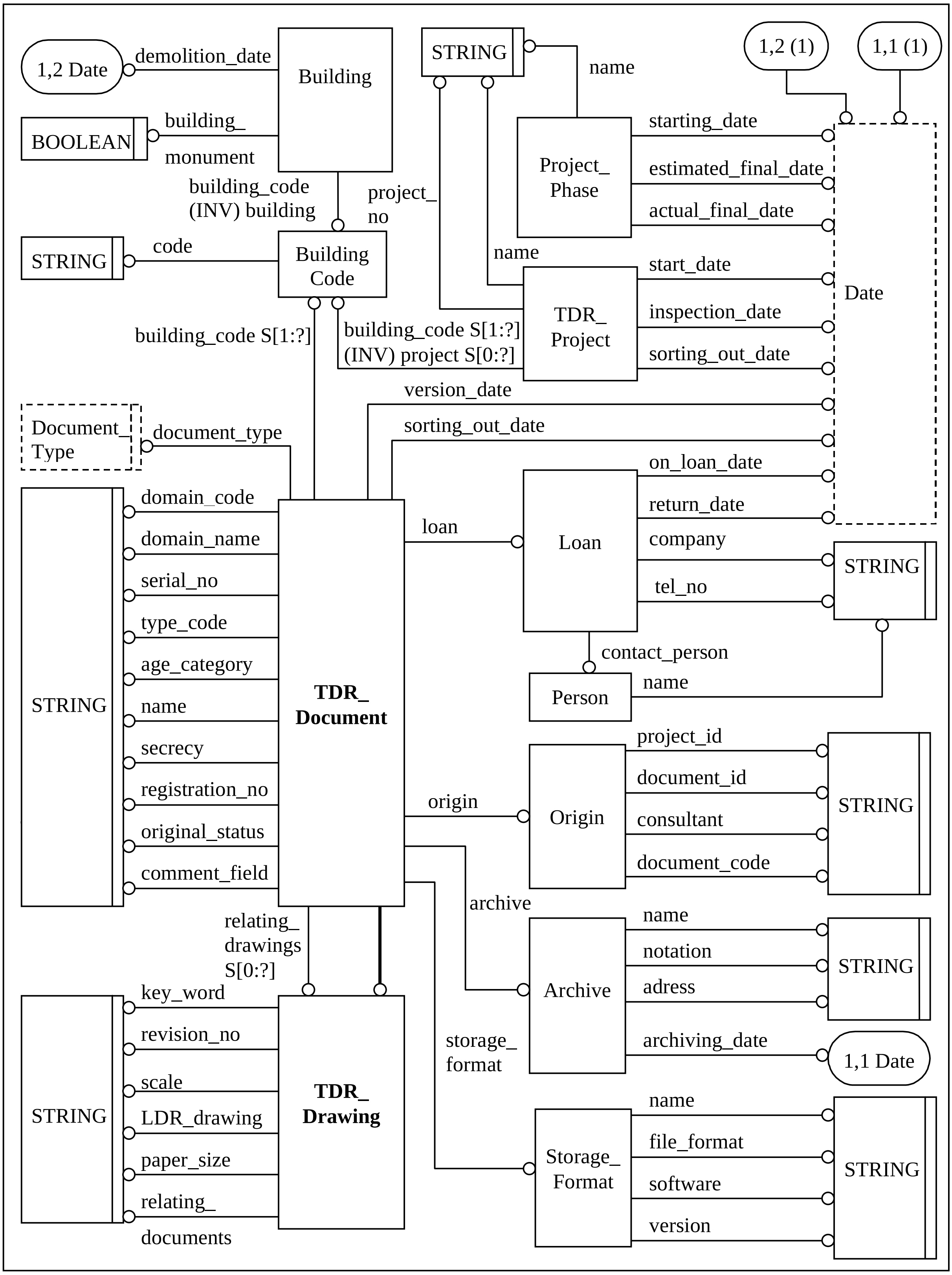

Figure 7:23 The conceptual schema of the TDR database in the Kronoberg prototype

In order to be able to deal with drawings which exist in paper-based format and need to be converted to a digital form a number of already existing software modules [*Zabielski*, 1993] were used. These also provided some of the hyper-media functionality needed for the user interface. The *RasterEdit* module is a Windows-based editor of raster and vector data. The *InfoRaster* module integrates the scanned drawing with relational databases and measuring tools. User programmable objects can be placed in the drawing. Figure 7:24 shows a block of rows and the measured area of 95.89 sq. m.

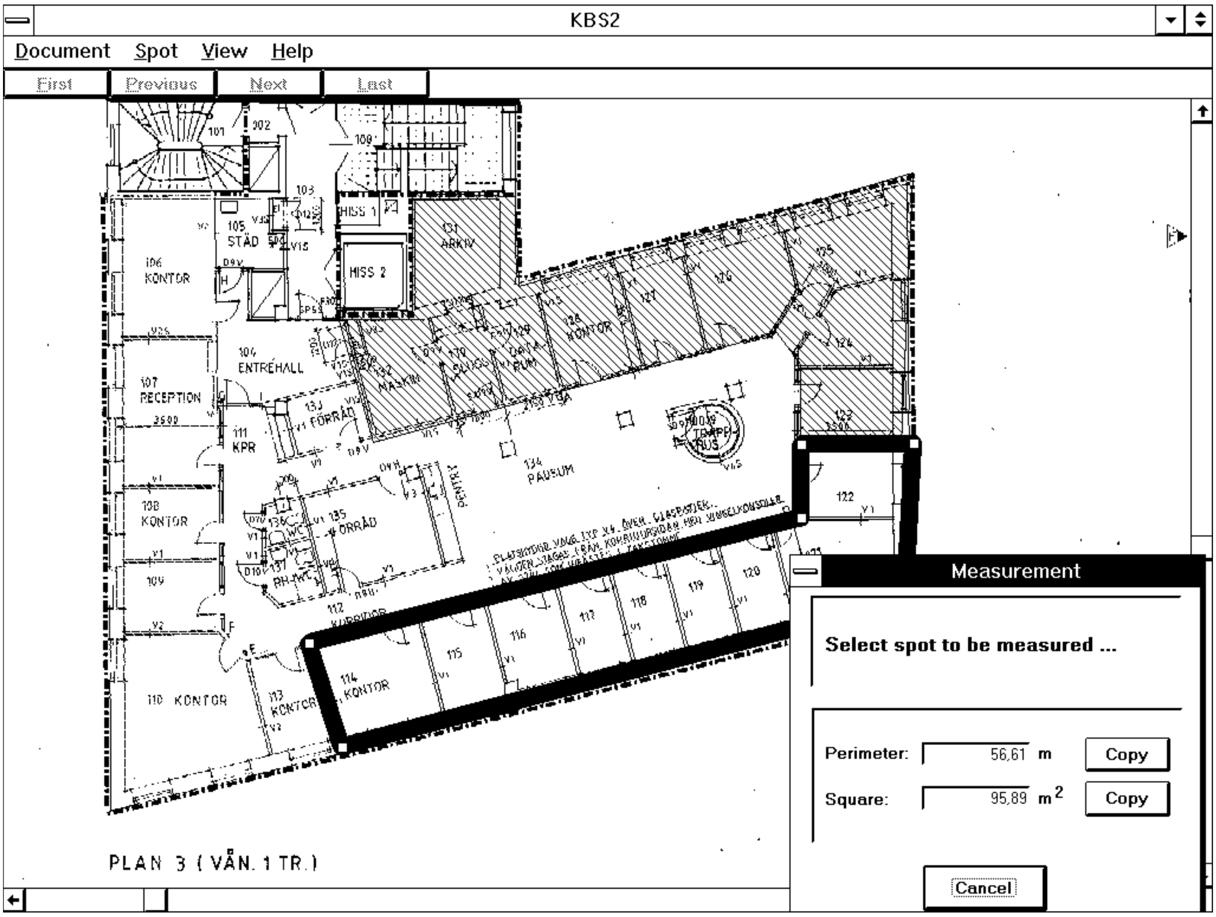

Figure 7:24 Measuring on a scanned drawing with InfoRaster objects pasted on it

The *HyperDoc* module provides a possibility to connect documents to each other and with information in underlying relational databases.

In order to provide an easy way of finding the necessary information, either database records or documents, an object-oriented navigation capability was implemented in the prototype system. All functions of the Kronoberg prototype system are consequently accessible in an integrated system and allows navigation through a unified space of objects, database records, documents and applications. This capability is based on the BPM data base and the TDR and LDR databases incorporated. It has been achieved by defining the required relations in the database of the prototype system. Figure 7:25 below exemplifies the database structure. A 'building info' form has been displayed by double- clicking the 'info spot' in the drawing.

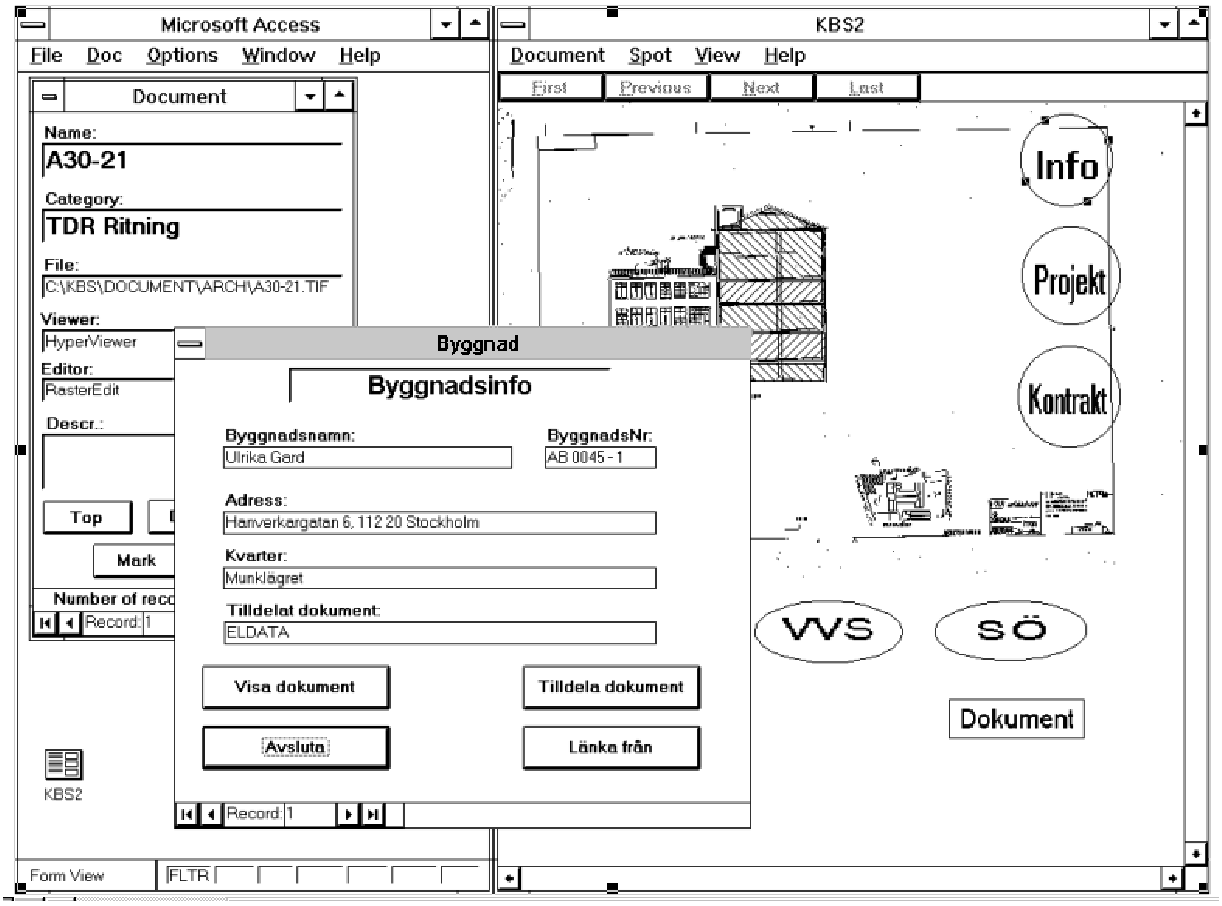

Figure 7:25 Linking of drawing with other documents

Additionally, it provides a link via a standardised BSAB based classification of documents registered in the TDR database, with different technical areas and with the space information in the LDR database. By selecting appropriate records in the hierarchy, the user may easily display a list of all TDR-registered documents and spatial data of the LDR which satisfy the selection criteria.

Different types of links, for instance between documents and databases, were described above. The process of linking a group of documents to a spot defined on a drawing consists basically of the following:

- clicking on a spot to select it and
- choosing document files or documents registered in the database.

Conclusions of the Kronoberg prototype

- The prototype system was presented at a number of seminars in which the people involved in the project and others interested in the application took part. The impression was generally positive and numerous detailed comments have contributed to the conclusions presented below.
- The prototype proved that the particular subset of the KBS schema provided the infrastructure to integrate different types of information currently used in

FM organisations; drawings, textual documents and existing relational databases.

- As all functions of the Kronoberg prototype system were accessible in an integrated system it was easy to navigate through a unified space of objects, database records, documents and applications.
- Experiments with existing real data show that the KBS Model structure may be effectively used to organise large amounts of information in an object-oriented structure.
- Drawings and other paper documents may be integrated with each other and with the database records through information spots in the documents.
- The prototype provides an overall structure for handling information of multimedia type by using a compound document technique.
- The prototype system architecture provides for utilisation of existing databases and database servers.
- The prototype demonstrated the applicability of a PC-based platform for creating a useful FM information system.

7.6 Overall Conclusions from the Prototype Work

The prototype work can be summarised as follows:

- Three different integrated prototypes were built.
- Each of these implemented different subschemas of the comprehensive KBS model, in some cases also with slight modifications.
- In all of the prototypes the central building product model was used to provide input information needed for downstream applications. In all three prototypes there were downstream applications.
- The central BPM:s also provided a user interface and querying structure for accessing information in already existing drawings and data bases.
- In one case the main part of the information in the central BPM was generated from CAD files.
- The prototype work pinpointed a crucial feature in the generation of a BPM databases; the automated or semi-automated generation of spaces and space-to-building parts connections from CAD data which lack this as explicit data.

In conclusion the scope of the prototype work, the coverage of the implemented schemes and the amount of testing with real data is proposed to be sufficient for the purpose of showing that the KBS schema is adequate for supporting the integration of most FM information generation and management functions within the traditional areas of FM i.e. operation and maintenance and spatial maintenance.

8 Results and Discussion

Introduction

The results part of this chapter provides a reference to the purpose and method of the current research, as well as a short review of the work. The discussion part presents principles, relationships and generalisations as well as exceptions shown by the results and relates the results and their interpretation to previously published work.

8.1 Degree of Evidence in the Three Prototypes

Purpose and method of the research work

The **aim** of the research was to *develop suitable information structures to support the processes for FM*. Specifically, the **objectives** were twofold:

- To develop a building product model, to be used as a basic information structure for the use of IT within FM. The main purpose of the model was to *provide an infrastructure for FM information*. The model must *fulfil certain requirements to be appropriate for FM.*

- To develop a generic FM process model in the provision of IT support within FM. The main purpose of the generic process model was to *provide better conditions for integration*. The model should also *capture important aspects of the essence of FM*.

The research was carried out through theoretical work resulting in building product and FM process models. An important question to discuss in this chapter is the suitability of these models for supporting FM work.

The research was evaluated by prototyping. Three different prototypes were developed and evaluated. They can be briefly described as follows:

- **the Klara prototype** - a system for planning and carrying out operation and maintenance of building services systems
- **the Blandaren prototype** - an object-oriented database system for indoor climate calculation and other types of typical FM tasks
- **the Kronoberg prototype** - a GIS-like system for facilities manager information

Degree of evidence in the three prototypes

Different aspects of the models were tested in each of the three prototypes. The degree of evidence that the prototypes managed to achieve varied. To quantify this, a taxonomy of empirical CAD research, e.g. product model research, proposed by *Clayton et al*. [1997], is applied. Clayton et al. classify the argument methods for demonstrating the validity of the product model proposals into four categories.

- The **'logical argument',** which is an essential part of any research project. A typical example of research work carried out at this level of evidence is the work on conceptual modelling of spaces, space boundaries and enclosing structures described by *Björk* [1992].
- The **'worked example',** which has frequently been the level of evidence provided in building product model research. Typically, 'worked examples' in the product model domain contain 5-15 classes and a few instances of each. Many functions are emulated. The worked example shows how the research relates to real world practice and is relatively easy to achieve. It suffers from a lack of generality, which means the evidence that the process can be used by people other than the researchers is weak. Examples of 'worked example' are the Auto CAD prototypes developed by *Penttilä et al*. [1991], using the RATAS model as a basic information structure.
- The **'demonstration',** which shows a working software prototype to other people, typically credible experts in the field of application. It requires considerably more effort to produce a prototype of this kind compared to a worked example but it still lacks evidence of generality because the test case can be tailored precisely to the research. The research carried out and described by *Karhu* [1997] concerning "product model-based design of precast facades" can be mentioned as an example of research work carried out at the 'demonstration' level.
- The **'trial',** which means that the participants use the software to perform a task and their actions and interactions with the software are observed and compared. It requires a larger effort in producing the software to make it work without interruption from bugs and crashes. Two examples of research and development projects including a 'trial' is the MCAD project [*Paulsson et al*., 1990] and the Prefacto work [*Jägbeck*, 1996].

The three prototypes in this thesis can be compared using this framework, as described in table 8:1.

Table 8:1 A comparison of the degree of evidence in the three prototypes.

Type of evidence	***Klara***	***Blandaren***	***Kronoberg***
The logical argument	*	*	*
The worked example	*	*	*
The demonstration	*	(*)	*
The trial	*	-	(*)

This implies that of the three prototype projects, Klara provides the highest degree of evidence and Blandaren the lowest. Actually, the Klara project is used nowadays as a commercial system at the property management district where the prototype project was carried out. The demonstrations accomplished with the Kronoberg prototype proved it had the qualities to become commercially usable after some changes and additions. This work was never done, however, due to changes in the organisation where the prototype work was carried out. The main ideas are nevertheless used in systems developed later by the partner responsible for implementation of the Kronoberg prototype. Finally, the results of the Blandaren prototype have mainly been used as background information in different research and development activities with which persons involved have later worked.

8.2 The Building Product Model

Requirements on a suitable BPM for FM

According to chapter 5, a building product model for facilities management should be: flexible, stable, adaptable, comprehensible and cost-effective. The suitability of the KBS Model for its overall purpose can be evaluated by measuring how well it fulfils these requirements. This is analogous to comparing a building design solution with the client’s requirements. In the following, their fulfilment in the prototypes is briefly discussed.

Flexible *i.e. the model can be used in different situations or to fulfil different requirements.*

Evidence that the model fulfilled this criterion was provided by the fact that the three prototypes were developed using different hard- and software platforms, as well as the fact that they integrated different types of applications. Also, it was possible to use the model as an integrating platform for both new and existing documents and database information.

Equal support for paper-based documents and digital documents (e.g. CAD drawings) as information sources in the system, should also contribute to the flexibility of the IT support for FM. This functionality was provided particularly in the Kronoberg prototype.

Stable *i.e. the model is not likely to undergo any sudden changes.*

The fulfilment of this criteria is difficult to prove in a research project of short duration. Indirect evidence is provided by the fact that the model uses the existing Swedish construction classification system as its backbone. This classification system has remained relatively stable over the years, with major revisions occurring at intervals of 10-15 years (latest editions 1983 and 1996).

Adaptable *i.e. the model can be changed, when felt necessary, in order to deal with a new situation or purpose.*

The modelling methodology used, EXPRESS, allows the creation of subtypes through specialisation, without disturbing the basic structure. Also, it was possible to use different subsets of the classes in the different prototypes, and combine them with other prototype-specific classes which do not occur in the KBS Model itself.

Comprehensible *i.e. the model can easily be understood and used by the system users (and system developers).*

This was indirectly tested in the prototype development process, as well as in the use of the prototypes. Some problems were initially encountered with the software developers, to do with the fact that the model was not initially modelled using the EXPRESS language, leaving some ambiguity concerning, for instance, attribute cardinalities etc.

The comprehensibility versus end-users was tested through the user interfaces of the developed prototypes. The experiences were good, which in all likelihood is mainly due to the fact that the concepts of the model correspond well with the physical building parts and existing classification systems familiar to practitioners.

Cost-effective *i.e. the resources spent on developing the model should be kept low and reasonable in comparison with its benefits.*

The resources used for developing the model were in the order of two man-years, which is relatively low compared to the efforts involved in the development of either STEP application protocols or national building element classification systems. This is largely explained by the reuse of the already existing BSAB-system.

Entities of an appropriate BPM

KBS Model entities

A comparison of how the three prototypes used the entities of the core of the KBS Model is given in table 8:2 below. Sometimes the same entity is used under different names in the different prototypes.

The table shows that the three prototypes used a different number of entities. The Blandaren prototype used almost all of the entities of the KBS Model core, while both the Klara and Kronoberg prototypes used half the number.

Table 8:2 Entities of the KBS Model tested in each of the prototypes

Entities of the KBS Model core	***Klara***	***Blandaren***	***Kronoberg***
Real Estate Unit	X	X	X
Building	X	X	X
Enterprise	X	X	
Surroundings	X		X
Interested Party	X	X	X
(ABS) System			
System Assembly		X	
(ABS) Spatial System		X	X
Spatial Volume	X	X	X
Stage			
Form Description		X	
Spatial Configuration		X	
Location	X	X	X
(ABS) Physical Part		X	
Port		X	
Fittings and Furnishing		X	
Construction Part	X	X	X
Construction Part Assembly		X	
Shape Description		X	
Position		X	
Technical System	X	X	X
System Configuration		X	
No of entities in each prototype	*10*	*19*	*9*

The entities used by all prototypes were: real estate unit, building, interested party, space, technical system and construction part. This could be interpreted as meaning that they are the most important entities of a core/reference model for FM. Most of these entities are also provided in the models provided by *Möttönen et al*. [1994], *Bos* [1995] and *Majahalme* [1995].

As described in chapter 3, facilities management may be viewed as planning, supporting and monitoring the use of individual units of space in relation to organisational requirements [*Then and Akhlaghi*, 1994]. Both *Bos* [1995] and *Möttönen et al*. [1994] emphasise the importance of a spatial view in the models used for handling FM information. All of this underlines the idea that a spatial description of the building is of major importance in FM.

In chapter 4, two articles are referred to describing the spatial aspect of buildings. *Ekholm and Fridqvist* [1997] discuss how the concept of space can be seen both as a property of things and as a thing in itself and how it can be handled in building product modelling. *Maher et al*. [1997] discuss formalising building requirements using an “activity/space model”. This chapter includes (in section 8.3) a conceptual schema called the “spatial arrangement model”, with the main purpose of describing a building and its surroundings from a spatial viewpoint. The schema provides a model in which a space could be seen from three standpoints:

- as a set of environmental or functional requirements,
- as a sovereign entity or
- as the result of a spatial relationship between physical entities.

Maher et al. [1997] stresses the relationship between the first and second standpoint, while Ekholm and Fridqvist stress the relationship between the second and third standpoint. However, none of the articles emphasises the usage phase of the building, but mainly discuss the design phase.

Figure 8:1 describes an alternative way of how different objects dominate during different stages in the life-cycle of the construction product.

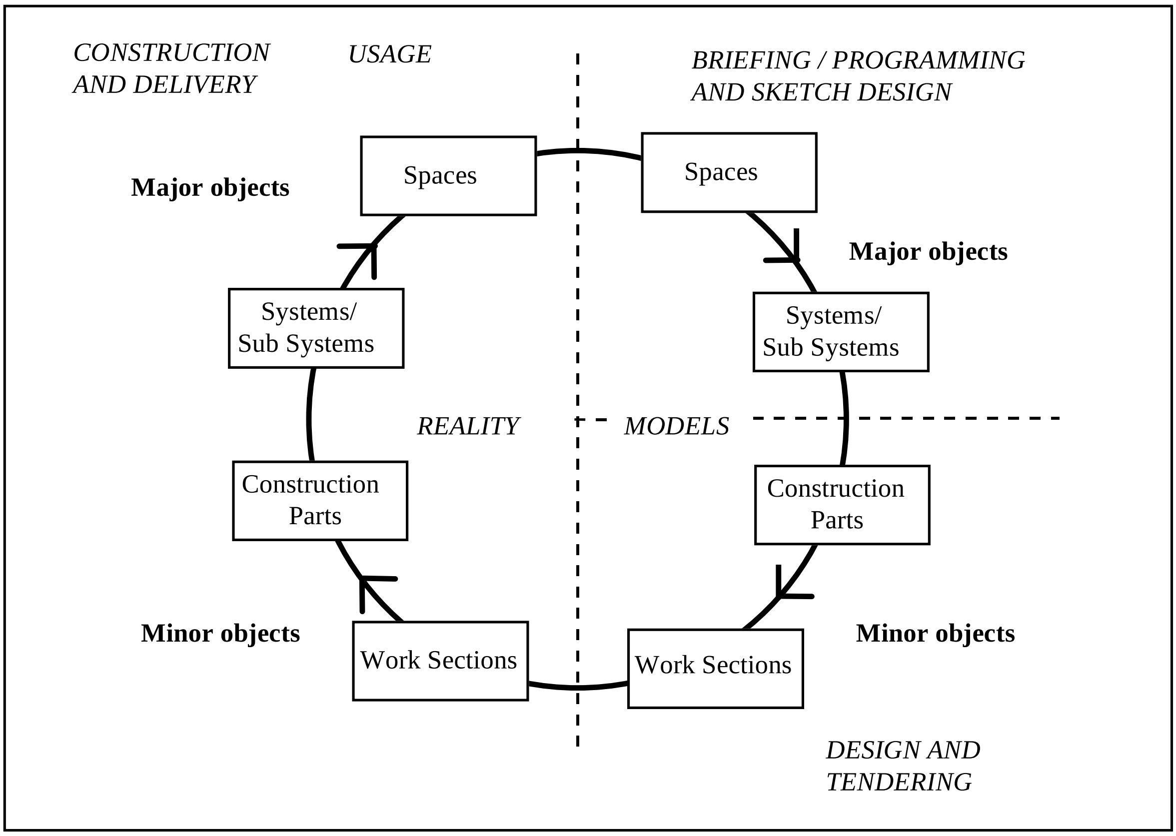

Figure 8:1 Granulation of the construction objects during different phases in the life-cycle of the construction product

Objects at a low level of detail are mainly in focus during the briefing phase, the first stage of the design phase and the usage phase, while during the later stages of the design phase and the tendering and construction phases, objects of interest are mainly at a high level of detail. During design and tendering, a planned (future) reality is described, while during construction, delivery and usage, the existing reality is dealt with.

Additional entities

Experiences from the three prototypes imply that a number of entities in addition to the ones found in the KBS Model are required or useful for traditional FM purposes. Examples of such additional entities are accounted for in table 8:3.

Table 8:3 Entities not included in the KBS Model which are of interest for FM

Required entity	***Klara***	***Blandaren***	***Kronoberg***
tenant	X	X	X
tenant-related entities	X	X	X
surroundings		X	
surroundings-related entities		X	
project		X	X
drawing	X	X	X
text document	X	X	X

Existing domain concepts and classification - a basis for the models and systems

An important point of departure when developing the KBS Model was, as described in chapter 6, to reuse the Swedish national construction classification (the BSAB System) containing tables with classes of building objects. The definition of these classes is intended to cover the complete life cycle of buildings from design through construction/production, operation and maintenance, to demolition. All three prototype systems used the current BSAB system as a basis for the identification of product model entities. Also, the codes of the BSAB system were used with some additions. In all three prototypes, additions to existing BSAB classes were nevertheless needed.

The entity types used in the KBS Model correspond well not only to the types in the Swedish national classification tables, but also to the entities handled in the on-going international standardisation work within the construction field, according to figure 8:2. The substance of the figure is taken from [*ISO*, 1997] and it describes the resources, (processes), results and contextual information used in the construction industry. For the sake of clarity, the structure has here been described with EXPRESS-G notation.

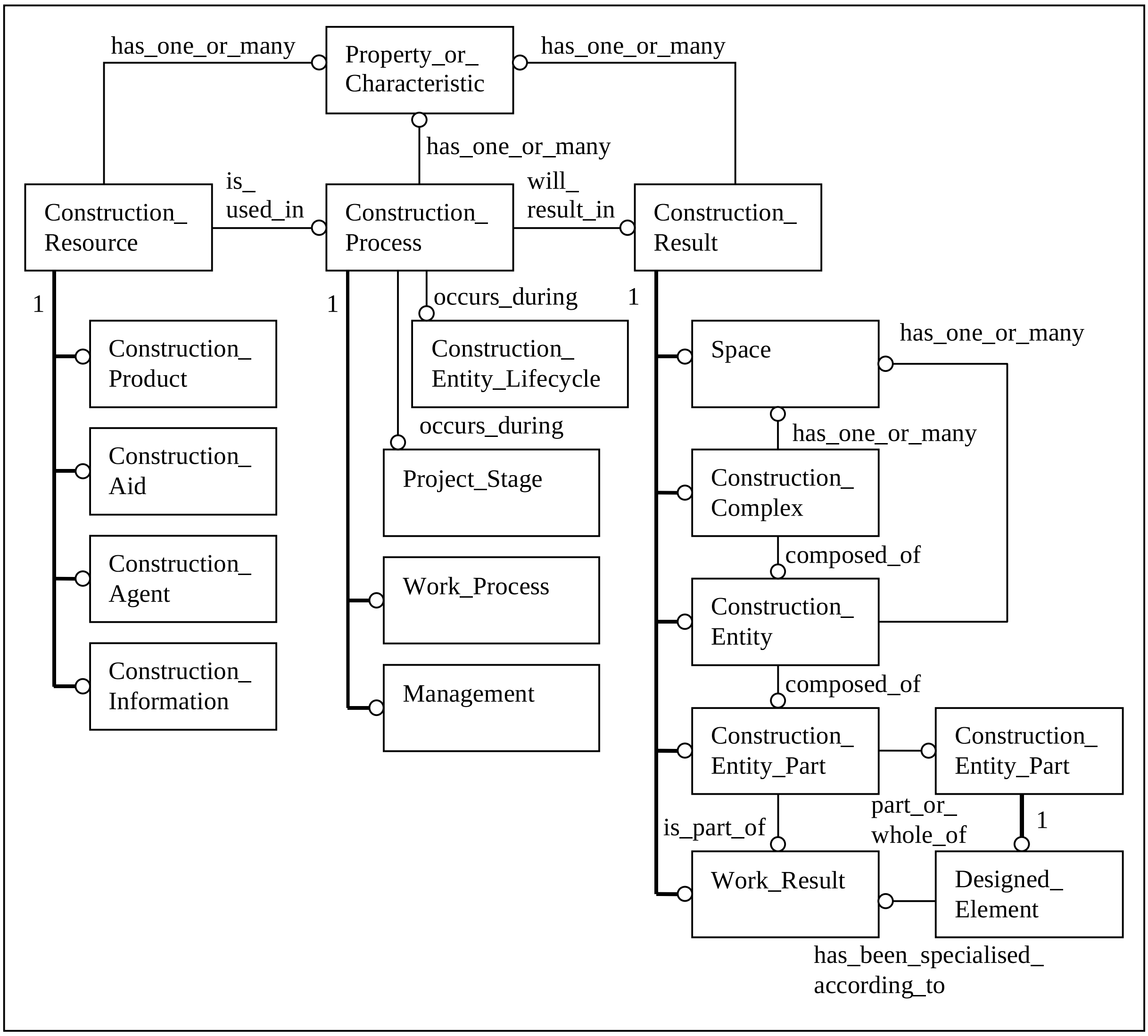

*Figure 8:2 Proposed framework for international construction classification. After [*ISO*, 1997].*

The importance of common structures and classes as a basis for conceptual modelling still remains, or has even increased. Many advantages could be won by including a uniform construction classification and other domain concepts in the framework of a logical meta model for developing the FM information system.

User interface issues

Using the building structure as an infrastructure of innovative user interfaces makes it easier for the different users of the system to navigate in the systems and use their information content. This was especially experienced in the Kronoberg prototype, where all types of information used by the FM professionals were captured in a single system.

Graphical user interfaces (GUI) are normal in information systems today. User-friendly interfaces are of major importance within the FM domain because a very heterogeneous group of people both create and access information in it. This is why the GUI:s of FM systems should have a graphical building/facility description as their most essential part. User-friendly and user-efficient interfaces can greatly contribute to the effectiveness of decision-making, services and other types of FM work. All three prototype systems included drawings and BPM structures as parts of their user interfaces. It was found to be valuable by the end-users. Especially the Kronoberg prototype demonstrated the usefulness of maps and drawings as the most essential way of navigating for the information searched.

8.3 The Spatial Arrangement Model - A Proposed STEP Application Protocol

Partly based on the work reported in this thesis, a proposal for a new work item within the STEP building construction subcommittee (the Spatial Arrangement Model) was elaborated by this author in collaboration with researchers from other countries. Primarily due to lack of financial resources, the work is at the moment (April 1998) a dormant project. The model was developed after the prototype work of the research work reported in this thesis was carried out and as a result of, among other things, the experience gained in this work. The full proposal is described in Appendix 8. Only a very brief account is given here.

The scope of the Spatial Arrangement Model is that it should handle the description and representation of:

- the requirements for the internal and external spaces of a facility,
- the spatial entities required to fulfil these requirements, and
- the physical entities that enclose and support the spatial entities.

The model should include the whole life cycle of the building and its surrounding. This means that the model entities must persist over their respective life cycles - from the briefing/programming phase, through design and tendering, construction and delivery, and into facility usage management and finally demolition.

The model should support the description and transfer of product data necessary for e. g. the following activities, during the life cycle of the building product:

- identification and consolidation of operational activities (briefing, building and planning regulations, codes, user needs) into a comprehensive and fully-integrated set of spatial requirements
- analysis of spatial requirements
- planning and analysis of alternative spatial layouts
- energy and thermal analysis
- preliminary cost calculation
- site planning
- production planning
- construction management
- operation, maintenance and other sorts of facilities management functions
- demolition of the facility

The full model is shown in figure 8:3.

In comparing this model (the S-A Model) and the KBS Model as described in chapter 6, the following can be noted:

- Both models are developed for handling the building during its whole life-cycle and from different aspects.
- The S-A Model handles the building preferably on a low level of building object granulation while the KBS Model handles the building both on a high and a low level of granulation.
- The S-A Model includes the handling of requirements more explicitly than the KBS Model.
- The S-A Model includes an entity called ‘Activity or function’ meaning the core process activities taking place inside spaces.
- In the KBS Model the handling of catalogue parts and the connection to (national) construction classification are central, while in the S-A Model these aspects are scarcely handled at all.

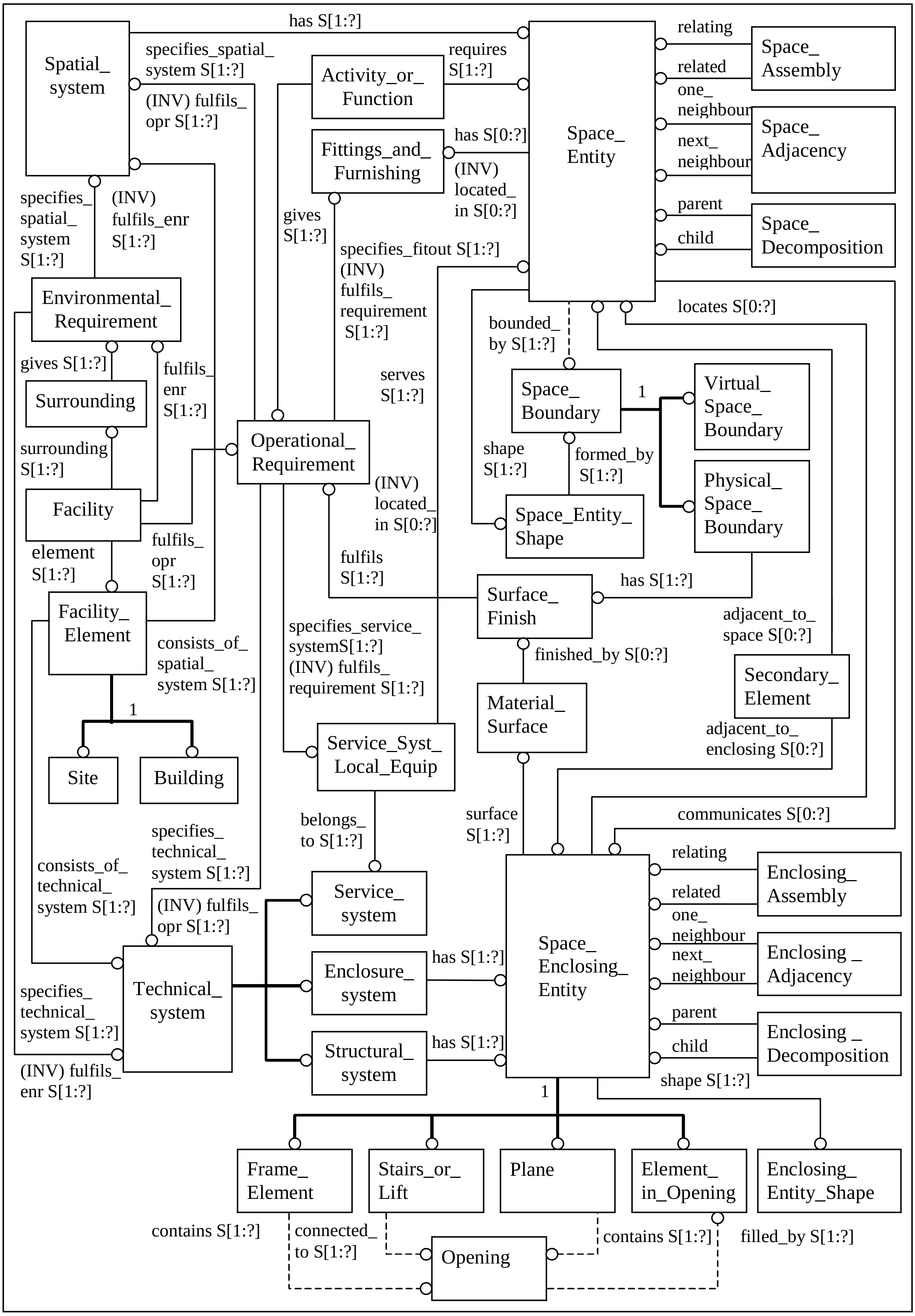

Figure 8:3 The Spatial Arrangement Model.

8.4 The generic FM Process Models

In chapter 3 the purpose of the generic FM process modes was defined in the following way:

- Firstly to provide a basic framework which would help in the overall planning and design of IT applications for FM.
- Secondly to define the scope and context of the conceptual schemas (the KBS Model) presented in this thesis.

The first objective can be further elaborated into a number of more explicit requirements. Some requirements which emanate from the analysis of chapter 3 are:

- A generic process model should offer a basic structure on which a particular system, together with its application, could be built as a layered architecture (1).

- The relationships between the FM process and the core process of the tenant on one hand and the design and construction process of new facilities on the other should be explicitly shown (2).

- The model should include all three levels of the decision pyramid of the FM organisation; strategic, tactical and operational (3).

- The model should include explicit feedback mechanisms, showing how the execution of work orders is monitored, how post-occupancy evaluation reports are used subsequently etc. (4).

The FM process model was tested in a very limited way in one of the prototype projects, the Klara prototype, where the generic process model provided a high-level description of functions actually implemented in the prototype. This testing thus offers some degree of empirical evidence that the model fulfils the first requirement. As to the three other requirements (2-4) the evidence supporting that the process model fulfils them lies mainly in the argumentation provided in chapter 3 ("logical argument" in terms of Clayton's categories presented in section 8.1). The model explicitly contains the three decision levels, has a feedback mechanism and contains a link between the FM activities and the core process activities. (The integration with design and construction activities is not shown in the IDEF0 diagrams but is discussed in section 3). These features are, however, defined on such a high level of abstraction that the evidence is almost trivial, and it is difficult to draw far-reaching conclusions as to the usefulness or validity of the model.

The second objective, to define the scope and context of the conceptual schemas presented in this thesis, is more clearly fulfilled. The process model, together with the verbal description of the features of the FM process in chapter 3, work in much that same way as the Application activity model (AAM) and scooping statement demanded for STEP application protocols.

A comparison of the generic FM process model provided by the research work described in this thesis and the set of process models developed and described by *Majahalme* [1995] could be summarised as follows.

- Both models describe the relationship between core business and FM activities.
- Majahalme's "Mafm" model describes quite in detail the process to establish a suitable FM organisation ('FM solution'). This functionality is described more concisely in the generic FM process model of this thesis.
- The focus of the generic FM process model is on on-going repetitive FM activities and the control of these. This aspect gets less attention in Majahalme's process models.
- Majahalme's "DSfm" model describes different activities that relates FM documentation to FM activities. This aspect is not explicitly handled by the generic FM process model.

An overall comparison of the work of Majahalme (as described in his thesis) and the research work accounted for in this thesis shows that both of the two include process and product models. The thesis of Majahalme emphasises the process models while this thesis is more focused on the product model part.

9 Conclusions and Recommendations

Introduction

In this chapter the implications and final conclusions of the research work are described. This is done in the form of generalisations from the results and discussion. Implications of current developments in Internet and general software technology are also discussed. Finally, recommendations for future research or areas of inquiry and practical applications are suggested.

9.1 Final Conclusions

Overall, the study indicated that there is a significant development potential in FM activities if IT applications in the domain could take advantage of the rapid development of hardware and software technology. Computers and information networks create unique opportunities for FM applications, providing more efficient tools for building management and operations. A prerequisite is, however, the development of a necessary infrastructure in the form of standardised information structures and process descriptions. Whereas general developments in hardware, software and networking technology take place independently of the FM business sector, it is only through conscious efforts by organisations within FM that the above infrastructure elements can be developed.

The thesis has discussed such an information framework for FM using process and product models as basic components and striven to provide some proof of concept through a number of prototypes. This framework supports an integrated information system for FM, but also data exchange with core business and design and construction processes.

An important factor in the overall strategies for developing information systems for FM are that they must take into account the current situation in the application domain. This implies in particular:

- integrating the vast amounts of mainly paper-based information existing today;
- reusing existing domain classification systems and terminology.

Current developments in general IT offer very favourable conditions for the development of user-friendly and integrated FM applications. Developments of particular interest include:

- PC-based computing
- Portable equipment
- Graphical user interfaces
- Use of object-oriented programming and database technology
- Compound and embedded document technology
- Internet and networking technology
- Product data technology

The KBS Model has explicitly taken account of some of these technological advances in current IT and can easily be adapted to the others. In the following, these development trends are briefly discussed.

When this research project started in the late 1980s open systems, object-orientation and the emerging STEP standard were three areas getting increasing attention. They still are, but new techniques and standards for electronic communication and distribution of information have also emerged (in particular web technology). Many of these developments rely heavily on the object-oriented paradigm for successful implementation.

As described in chapter 4, STEP is influencing both data exchange and system architectures. The implementation of STEP into a production environment is on its way e.g. in the automotive industry. The development of the IFC classes by the IAI (described in chapter 4), which should mean practical implementation of product data exchange within the construction industry, is also a sign of the maturity of the STEP technology.

The product model technology is developed from the idea that the system should be used during the entire life cycle of a given product, starting with its design. A building product model must thus have a very long average lifetime. Often the buildings to be modelled are existing ones where the information is not in digital format but paper-based, structured into documents of different kinds (drawings, specifications, lists etc). The product data technology employed must also be able to deal with such information. It should also be possible to include multimedia information in the form of digital images and videos in building product models. New technologies dealing with compound documents such as OLE, COM, CORBA etc. should facilitate this. Object Linking and Embedding (OLE) is an object-oriented technique that allows the integration of composite elements such as texts and graphics into an object. Common Object Model (COM) defines a standardised interface with the object enabling it to communicate with other objects. A framework for the integration of applications is provided by the CORBA (Common Object Request Broker Architecture) distribution standard. It allows messages between objects on an heterogeneous network of servers. Product data exchange should in the future be able to benefit from these techniques.

Furthermore, the buildings to be managed are often spread over a wide area and this means that distributed computing technology is needed to provide integration. In the past, computing applications both in construction and FM have often been limited to central offices. In today's world laptop computers, mobile-phone-based communication and the Internet make it possible to access information anywhere where it is needed. For instance, service staff needing information about the room they are in or equipment in it could access information just by plugging into the LAN network in the room in question, or remotely from their home when planning the day's work. The high visual quality of current user interfaces certainly helps in facilitating this. This aspect was also tested in the prototypes. The building product model provides a good intuitive structure for browsing information about a building. Likely future trends will include the use of HTML technology for presenting data from building product models through the World Wide Web (Including 3-D user interfaces).

Although the possibilities of IT have increased dramatically, the risks of failure are still comparatively high. The risk of failure when developing IT systems for FM could be minimised by a number of precautions. For example:

- The risk of limited capability and ability of the FM information system may be reduced by careful investigation of essential performance requirements.
- The risk of inconsistency with the requirements can be minimised by developing systems with broad capability and flexibility to interface with existing conditions.
- The risk of investing in the wrong type of hard- and software can be minimised by using the latest platforms and object-oriented software.

9.2 Some Recommendations for Future Research and Standardisation

This thesis work has included some preliminary FM process models, which still need further testing and validation. Currently, there are some efforts dealing with similar issues going on in Sweden and experts from industry and from the standardisation bodies are starting to realise the need for these kinds of process models as a part of the infrastructure required to develop the FM sector. Consequently, this work should continue, possibly within the framework of the "IT Bygg och Fastighet 2002" R&D program, which is about to start [*IT Bygg & Fastighet 2002,* 1997].

A main result of the thesis has been a proposed building product model, the KBS Model, which was also tailored to the particular needs of FM applications. Due to organisational changes there is no longer one organisation (earlier the National Board of Public Building) which can implement this model in its own development work. The emphasis has rather shifted to using the KBS Model as input to national or preferably international standardisation. This was reflected in the author's involvement in planning an application protocol for spaces within the STEP Building Construction subcommittee, an effort which unfortunately could never be properly started due to lack of funding. Currently, industrial interest in product data technology is rapidly growing, however, and it would seem natural to pursue similar standardisation efforts within the IFC development work.

Future research activities, could be directed towards testing the potential of the new technologies discussed earlier (portable equipment used for accessing web-bases, product models with 3-D user interfaces).

One very rewarding aspect of the last few years' development in product data modelling and building classification research and standardisation, has for this author been the increasing emphasis on explicit modelling of spaces and spatial requirements. In this respect there currently seems to be something of an on-going paradigm shift from only modelling physical building elements, as in current CAD systems, to also modelling spaces and the physical parts that form them as integrated systems.

In chapter 1 the following definition of the FM concept was proposed:

Activity	*"The continuous management of*
Object	*the workplace and operating environment of*
Client	*the organisation at all levels*
Aim	*with the purpose of providing user*
	satisfaction and value for money"

The scope of FM was examined and described in chapter 3. The description given indicated a wide area of FM applications, which should include the majority of conceivable FM applications. The applications described and used in the prototype work of this thesis are more focused to the traditional areas of FM, i.e. operation and maintenance of the building and to a certain degree spatial management.

Both the generic FM process model (described in chapter 3) and the two building product models (The KBS Model described in chapter 6 and the proposed

STEP spatial arrangement AP described in section 8.3) should in principle support the aim of FM, as it is described in the definition above and in the general examination of FM carried out and described in this thesis. Another important research direction could thus be to study empirically the benefits and effects of better IT applications for facilities management in terms of savings in energy cost, more optimal utilisation of available premises and in the end better value for money for the clients. Providing tangible evidence of the benefits of better IT applications in general and product data technology in particular could lead to a quicker uptake of new technology in the FM sector, which traditionally has been quite conservative.

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Appendices

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Appendix 1: People involved in and documentation of the prototype projects

This appendix is a description of the different people involved in the prototype projects and resulting documentation

Kronoberg Prototype	
People primarily involved:	
Kjell Svensson	National Board of Public Building
Leonard Zabielski	Tessel Systems AB
Prototype documentation:	
	Svensson, K. and Zabielski, L. (1993) **Prototyp av Objektstrukturerad fältdatabas med ritningar,** [Swedish for Prototype of Object Structured Field Database with Drawings] Working paper, The National Board of Public Building, Stockholm.
	Svensson, K. et al. (1991b) **Utvecklingplan för datorstödd ritningshantering. Teknisk beskrivning och rekommendationer**, [Development Plan for Computer Aided Drawing Management. Technical Description and Recommendations], Working paper, The National Board of Public Building, Stockholm.
	Svensson, K. and Bröchner, J. (1996) **Information Management for Facilities**, In Alexander, K. (ed.) 'Facilities Management. European Practice 1996', Arko Uitgeverij bv, Nieuwegein, The Netherlands.
	Svensson, K., Hunhammar, M. And Zabielski, L. (1994) **Are Scanned Drawings Sufficient for Facility Mangement Work?**, Paper presented at the CIB W78 Workshop on Computer Integrated Construction, 22-24 August 1994, Helsinki.

KBS Prototype

People primarily involved:

Örjan Falk	CASE&CAD Engineering AB/Cascade Computing AB / Digital Equipment AB
Torbjörn Holm	CASE&CAD Engineering AB/Cascade Computing AB / Digital Equipment AB
Claes-Göran Lövetoft	Astrakan Strategisk Datautveckling AB
Sven Eric Norén	CASE&CAD Engineering AB/Cascade Computing AB / Digital Equipment AB
Nail Sudin	CASE&CAD Engineering AB/Cascade Computing AB / Digital Equipment AB
Kjell Svensson	National Board of Public Building
Väino Tarandi	Arcona AB

Prototype documentation:

Sudin, N., Svensson, K., Tarandi, V. (1988)
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[Swedish for Prototype for Neutral Building Product Model - The KBS Model],
Report KTH, Information Technology in Construction, Stockholm.

Klara Prototype

People primarily involved:

Bo Andersson	National Board of Public Building/ Statens Fastighetsverk
Hans-Erik Forsell	National Board of Public Building/ Statens Fastighetsverk
Kjell Svensson	National Board of Public Building

Prototype documentation:

Andersson, B. (1994)
Delrapport över försöksverksamhet med vidareutveckling av av system för drift och förebyggande underhåll inom Fastighetsverket, FD 3.
[Part Report from Experimental Work with System for Operation and Maintenance at National Property Board, FD 3], Working paper, Fastighetsverket, Stockholm, 1994-12-15.

Appendix 2: Different lists describing the scope of FM

This appendix provides a number of lists found in different sources describing the scope of FM.

The International Facility Management Association (IFMA) has determined, through polling its members, that there are nine functional areas which represent the job responsibilities of between 80 and 95 percent of FM professionals. These functional areas are listed below.

Long-range facility planning
Annual facility planning (tactical planning)
Facility financial forecasting and budgeting
Real estate acquisition and/or disposal
Interior space planning, work space specification, furniture and equipment installation, and space management
Architectural and engineering planning and design
New construction and/or renovation
Maintenance and operations management of the physical plant
Telecommunications integration, security, and general administrative service (food services, reprographics, transportation, etc.)

The above list is from 1994. There also exists an earlier version of this list, dated 1984. Source: [*IFMA*, 1984] reproduced by [*Becker*, 1990]

Real Estate Building acquisition-purchase Building acquisition-lease Site selection Site acquisition Property disposal Out leasing	**Interior planning** Planning Replanning Furniture specification Major changes
Long Range Planning Developing one to three-year plans Developing three ten-year plans Developing ten-plus-year plans	**Space Management** Space allocation Space inventory Space forecasting
Interior Installation Furniture installation Furniture moving Furniture moving Furniture maintenance Furniture inventory Minor changes Design evaluation Employee satisfaction evaluation	**Maintenance and Operations** Exterior maintenance Breakdown maintenance Preventive maintenance Maintenance of finishes Landscape maintenance Housekeeping Trash removal Hazardous waste disposal Energy management
Architecture and Engineering Services Architectural design Systems design Code compliance Construction management	**Budgeting** Capital Operating Furniture

Two more American lists could be added. *Binder* [1989] states that the following diverse functions are incorporated in FM.

Master space planning	Scheduling
Space inventory	Layout and design
Space and furniture standards setting	Purchasing (furniture and construction items)
Project management (administration and setting)	Construction management
Programming requirements	Ongoing maintenance management
Financial control (budgeting and forecasting)	

Hamer [1988] adds the following to Binder's list:

Real estate strategy
Site management
Overall system co-ordination

Finally a non-American list, where FM functions are grouped into four areas, can be mentioned [*Quah Lee Kiang*, 1992].

Financial Management	Purchase/sell	
	Rental/return	
	Demolition and rebuild/modernise	
Space Management	Utilisation	
	Relocation	
	Interior design	
	Furniture and equipment	
Operational Management	Building enclosure	structure and fabric
		components and finishes
	Building services	electrical
		plumbing and waste disposal
		HVAC
		transportation
		communication
		fire protection
	Building environment	cleaning
		security
		indoor air
		visual/thermal
	Building grounds	car parks
		landscaping
		outbuildings and amenities
Behavioural Management	Occupiers perception	
	Occupiers participation	
	Occupiers satisfaction	

Using the different descriptions of the FM functions above as a basis, another structure is proposed in the table below.

Grouping of Functional Area	**Functional Areas**	**Function Types**	**Functions**
Real Estate and Financial Management	Long Range Facility Planning	Real Estate Strategy 1-3 years plan 3-10 years plan >10 years plan	
	Annual Facility Planning		
	Facility Finical Forecasting and Budgeting		
	Real Estate Acquisition and Disposal	Site Acquisition	Site Selection Site Acquisition
		Building Acquisition	Building Purchase Building Lease Property Disposal
Customer Management	User Support	User's Perception, Participation and Satisfaction	
Spatial Management	Spatial Management and Operation and Planning	Space Management	Space Allocation Space Inventory Space Forecasting
		Interior Planning	Planning Replanning Space and Furniture Standard Setting Furniture and Equipment Specification
		Interior Installation	Furniture and Equipment Installation Moving Maintenance Inventory
Operation and Maintenance	Operation	Energy and Media Management	
		Inspection	
		Operation	Security Cleaning Trash Removal
			Hazardous waste disposal Housekeeping
	Maintenance	Preventive Maintenance	Inspection based Maintenance
			Planned Maintenance
		Repair Maintenance	Breakdown Maintenance
			Other Continuos Maintenance
Renovation, Rebuilding and Expansion	Planning and Design	Programming	
		Architectural Design	
		Technical System Design	
	Renovation and Construction	Renovation and Constr. Work	
		Management Work	

Appendix 3: Examples of a few classes of the KBS Model

This appendix contains examples of classes defined in the KBS Model project using the BSAB System as a point of departure.

1 EARTHWORKS ETC

10 COMPLEX

11 EARTHWORKS
- **110 Complex**
  - 110.1 Technical documentation (A8)
  - 110.2 Investigation, tests, etc. (B1)
  - 110.3 Auxiliary works (B2)
  - 110.4 Relocation, demolition (B3)
- **111 Built areas**
  - 111.1 Excavation in soil (B5)
  - 111.2 Excavation in rock (B6)
  - 111.3 Filling (C1)
  - 111.4 Filter, reshaping and separating courses (C3)
  - 111.5 Soil reinforcement (C4)
  - 111.6 Rock reinforcement (C5)
- **112 Trenches**
  - 112.1 Excavation in soil (B5)
  - 112.2 Excavation in rock (B6)
  - 112.3 Filling (C2)
  - 112.4 Filter, reshaping and separating courses (C3)
  - 112.5 Soil reinforcement (C4
  - 112.6 Rock reinforcement (C5
- **113 Paved ground**
  - 113.1 Excavation in soil (B5)
  - 113.2 Excavation in rock (B6)
  - 113.3 Filling (C1)
  - 113.4 Filter, reshaping and separating courses (C3)
  - 113.5 Soil reinforcement (C4)
  - 113.6 Rock reinforcement (C5)
- **114 Grassed areas**
  - 114.1 Excavation in soil (B5)
  - 114.2 Excavation in rock (B6)
  - 114.3 Filling (C1.5)
  - 114.4 Filter, reshaping and separating courses (C3)
- **116 Other Ground**
  - 116.1 Excavation in soil (B5)
  - 116.2 Excavation in rock (B6)
  - 116.3 Filling (C2)
  - 116.4 Filter, reshaping and separating courses (C3)
  - 116.5 Soil reinforcement (C4)
  - 116.6 Rock reinforcement (C5)

13 EXTERNAL PIPE SYSTEMS
- **130 Complex**
  - 130.1 Technical documentation (A8)
  - 130.2 Investigation, tests, etc. (B1)
  - 130.3 Auxiliary works (B2)
  - 130.4 Relocation, demolition (B3)
  - 130.5 Tree felling, clearance etc (B4)
- **131 Built areas**
- **132 Trenches**
  - 132.1 Pipes, underground (I1)
  - 132.2 Heating mains (I2)
  - 132.3 Anchorages (I5)
  - 132.4 Isolation (I6)
  - 132.5 Manholes etc. (I7)
  - 132.6 Installation materials (J2)
  - 132.7 Pipe entries (J3)
  - 132.8 Electrical and telephone lines (J4)
  - 132.9 Protecting devices (J8)
- **133 Paved ground**
- **134 Grassed areas**
- **136 Other Ground**

14 STRUCTURAL SYSTEMS ABOVE GROUND
- **140 Complex**
  - 140.1 Technical documentation (A8)
  - 140.2 Investigation, tests, etc. (B1)
  - 140.3 Auxiliary works (B2)
- **141 Built areas**
  - 141.1 Piling (C6)
  - 141.2 Bridges etc (E)
- **142 Trenches**
  - 142.1 Piling (C6)
  - 142.2 Pre-cast site steps, walls (D5)
- **144 Grassed areas**
- **146 Other Ground**

16 SURFACING ETC.
- **160 Complex**
  - 160.1 Technical documentation (A8)
- **162 Trenches**
- **163 Paved ground**
  - 163.1 Sub-base, base course and separating courses (D1)
  - 163.2 Surfacing etc (D2)
  - 163.3 Edge strips, gutters, surface markings (D4)
  - 163.4 Pre-cast site steps, walls (D5)
  - 163.5 Underground bases (D6.1)
  - 163.6 Thermal insulation (K1.2)
- **164 Grassed areas**
  - 164.1 Planted areas (D3)
  - 164.2 Underground bases (D6.1)
- **166 Other Ground**

17 PLANTS
- **170 Complex**
- **174 Grassed areas**
  - 174.1 Technical documentation (A8)

174.2 Sowing, planting (D3.3)
174.3 Support & protection (D3.4)
175 Natural ground
175.1 Sowing, planting (D3.3)
175.2 Support & protection (D3.4)
176 Other Ground

18 FIXTURES ON GROUND
180 Complex
180.1 Technical documentation(A8)
183 Paved ground
183.1 Fixtures above ground (D6)
184 Grassed areas
184.1 Fixtures above ground (D6)
185 Natural ground
185.1 Fixtures above ground (D6)
186 Other Ground

Appendix 4: A classification of attributes according to the CIB Master List

Appendix 4A: Attribute classification in the KBS Model (based on the CIB Master List)

Class No	Class Name	Information content
0	**Identification and Complex**	
0.1	**Identification**	Information that identifies the BPM entity, its usage and purpose and the identification of relevant documents
0.2	**Complex**	Information that belongs to two or more attribute classes
1	**External effects and Requirements**	
1.1	**External effects** *(Agents)*	Information about external effects from e.g. climate, site and usage. Different types of external effects are: -mechanical effects, forces -electromagnetic effects -thermal effects -chemical effects -biological effects
1.2	**Requirements** *(Requirements)*	Information from authorities, owners and/or users of the building concerning e.g.: -load bearing capacity -durability -fire safety -safety in use/protection -indoor climate -hygiene -environmental considerations/requirements -production requirements -requirements on maintenance (e.g. economic and energy -aesthetic requirements -usability and accessibility
2	**Product Description** *(Description)*	Information about characteristics properties of the BPM entity concerning e.g.: -assembly including methods -material -shape, size, geometry, quantities -weight, density -surface texture, colour, finish -position, placing
3	**Environmental Properties** *(Properties)*	Information about the characteristics of the BPM entities from an environmental perspective concerning e.g.: -capacity, output and consumption -structural and mechanical -fire -matter: gaseous, liquid, solid, physical and chemical -biological -thermal -optical -acoustic, magnetic, electro-magnetic radiation, energy -service life: reliability and durability

4	**Design** *(Design Work)*	Information about technical and economic suitability, restrictions and precautionary measures e.g.: -functionality -economic factors -legality -economising of resources -typical details, special solutions -calculation methods, computer programs -pitfalls, cautions
5	**Production** *(Site Work)*	Information concerning working methods, storage and assembly e.g.: -requirements on human effort, construction products and aids and media/energy -handling and storage -mounting, installation, temporary supports, methods -cleaning, protection of finished work -safety, staff welfare -times, phases
6	**Operation** *(Operation)*	Information about continuous efforts for the usage and exploration of the building e.g.: -energy consumption, expandable items, starting instructions -operating and checking instructions -management, servicing and cleaning -diagnosis of faults -safety, security, welfare
7	**Maintenance** *(Maintenance)*	Information concerning preventive or repair maintenance in order to keep the building in good order e.g.: -access -repair work -replacement of parts, renewal, making good -protective measures -safety, security and welfare
8	**Supplier and Supply**	
8.1	**Supplier** *(Supplier)*	Information about the supplier e.g.: -commercial, administrative organisation -references -catalogues
8.2	**Supply** *(Supply)*	Information about delivery terms e.g.: -ordering -conditions for sale -prices -delivery and special services
9	**Other types of information**	

Appendix 4B: An example of an attribute table for one particular KBS Model entity

355.2 French window 1

1 BRIEFING/PROGRAMMING
2 DESIGN
3 TENDERING
4 CONSTRUCTION
5 DELIVERY
6 FACILITY USAGE

L = Add data F = Update Data
H = Retrieve Data T = Delete Data

		1	2	3	4	5	6
0 IDENTIFICATION AND COMPLEX							
ID	ID No	L	F	H	H	H	H
FILNAMN	Drawing file name	L	F	H	H	H	H
TYP	Type designation	L	F	H	H		
UTTNR	Class No	L	F	H	H		
BDTK	Bldg element type code	L	F	H	H		
STANS	Phase in process	L	F	H	H		
1 EXT. ACTION, REQUIREMENTS							
VIND	Wind load	L	H	H			
TEMP	Temperature	L	H	H			
ANV	Usability	L	H	H			
ESTET	Aesthetic requirements	L	F	H			
2 PRODUCT DESCRIPTION							
MHOJD	Mod. dim. height	L	F	H			
MBREDD	Mod. dim. width	L		H			
KARMDJ	Frame depth		L	H	H		
VAGGAVST	Wall distance		L	H	H		
DREV	Caulking allowance		L	H	H		
DH	Ref. height from bottom		L	H	H		
LAGE	Position		L	H	H		
ANTAL	Number off	L	F	H	H	H	H
BVAREA	Gross vert. area		L	H	H		
LASCYL	Lock cylinder id		L	H	H	H	F
TOL	Tolerance		L	H	H		
OPPNS	Opening method		L	H	H		
LUFT	Light		L	H	H		
KOMP	Component		L	H	H		
DELN	Division		L	H	H		
KARMDJUP	Frame depth		L	H	H		
MTRLFORM	Material and shape	L	F	H	H		
LSTYP	Lock type		L	H	H	H	H
SPANJOL	Espagnolette		L	H	H	H	H
HANDTAG	Handle		L	H	H	H	H
GANGJARN	Hinge		L	H	H	H	H
KOPPELB	Fittings for coupled panes		L	H	H	H	H
BROMS	Door closer		L	H	H	H	H
VENTIL	Valve		L	H	H	H	H
HALTAGN	Holes		L	H	H		
TATNLIST	Weather- proofing		L	H	H		
FONSTLAS	Window lock		L	H	H	H	H
SOLSKYDD	Sunshade		L	H	H		
GLASNING	Glazing		L	H	H		
SKYDDSB	Protective coating		L	H	H		
KARMDET	Frame details		L	H	H		
BESLAGN	Furniture		L	H	H	H	H
KANALIS	Chases		L	H	H		
KARMMTRL	Frame material		L	H	H		
KARMYTBE	Frame finish		L	H	H	H	F
KARMKVLO	Frame colour		L	H	H	H	F
KARMGLAN	Frame gloss		L	H	H	H	H
KARMMALN	Frame painting class		L	H	H	H	F
TKELUTF	Threshold construction		L	H	H		
TKELMATRL	Threshold material		L	H	H		

Appendix 5: Description of frequently used modelling notations

This appendix encompasses a description of SADT/IDEF0 process modelling technique and the graphical presentation of the EXPRESS language known as EXPRESS-G.

The descriptions are taken from [*ISO*, 1996d] and [*Karhu*, 1997]. Other useful references are [*Appelton*, 1995], [*ISO* , 1993a], [*ISO* , 1993b] and [*Schenck & Wilson*, 1994].

Appendix 5A: The SADT/IDEF0 process modelling method

The SADT (Structured Analysis and Design Techniques) method was developed in the late 1960s. SADT consists of techniques for performing system analysis and design, but also a techniques for defining requirements and system development. The US Air Force's Integrated Computer-Aided Manufacturing project adopted SADT and placed a subset of it into the public domain as IDEF0. IDEF stands for Integrated computer-aided manufacturing DEFinition and the technique consists of three parts (IDEF0, IDEF1 and IDEF2) that may be used independently. In the following IDEF0 is described.

In an IDEF0 model the activities are represented by a box as shown in Figure 1. The information or objects used are represented by arrows called input, output, control and mechanism:

- The input enters the box from the left. Example: raw data.
- The output is represented with an output arrow. Example: drawing.
- The control enters the box from the top. Example: design instructions.
- The mechanism enters from the bottom. Example: computer program.

Each box that appears on an IDEF0 diagram represents an activity that modifies input(s) to produce output(s).

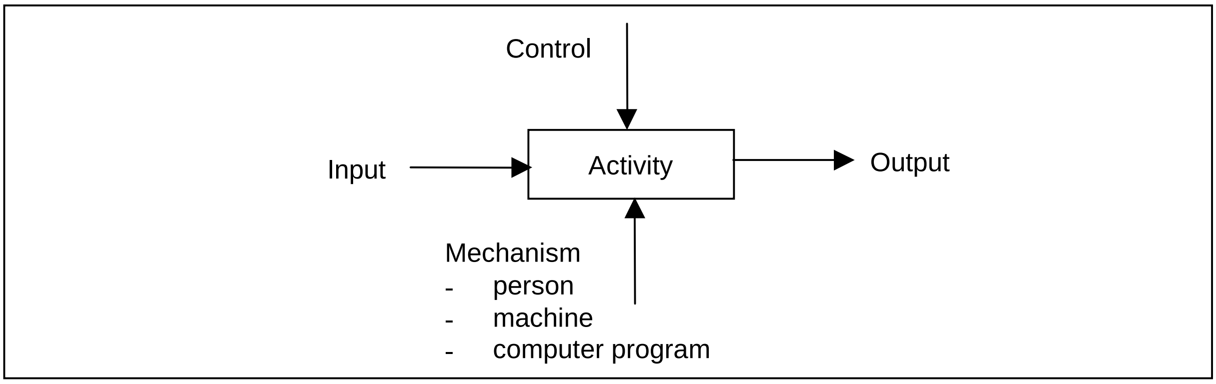


Figure 1. The SADT/IDEF0 activity box.

The arrows are needed by or produced by the activity. The distinction of the input arrows and controls is that the input arrows represent the information which are processed by the activity while the control arrows describe conditions or specifications that govern the activity. The output arrows are the information produced by the activity.

The activities are drawn in hierarchical diagrams. A schematic view of the hierarchy of the diagrams is shown in Figure 2. The hierarchy of the diagrams may be traced by the node number or the context.

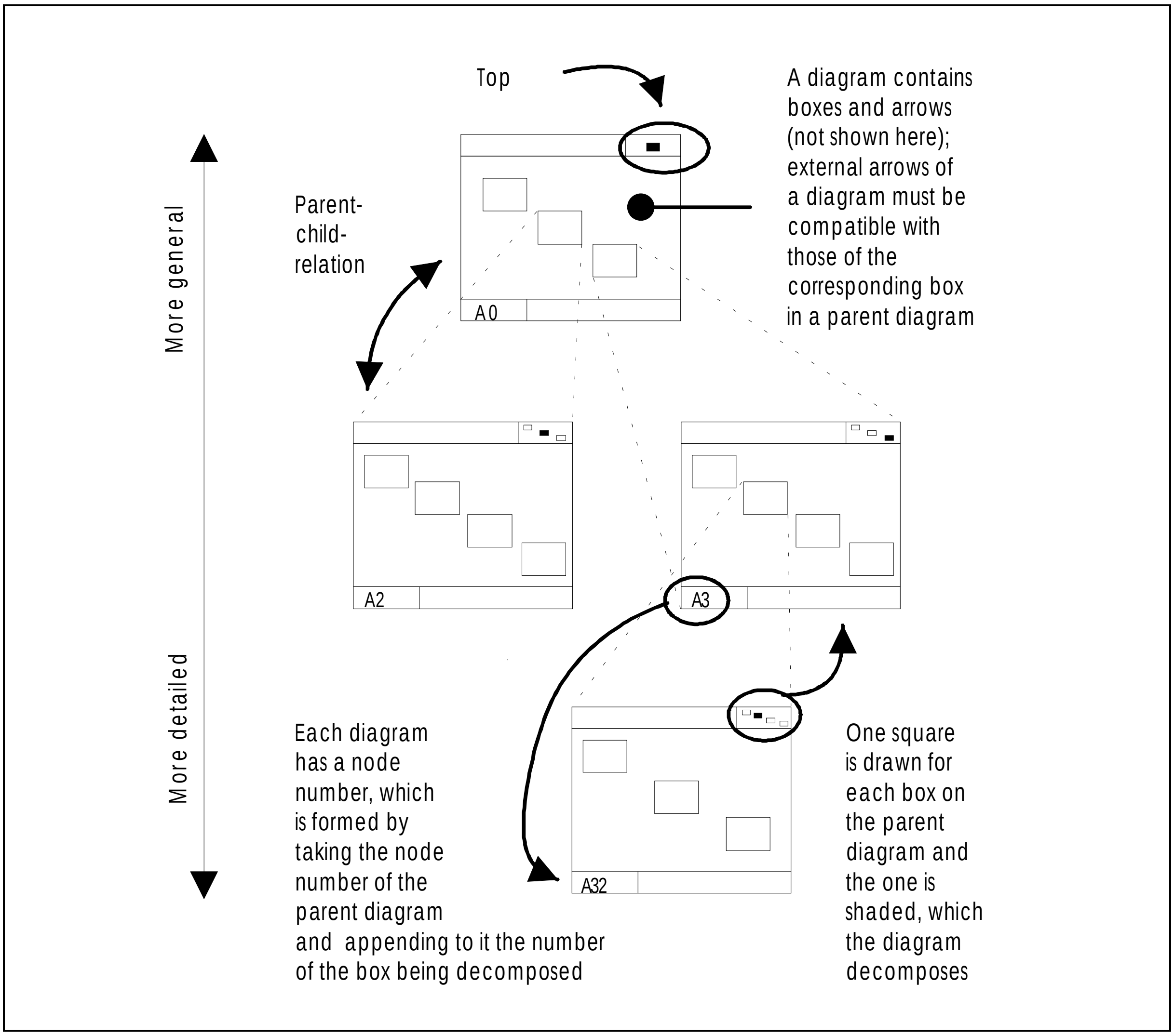


Figure 2. The hierarchical structure and reference systematic of the IDEF0 modelling system.

Appendix 5B: EXPRESS and EXPRESS-G notation

The EXPRESS language

According to Schenck and Wilson [*Schenck & Wilson,* 1994], EXPRESS is an object-flavoured information model specification language which was initially developed in order to enable the writing of formal information models describing mechanical products. It is fully described in [*ISO,* 1993b].

In rough terms, its main features are:

- the containing structure, called **schema** can be seen as a frontier of the interest area described. The different contexts defined through the schemata can reference each other (USE FROM or REFERENCE clauses)

- the definition of objects, called « **entities** » in EXPRESS. The properties of an entity are represented as attributes and constraints. Furthermore, an entity could be included into an inheritance graph (« **subtype** » and « **supertype** » clauses). EXPRESS allows the definition of entities as subtypes of other entities, where a subtype entity is a specialisation of its supertype. This establishes an inheritance relationship, in which the subtype inherits the characteristics (attributes and constraints).
- the attributes can be seen as relationships between the entity and a « **type** ». They are typified according to several possible type definitions:
  - **simple data types** (binary, boolean, logical, string, number, integer, real)
  - **aggregation data types** - LIST, SET, BAG and ARRAY with the cardinality defined
  - **named data type** (either an entity data type or a defined data type - i.e. declared by a type definition)
  - **constructed data type** (select, enumeration).

  Furthermore, it is possible to declare an attribute as:
  - « optional », depending on it might or not have value;
  - « derive », its value is computed in some manner;
  - « inverse », its value consists of instances which use the entity in a particular role.

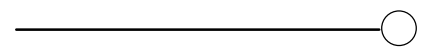
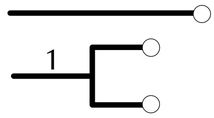
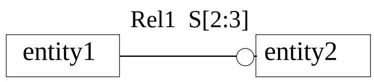
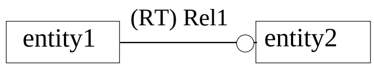
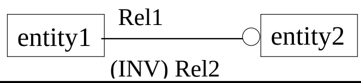
Additional mechanisms are provided in order either to constrain the use of entities by means of rules (uniqueness or domain rules for instance) or to provide executable statements.

EXPRESS-G is a formal graphical notation for the display of data specifications defined in the EXPRESS language. The notation only supports a subset of the EXPRESS language. According to Annex D in [*ISO*, 1993b], EXPRESS-G describes graphically the aforementioned language with the following conventions:

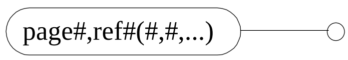
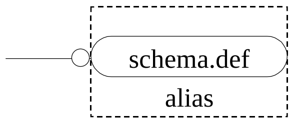
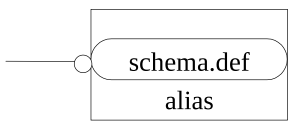
Definition:
The definition of things - either types or entities - is depicted by a box with several graphical possibilities:

EXPRESS	***Graphical symbols***	***Example***
Schema	rectangular solid box divided in two sub-boxes by an horizontal line. In the upper part is located the name of the schema	my_schema
Simple data type	rectangular solid box with a double vertical line at the right end of the box. The label within the box is the pre-defined name of the data type	STRING REAL
Constructed data types	rectangular dashed box. The label within the box is the name of the data type SELECT data type : double vertical line on the left ENUMERATION data type : double vertical line on the right	example_select example_enumeration
Defined data type	rectangular dashed box. The label within the box is the name of the data type	new_defined_data_type
Entity data type	rectangular solid box. The label within the box i s the name of the entity	entity_name

Relationship:
The relationship between things are described using some lines between the boxes:

EXPRESS	***Graphical symbols***	***Example***
Optional attribute	dashed line	
Attribute non optional	line	
Inheritance relationship (subtype/supertype)	thick line An ***ONEOF*** relation may be indicated by the digit 1 placed at a branching junction.	
The preference sense of a relationship is outlined by an open circle	open circle at the end of the line and before the second term of the association.	
Cardinality of relationship with aggregation data types	On the relationship line for the attribute. The first letter of the aggregation data type (A, B, L, or S) is used. The default cardinality for a required relationship is one and zero or one for an optional attribute.	
Redeclaration of supertype attributes within a subtype	Characters RT enclosed in parentheses	
Inverse attribute	Characters INV enclosed in parentheses	
Derive attribute	Characters DER enclosed in parentheses	

Composition:
EXPRESS-G provides different supports the diagrams spanning more than one sheet of paper (called page references) or the current schema referencing other schemata (called inter-schema references). So two composition symbols may be found in a diagram : the page references and the inter-schema references :

EXPRESS	***Graphical symbols***	***Example***
Page reference onto the current page	relationship line terminated by a rounded box which contains a page number and the reference number. If several pages should be referenced, the box may contain a parenthesised list of the page numbers where references originated.	
Page reference onto another page	relationship line terminated by a rounded box which contains a page number and the reference number.	
Definition referenced from another schema	a round box enclosing the name of the definition qualified by the schema name. The REFERENCE statement is represented by a dashed enclosing rectangular box. *alias* is the name of an alias of the definition.	
definition used from another schema	a round box enclosing the name of the definition qualified by the schema name. The USE statement is represented by a solid enclosing rectangular box. *alias* is the name of an alias of the definition.	

Lastly, EXPRESS-G does not support the FUNCTION or PROCEDURE clauses.

Appendix 6: Essential schemas of the thesis described with EXPRESS code

Appendix 6A: The complete theoretical KBS Model (corresponds to the figures 6:11a - 6:11e)

```
(* *************** KBS_Core *************** *)
SCHEMA KBS_Core;

USE FROM Catalogue_of_Spatial_Systems
            (Type_of_Spatial_System);
USE FROM Catalogue_of_Technical_Systems
            (Type_of_Technical_System);
USE FROM Catalogue_of_Construction_Parts
            (Type_of_Construction_Part);
USE FROM Work_Section_Sub_Model
            (Work_Section);

ENTITY Building;
            building_system : SET [1:?] OF System;
            real_estate_unit : Real_Estate_Unit;
            interested_party : OPTIONAL SET [1:?] OF Interested_Party;
END_ENTITY;

ENTITY Construction_Part
 SUBTYPE OF (Physical_Part);
            type_of_construction_part : SET [1:?] OF Type_of_Construction_Part;
            work_section : SET [1:?] OF Work_Section;
            position : Position;
            shape : Shape_Description;
END_ENTITY;

ENTITY Construction_Part_Assembly;
            part_child : Construction_Part;
            part_parent : Construction_Part;
END_ENTITY;

ENTITY Enterprise;
END_ENTITY;

ENTITY Fittings_and_Furnishing
 SUBTYPE OF (Physical_Part);
END_ENTITY;

ENTITY Form_Description;
END_ENTITY;

ENTITY Interested_Party;
END_ENTITY;

ENTITY Location;
            spatial_system_location : Spatial_System;
            physical_part_location : Physical_Part;
END_ENTITY;

ENTITY Physical_Part
 ABSTRACT SUPERTYPE OF (ONEOF(Fittings_and_Furnishing,Construction_Part));
 INVERSE
            connection_port : SET[0:?] OF Port FOR port_part;
END_ENTITY;

ENTITY Port;
            port_part : ARRAY [1:2] OF Physical_Part;
END_ENTITY;

ENTITY Position;
END_ENTITY;
```

```
ENTITY Real_Estate_Unit;
            enterprise : OPTIONAL SET [1:?] OF Enterprise;
            surrounding : OPTIONAL SET [1:?] OF Surrounding;
END_ENTITY;

ENTITY Shape_Description;
END_ENTITY;

ENTITY Space_Configuration;
            space : Spatial_Volume;
            construction_part : Construction_Part;
END_ENTITY;

ENTITY Spatial_System
 SUBTYPE OF (System);
            type_of_spatial_system : Type_of_Spatial_System;
            space : Spatial_Volume;
END_ENTITY;

ENTITY Spatial_Volume;
            form_description : Form_Description;
END_ENTITY;

ENTITY Surrounding;
END_ENTITY;

ENTITY System
 ABSTRACT SUPERTYPE OF (ONEOF(Technical_System,Spatial_System));
END_ENTITY;

ENTITY System_Assembly;
            system_child : System;
            system_parent : System;
END_ENTITY;

ENTITY System_Configuration;
            system : Technical_System;
            construction_part : Construction_Part;
END_ENTITY;

ENTITY Technical_System
 SUBTYPE OF (System);
END_ENTITY;

END_SCHEMA;

(* ************** Work_Section_Sub_Model ************** *)
SCHEMA Work_Section_Sub_Model;

ENTITY Apparatus_or_Unit
 SUBTYPE OF (Work_Section_Type);
END_ENTITY;

ENTITY Complement
 SUBTYPE OF (Work_Section_Type);
END_ENTITY;

ENTITY Component
 SUBTYPE OF (Work_Section_Type);
END_ENTITY;

ENTITY Construction_Aid
 SUBTYPE OF (Resource_Type);
END_ENTITY;

ENTITY Construction_Product
 SUBTYPE OF (Resource_Type);
END_ENTITY;

ENTITY Layer
 SUBTYPE OF (Work_Section_Type);
```

```
END_ENTITY;

ENTITY Excavation_or_Filling
 SUBTYPE OF (Work_Section_Type);
END_ENTITY;

ENTITY Fitting_and_Appurtenance
 SUBTYPE OF (Work_Section_Type);
END_ENTITY;

ENTITY Labour
 SUBTYPE OF (Resource_Type);
END_ENTITY;

ENTITY Method;
            description : Method_Description;
END_ENTITY;

ENTITY Method_Description;
END_ENTITY;

ENTITY Other_Resource
 SUBTYPE OF (Resource_Type);
END_ENTITY;

ENTITY Pavement
 SUBTYPE OF (Work_Section_Type);
END_ENTITY;

ENTITY Pile_Foundation
 SUBTYPE OF (Work_Section_Type);
END_ENTITY;

ENTITY Profile
 SUBTYPE OF (Work_Section_Type);
END_ENTITY;

ENTITY Recipe;
            resources : OPTIONAL SET [1:?] OF Resource_Type;
            methods : OPTIONAL SET [1:?] OF Method;
END_ENTITY;

ENTITY Resource_Type
 ABSTRACT SUPERTYPE OF
  (ONEOF(Labour,Construction_Aid,Construction_Product,Other_Resource));
END_ENTITY;

ENTITY Soil_Reinforcement
 SUBTYPE OF (Work_Section_Type);
END_ENTITY;

ENTITY Trench
 SUBTYPE OF (Work_Section_Type);
END_ENTITY;

ENTITY Work_Section;
            has_work_section_type : SET [1:?] OF Work_Section_Type;
            processes : OPTIONAL SET [1:?] OF Work_Section_Process;
END_ENTITY;

ENTITY Work_Section_Process;
            recipes : OPTIONAL SET [1:?] OF Recipe;
END_ENTITY;

ENTITY Work_Section_Type
 ABSTRACT SUPERTYPE OF (ONEOF(Trench, Pile_Foundation, Apparatus_or_Unit,
  Complement,Pavement, Fitting_and_Appurtenance, Layer, Excavation_or_Filling,
   Soil_Reinforcement, Profile,Component));
END_ENTITY;

END_SCHEMA;
```

```
(* *************** Catatolgue_of_Construction_parts *************** *)
SCHEMA Catalogue_of_Construction_Parts;

USE FROM Work_Section_Sub_Model
            (Work_Section);

ENTITY Frame_Element
 SUBTYPE OF (Type_of_Construction_Part);
END_ENTITY;

ENTITY Installation_Element
 SUBTYPE OF (Type_of_Construction_Part);
END_ENTITY;

ENTITY Lining_and_Coverings
 SUBTYPE OF (Type_of_Construction_Part);
END_ENTITY;

ENTITY Opening_and_Connection
 SUBTYPE OF (Type_of_Construction_Part);
END_ENTITY;

ENTITY Plate
 SUBTYPE OF (Type_of_Construction_Part);
END_ENTITY;

ENTITY Secondary_Building_Element
 SUBTYPE OF (Type_of_Construction_Part);
END_ENTITY;

ENTITY Type_of_Construction_Part
 ABSTRACT SUPERTYPE OF (ONEOF(Frame_Element, Plate, Installation_Element,
  Lining_and_Coverings, Opening_and_Connection, Secondary_Building_Element));
            has_work_section : OPTIONAL SET [1:?] OF Work_Section;
END_ENTITY;

END_SCHEMA;

(* *************** Catalogue_of_Spatial_Systems *************** *)
SCHEMA Catalogue_of_Spatial_Systems;

ENTITY Area
 SUBTYPE OF (Type_of_Spatial_System);
END_ENTITY;

ENTITY Block
 SUBTYPE OF (Type_of_Spatial_System);
            blocks : OPTIONAL SET [1:?] OF Block;
END_ENTITY;

ENTITY Building_Space
 SUBTYPE OF (Type_of_Spatial_System);
            sections : OPTIONAL SET [1:?] OF Section;
            storey_spaces : SET [1:?] OF Storey_Space;
END_ENTITY;

ENTITY Part_of_Room
 SUBTYPE OF (Type_of_Spatial_System);
END_ENTITY;

ENTITY Room
 SUBTYPE OF (Type_of_Spatial_System);
            parts_of_room: OPTIONAL SET [1:?] OF Part_of_Room;
END_ENTITY;

ENTITY Section
 SUBTYPE OF (Type_of_Spatial_System);
            storey_spaces : OPTIONAL SET [1:?] OF Storey_Space;
END_ENTITY;

ENTITY Stage
 SUBTYPE OF (Type_of_Spatial_System);
```

```
END_ENTITY;

ENTITY Storey_Space
 SUBTYPE OF (Type_of_Spatial_System);
           blocks : OPTIONAL SET [1:?] OF Block;
           rooms : SET [1:?] OF Room;
END_ENTITY;

ENTITY Type_of_Spatial_System
 ABSTRACT SUPERTYPE OF (ONEOF(Room, Block, Area, Stage, Section,
  Storey_Space, Building_Space, Part_of_Room));
END_ENTITY;

END_SCHEMA;


(* *************** Catalogue_of_Technical_Systems *************** *)

SCHEMA Catalogue_of_Technical_Systems;

ENTITY Control_and_Monitoring
 SUBTYPE OF (Installation_Systems);
END_ENTITY;

ENTITY Earth_works
 SUBTYPE OF (Type_of_Technical_System);
END_ENTITY;

ENTITY Electrical
 SUBTYPE OF (Installation_Systems);
END_ENTITY;

ENTITY HVAC_and_Sanitation
 SUBTYPE OF (Installation_Systems);
END_ENTITY;

ENTITY Installation_Systems
 ABSTRACT SUPERTYPE OF (ONEOF(HVAC_and_Sanitation, Electrical, Transport,
  Control_and_Monitoring))
 SUBTYPE OF (Type_of_Technical_System);
END_ENTITY;

ENTITY Structural_Systems
 SUBTYPE OF (Type_of_Technical_System);
END_ENTITY;

ENTITY Transport
 SUBTYPE OF (Installation_Systems);
END_ENTITY;

ENTITY Type_of_Technical_System
 ABSTRACT SUPERTYPE OF (ONEOF(Earth_works, Installation_Systems,
  Structural_Systems));
END_ENTITY;

END_SCHEMA;
```

Appendix 6B: The implemented version of the KBS Model used in the Blandaren prototype (corresponds to the figures 7:9a - 7:9b)

```
SCHEMA Blandaren;

TYPE Measurement = LIST [1:?] OF REAL;
END_TYPE;

TYPE Part_Catalogue_Reference = STRING;
END_TYPE;
```

```
TYPE Space_Catalogue_Reference = STRING;
END_TYPE;

TYPE integer_array = LIST [1:?] OF INTEGER;
END_TYPE;

TYPE opening_hanging = ENUMERATION OF
            (left,
             right);
END_TYPE;

TYPE real_array = LIST [1:?] OF REAL;
END_TYPE;

TYPE revision = ENUMERATION OF
            (deleted,
             new,
             updated);
END_TYPE;

ENTITY Beam_Part
 SUBTYPE OF (Construction_Part);
            beam_length : Measurement;
            dx : Measurement;
            dy : Measurement;
END_ENTITY;

ENTITY Building;
            real_estate_unit : Real_Estate_Unit;
END_ENTITY;

ENTITY Building_Part_Default
 SUBTYPE OF (Construction_Part);
END_ENTITY;

ENTITY Building_Space
 SUBTYPE OF (Space);
END_ENTITY;

ENTITY Column_Part
 SUBTYPE OF (Construction_Part);
            column_length : Measurement;
            dx : Measurement;
            dy : Measurement;
END_ENTITY;

ENTITY Construction_Part
 SUPERTYPE OF (ONEOF(Column_Part, Beam_Part, Wall_Part, Plate_Part,
  Opening_Part, Building_Part_Default))
 SUBTYPE OF (Physical_Part);
            part_name : Part_Catalogue_Reference;
            history_part : History;
            volume_part : Volume;
            free_volume_part : Volume;
END_ENTITY;

ENTITY Enterprise;
END_ENTITY;

ENTITY Fittings_and_Furnishing
 SUBTYPE OF (Physical_Part);
END_ENTITY;

ENTITY Floor_Plan
 SUBTYPE OF (Space);
END_ENTITY;

ENTITY History;
            status : revision;
            classification : STRING;
            partname : STRING;
```

```
            typename : STRING;
            date : STRING;
            source_doc : STRING;
            source_id : INTEGER;
END_ENTITY;

ENTITY Line;
            surface_line : SET [1:2] OF Surface;
            x : real_array;
            y : real_array;
            z : real_array;
            weight : real_array;
            line_function : integer_array;
END_ENTITY;

ENTITY Location;
            spatial_system_location : Spatial_System;
            physical_part_location : Physical_Part;
END_ENTITY;

ENTITY Opening_Part
 SUBTYPE OF (Construction_Part);
            wall_distance : Measurement;
            space_tolerance : Measurement;
            offset : Measurement;
            opening_height : Measurement;
            opening_width : Measurement;
            hanging : opening_hanging;
END_ENTITY;

ENTITY Part_Assembly;
            part_child : Physical_Part;
            part_parent : Physical_Part;
END_ENTITY;

ENTITY Part_of_Room
 SUBTYPE OF (Space);
END_ENTITY;

ENTITY Participant;
            space : SET [0:?] OF Space;
END_ENTITY;

ENTITY Physical_Part
 ABSTRACT SUPERTYPE OF (ONEOF(Construction_Part, Fittings_and_Furnishing));
 INVERSE
            connection_port : SET[0:?] OF Port FOR port_part;
END_ENTITY;

ENTITY Plate_Part
 SUBTYPE OF (Construction_Part);
            plate_thickness : Measurement;
END_ENTITY;

ENTITY Port;
            port_part : ARRAY [1:2] OF Physical_Part;
            yarray : real_array;
            zarray : real_array;
            warray : real_array;
END_ENTITY;

ENTITY Real_Estate_Unit;
            enterprise : OPTIONAL SET [1:?] OF Enterprise;
END_ENTITY;

ENTITY Room
 SUBTYPE OF (Space);
END_ENTITY;

ENTITY Space
 ABSTRACT SUPERTYPE OF (ONEOF(Room, Part_of_Room, Space_Type_Default, Floor_Plan,
  Building_Space))
```

```
 SUBTYPE OF (Spatial_System);
            space_name : Space_Catalogue_Reference;
END_ENTITY;

ENTITY Space_Configuration;
            space_configuration : Space;
            construction_part_configuration : Construction_Part;
END_ENTITY;

ENTITY Space_Type_Default
 SUBTYPE OF (Space);
END_ENTITY;

ENTITY Spatial_System
 ABSTRACT SUPERTYPE OF (Space)
 SUBTYPE OF (System);
            volume : Volume;
END_ENTITY;

ENTITY Surface;
            volume_surface : Volume;
 INVERSE
            line_surface : SET[3:?] OF Line FOR surface_line;
END_ENTITY;

ENTITY System
 ABSTRACT SUPERTYPE OF (ONEOF(Spatial_System, Technical_System));
            buildings : SET [1:?] OF Building;
END_ENTITY;

ENTITY System_Assembly;
            system_parent : System;
            system_child : System;
END_ENTITY;

ENTITY System_Configuration;
            system : Technical_System;
            construction_part : Construction_Part;
END_ENTITY;

ENTITY Technical_System
 SUBTYPE OF (System);
END_ENTITY;

ENTITY Volume;
 INVERSE
            surface_volume : SET[4:?] OF Surface FOR volume_surface;
END_ENTITY;

ENTITY Wall_Part
 SUBTYPE OF (Construction_Part);
            wall_thickness : Measurement;
            wall_height : Measurement;
END_ENTITY;

END_SCHEMA;
```

Appendix 6C: The transfer schema used in the Blandaren prototype (corresponds to the figure 7:11)

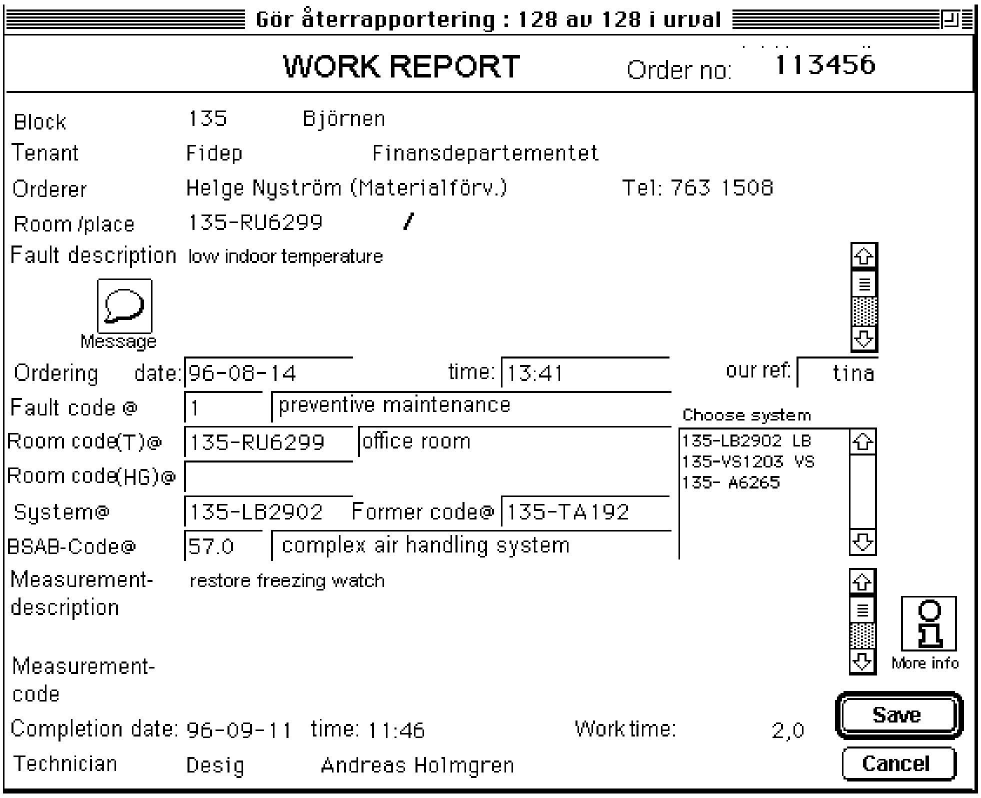
```
SCHEMA BOLOSO;

TYPE lineOrLines = SELECT
            (linelist,
             polyline);
END_TYPE;

ENTITY area
 SUBTYPE OF (loid);
```

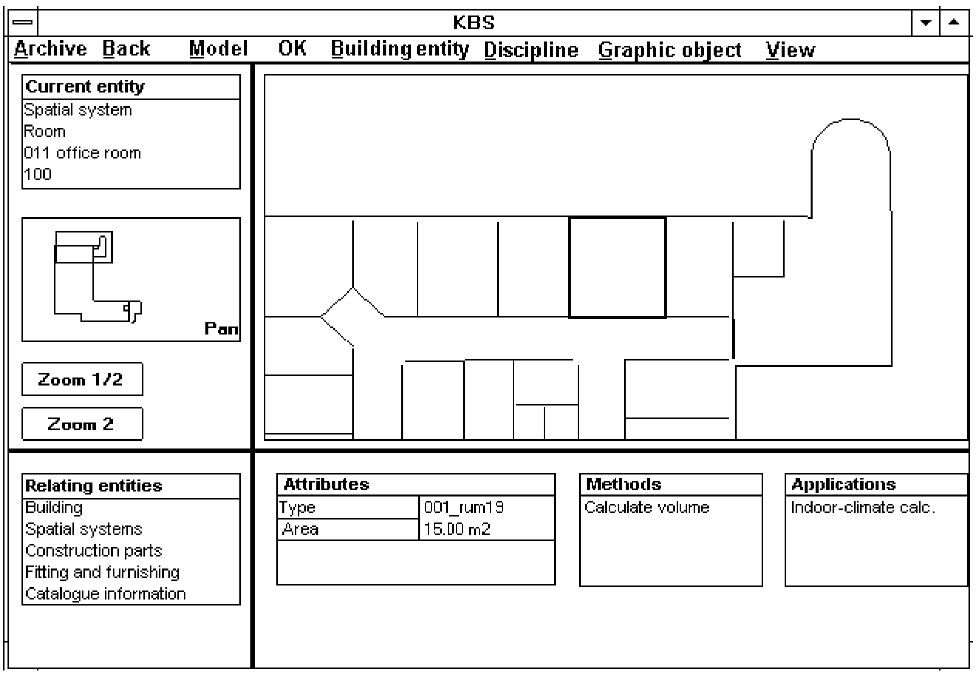
```
END_ENTITY;

ENTITY attribute;
            attribute_name : STRING;
            attribute_value : STRING;
            attribute_unit : OPTIONAL STRING;
END_ENTITY;

ENTITY block
 SUBTYPE OF (loid);
END_ENTITY;

ENTITY boid
 SUBTYPE OF (goid);
END_ENTITY;

ENTITY building_space
 SUBTYPE OF (loid);
END_ENTITY;

ENTITY contain;
            system : soid;
            buildingpart : boid;
END_ENTITY;

ENTITY floor_plan
 SUBTYPE OF (loid);
            ref_x : REAL;
            ref_y : REAL;
END_ENTITY;

ENTITY goid
 ABSTRACT SUPERTYPE OF (ONEOF(loid, boid, soid));
            code : STRING;
            complete_code : STRING;
            revision : STRING;
            date : STRING;
            goid_type : STRING;
            attributes : OPTIONAL SET [1:?] OF attribute;
            unique_id : OPTIONAL id;
            shape : OPTIONAL shape;
END_ENTITY;

ENTITY id;
            id_number : INTEGER;
            source_name : STRING;
END_ENTITY;

ENTITY linelist;
            line : LIST [1:?] OF polyline;
END_ENTITY;

ENTITY loid
 ABSTRACT SUPERTYPE OF (ONEOF(building_space, floor_plan, area,
  block, room))
 SUBTYPE OF (goid);
END_ENTITY;

ENTITY occurence;
            buildingpart : boid;
            placement : loid;
END_ENTITY;

ENTITY point;
            x : REAL;
            y : REAL;
            z : OPTIONAL REAL;
END_ENTITY;

ENTITY polyline;
            points : LIST [2:?] OF point;
END_ENTITY;
```

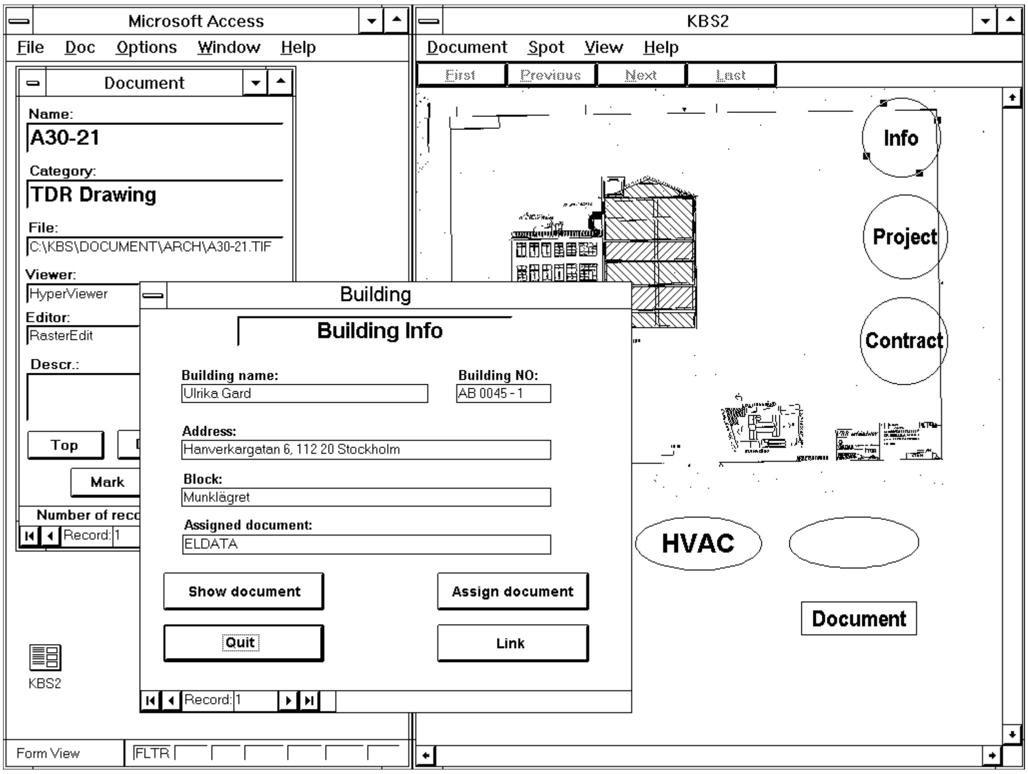
```
ENTITY room
 SUBTYPE OF (loid);
END_ENTITY;

ENTITY shape;
            line : OPTIONAL lineOrLines;
            ref_point : point;
            angle : REAL;
END_ENTITY;

ENTITY soid
 SUBTYPE OF (goid);
END_ENTITY;

ENTITY structure;
            parent : goid;
            child : goid;
END_ENTITY;

END_SCHEMA;
```

Appendix 7: Translation of screen dumps into English

Translated versions of a number of screen dumps of chapter 7 are given in this appendix. These correspond to the figures 7:6, 7:14 and 7:25 in chapter 7.






Microsoft Access
File Doc Options Window Help
Document
Name:
A30-21
Category:
TDR Drawing
File:
C:\KBS\DOCUMENT\ARCH\A30-21.TIF
Viewer:
HyperViewer
Editor:
RasterEdit
Descr.:
Top
Mark
Record: 1
KBS2
Form View
FLTR
Building
Building Info
Building name:
Ulrika Gard
Building NO:
AB 0045 - 1
Address:
Hanverkargatan 6, 112 20 Stockholm
Block:
Munklägret
Assigned document:
ELDATA
Show document
Assign document
Quit
Link
Record: 1
KBS2
Document Spot View Help
First Previous Next Last
Info
Project
Contract
HVAC
Document

Appendix 8: The Spatial Arrangement Model - A proposed STEP Application Protocol

This appendix contain a description of the Spatial Arrangement Model, developed as a proposal for a STEP Application Protocol.

February 27, 1997 [1]
Kjell Svensson

Proposed New Work Item for

ISO TC184/SC4/WG3
Spatial Arrangements AP

1. Scope and Functional Requirements

The Application Protocol (AP) will be a member of a suite of related Reference Models, Resources and APs proposed within the Application Protocol Planning Project (APPP) for Building and Construction submitted to the Project Management Advisory Group of ISO TC184/SC4 in May 1994 (see N315).
The AP's functional scope is the description and representation of :

- the requirements on the internal and external spaces of a facility,
- the spatial entities required to fulfil these requirements, and
- the physical entities that enclose and support the spatial entities.

A nominated operational activity set out the requirements in terms of:
- **spatial requirements** (e.g. area and relationships)
- **environmental requirements and impact** (e.g. temperature ,humidity and acoustic)
- **shell systems requirements** (e.g. finishes)
- **service systems requirements** (e.g. air supply and removal, water supply and removal, gas and fuel supply and removal ,communications and finally transport)
- **fitout and furnishing requirements** (e.g. fittings and equipment)

The **requirements phase** identifies the operational activities to occur in the facility and sets of their spatial, environmental, finish, service and equipment requirements. In this stage the project database is primarily a description of the operational activities with associated spatial and physical requirements. The outcome of this phase is an activity description, expressed as spatial requirements neutral to different possible solutions.
The **schematic design phase** sees the translation of the activity description into a spatial form capable of analysis and of being communicated between project stockholders. Associated

[1] This document was originally written as a STEP document. The EXPRESS-G diagrams and font sizes have been reformatted in this appendix.

technical systems and their respective performance requirements are identified at a generic level.
The **developed design and documentation phase** sees generic systems translated into technical solutions (assemblies). While this phase of the work is focused on the physical system the spatial system will provide a frame of reference.
Data, developed in this stage for physical parts, such as work sections, work packages, construction aids and resources may need to be related to activity data.
The **construction phase** sees the construction of the nominated assemblies.
The **facilities management phase** comprises planning and carrying out of operation and maintenance work, services to the tenant and administration of these activities. To ensure the building users and managers are able to extract full value from the facility they must be able to access its features (projected performance).

The conceptual model of the AP shall:

- handle the operational and external requirements of the facility
- associate appropriate spatial entities with the requirements
- associate with the spatial entities appropriate physical entities (shell, services, fitout) and the respective attributes required for its successful conduct

Fundamental entities referenced in the model include external and operational requirements, building, site, spatial components and finally enclosure and other physical components primarily related to the spatial components.

The model entities must persist over their respective life-cycles - from requirements phase, through design, documentation and construction, to facilities management and final demolition.

The AP shall support the description and transfer of product data necessary for mainly the following activities of the construction process:

- the identification and consolidation of operational activities (brief, building and planning regulations, codes, user needs) into a comprehensive and fully integrated set of spatial requirements
- the analysis of spatial requirements
- the planning and analysis of alternative spatial layouts
- energy and thermal analysis
- preliminary cost calculation
- site planning
- production planning
- construction management
- operation, maintenance and other sorts of facilities management functions
- demolition of the facility

Enclosed: A preliminary "Spatial Arrangement Model".

FUNDAMENTAL PRINCIPLES FOR A SPACES AND SPACE ENCLOSURES MODEL

This section describes some of the concepts included within the architectural building product model for spaces and space enclosures described in next section.

Environment - outside - inside

A facility is a physical structure or installation, including related site works, serving one or more main purposes [*ISO*, 1994].Typical examples of facilities are bridge, railroad, harbour and building . A building is a type of facility comprising partially or totally enclosed spaces which provides shelter for its occupants or for machines or material as one of its main purposes and it is normally designed to stand permanently in one place (the site) [*ISO*, 1994].

A building is normally designed to stand on a certain site, and this site and its surroundings determine the external environment for the building. The external environment contains both natural and artificial factors. Typical examples of natural environmental factors are climate, topology and geology and examples of artificial factors are surrounding city plan and adjoining networks. The external environment, together with usage requirements, is the fundamental source for requirements of how the house must be designed. These requirements affect both the inside and the outside design of the building, but also the operation and the maintenance of the building and its surroundings.

Different players in the construction process have different views of the building and its surroundings. The two fundamental viewpoints are the technical and the spatial. For the majority of the professionals involved in the construction process the building and its surroundings is mainly regarded as technical systems. These technical systems are specified during the design process, created during the production process, and operated and maintained during the facilities management processes. For the user of the building it is primarily regarded from a spatial systems viewpoint.

For both the technical and the spatial viewpoint it is necessary to regard both the outside and the inside of the building. The outside and the inside must fit together and it is normally necessary to take both sides into account. For many different reasons it is not appropriate to divide the building and its surroundings into an inside and an outside part.

Different representations of the facility

Buildings have one or more purposes. During the briefing stage of the construction process one identifies the usage activities that will occur in the facility and sets out the environmental and operational requirements on the facility. The spaces, together with interior fittings and equipment and services, provide resources for the activities of the user. The result of the requirements phase is an activity description, neutral to different possible solutions in terms of physical objects, and expressed as spatial requirements. At the beginning of the design phase, a conceptual design of the building is made and it constitutes the overall basis for the further design and for the presentation to the client. The conceptual design is mainly structured from a spatial viewpoint. During the rest of the design phase and up to the end of the construction phase the building is mainly regarded as a collection of technical systems. Thus, the description and representation of the facility could be either as requirements on the internal and external spaces of the facility, or of the spatial entities required to fulfil these requirements or of the physical entities that enclose and support the spatial entities. The description above is illustrated in figure 1 below which also act as an principal description of the proposed model for spaces and space enclosures.

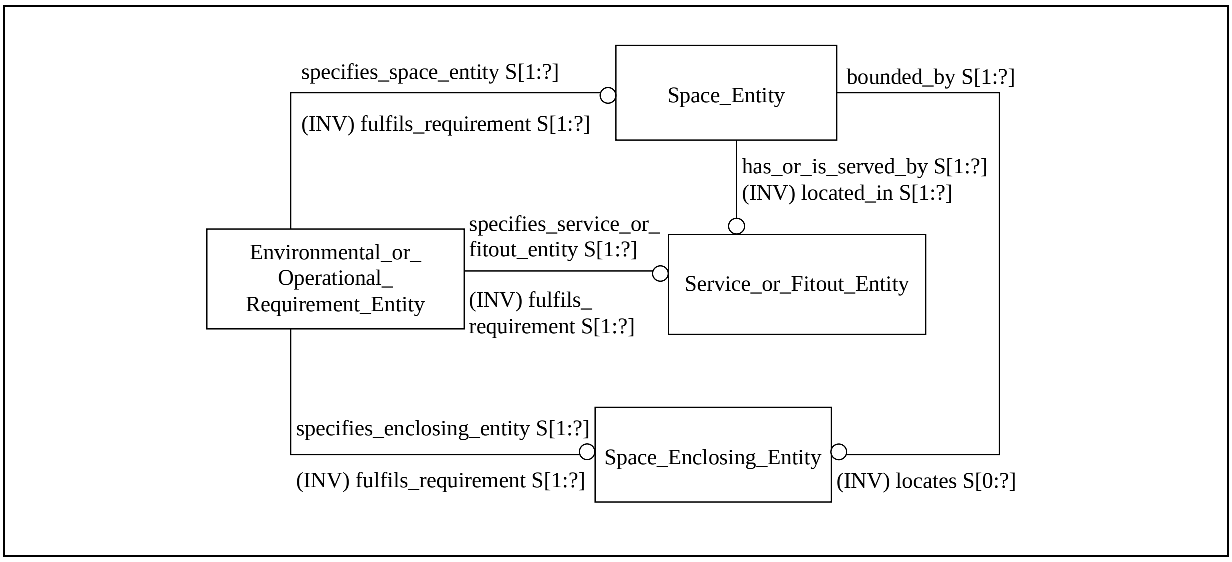


Figure 1 Different representations of the facility

Two ways of viewing the space concept

During the requirement phase the one or more purposes of the building are transformed into spatial requirements. The description of the types and amount of spaces needed and the relationships (configuration) between these spaces forms the foundation for the continued design of the building. A space (or a room) is a bounded area or volume, either inside or outside of the building or even both. The

spaces are bounded by material and/or non-material enclosures. From one standpoint one can state that the spatial objects of a building are established by the physical objects (enclosing objects) of the building. From another standpoint, on the other hand, it is necessary to be able to talk about spatial objects like spaces, rooms or areas without dealing with the physical objects needed to establish those spatial objects. This is also discussed by *Ekholm* [1996]. The "STEP AP model" should be useful in both cases of viewing of the spaces.

The basic constitution of a building

The concept building includes of a number of other concepts. There are a quite limited number of basic types of elements in buildings in general. Different players in the construction process are viewing different aspects of these elements. A very basic building consists of one or many rooms formed by space-enclosing elements: a number of walls , a ceiling, some sort of floor, and a number of openings, usually filled with secondary elements like windows and doors. The enclosure elements can aim at different degrees and types of enclosure. A wall normally encloses to a certain degree for both matter, sound and light. A window does not enclose light and when it is open it does not enclose matter (air) or sound either. In Figure 2 below the most important building envelope elements are described schematically. The codes accompanying the building elements are taken from the Swedish construction classification system called the BSAB system.

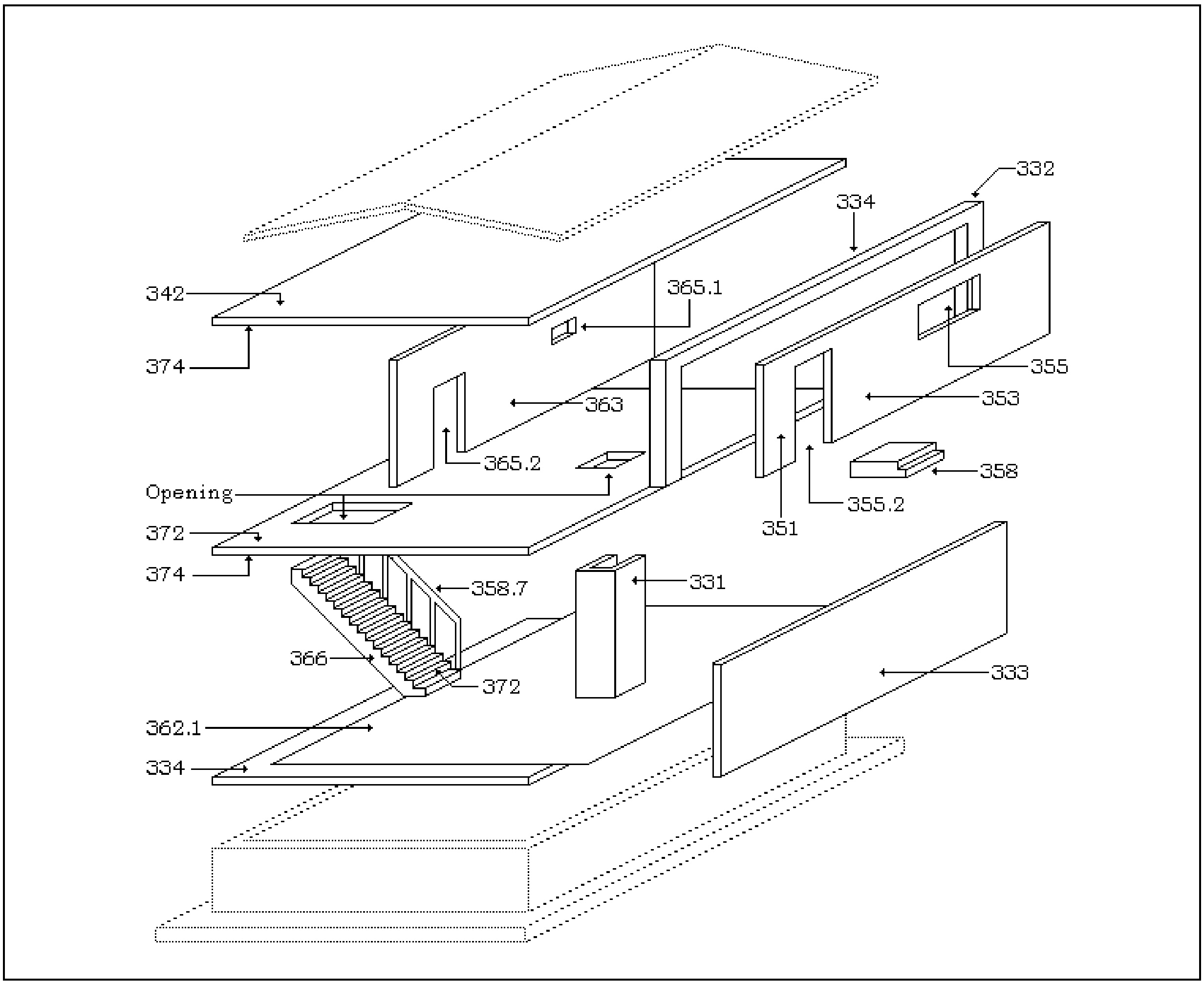


Figure 2 Schematical description of space enclosures objects including codes from construction classification tables of the BSAB-system

Grouping of spaces

In a building space model one must be able to describe the following different sorts of relationships between spaces:

- space object decomposition - one space is part of an other space,
- space object adjacency - one space is adjacent to other spaces,
- space object assembly decomposition - a hierarchy of space assemblies.

Space - shape - space boundary

A space could be seen as a solid of air with a certain shape. This shape has geometry and topology. The shape is formed by the boundaries of the space, which could be either material (physical) ones or immaterial (virtual) ones. A powerful resource to describe the shape of spaces is provided by the STEP AP 225 - Building Elements Using Explicit Shape Representation [*ISO*, 1996a].

Space boundary - surface - space enclosing element

A space element is physically connected to the space enclosing-elements through the surface of the latter. This surface should be described both by the surface finish and its specification and by the surface material of the space enclosing element. By this relation it is possible to relate a space and its characteristics to a part of a wall with its relation to other spaces.

THE STEP BASED SPACES AND SPACE ENCLOSURES MODEL AND ITS COMPARISON WITH OTHER MODELS

Below is the STEP related spaces and space enclosures model described with EXPRESS-G notation. The model, when described is divided into three parts.

1) The overall facility structure part - describing the overall facility structure and its relationship with external and usage (internal) requirements and with the building systems.
2) The space object part.
3) The space enclosing object part.

The overall facility structure part

The described model views of the building and its site from a spatial viewpoint. The building and its surrounding is seen as a conglomeration of spaces which are more or less enclosed by building elements. The model is developed to specify a conceptual description of the spatial entities and enclosing entities in and around buildings, capable of structuring product data of these throughout the whole life cycle of the building.

With the entity facility in the model is meant one or many buildings together with the site these occupy. The unit as a whole has a certain purpose and has normally the same owner/user. The external spaces on the site are in many instances shared by several buildings. The facility is normally divided into "facility elements" which are either an building or its site. Both of these consist of spatial and technical systems. The requirement and performance of the facilities are to a certain extent dependent on the surrounding of the building and its external requirements. Usage requirements are the second main source of demands put on the spaces and the space enclosures. The model should be able to capture both the functional requirements and descriptions of the technical solution. The spaces normally contain fitting and furnishing objects and is normally supported by service systems through their local equipment.

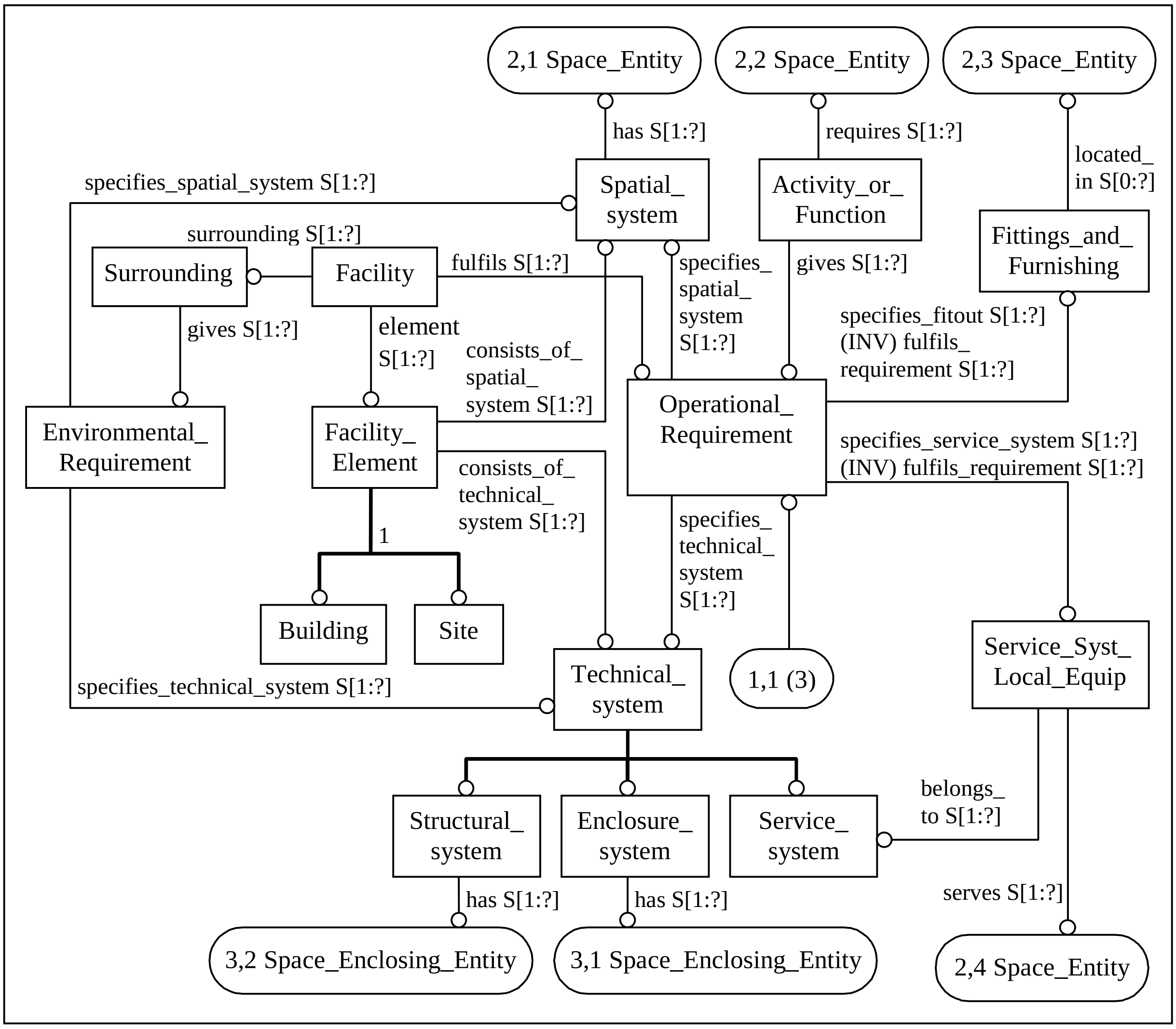


Figure 3 The overall facility structure part model

The space entity part of the model

From an end user of a building point of view the spaces are probably the most important entity of the building. That is also a reason for why the space entity has such a central position in the model. A space is an area or volume within or around buildings (or other facilities) bounded actually (physically) or theoretically (virtually). The space has normally a certain function, a shape and a position. The function of the space is described by an attribute which specifies the purpose of use of the space. The shape of the space is bounded by the space boundaries by which the space is bounded.

The space is also characterised by its connections with other spaces, adjacent or not. The spaces could be decomposed and aggregated in several levels, which together forms a whole-part hierarchy of spatial objects. A traditional room, that is a space entity which is enclosed by physical space boundaries on all sides could be subdivided into subspaces. Examples of such subspaces are work space and ceiling space. A set of space objects can be grouped together in different ways according to some criteria. These are many-to-many relationships, because a space object could be a part of many groups. Examples of groups of spaces are flat, communication areas, floor level, heating or ventilation zone, and the whole building.

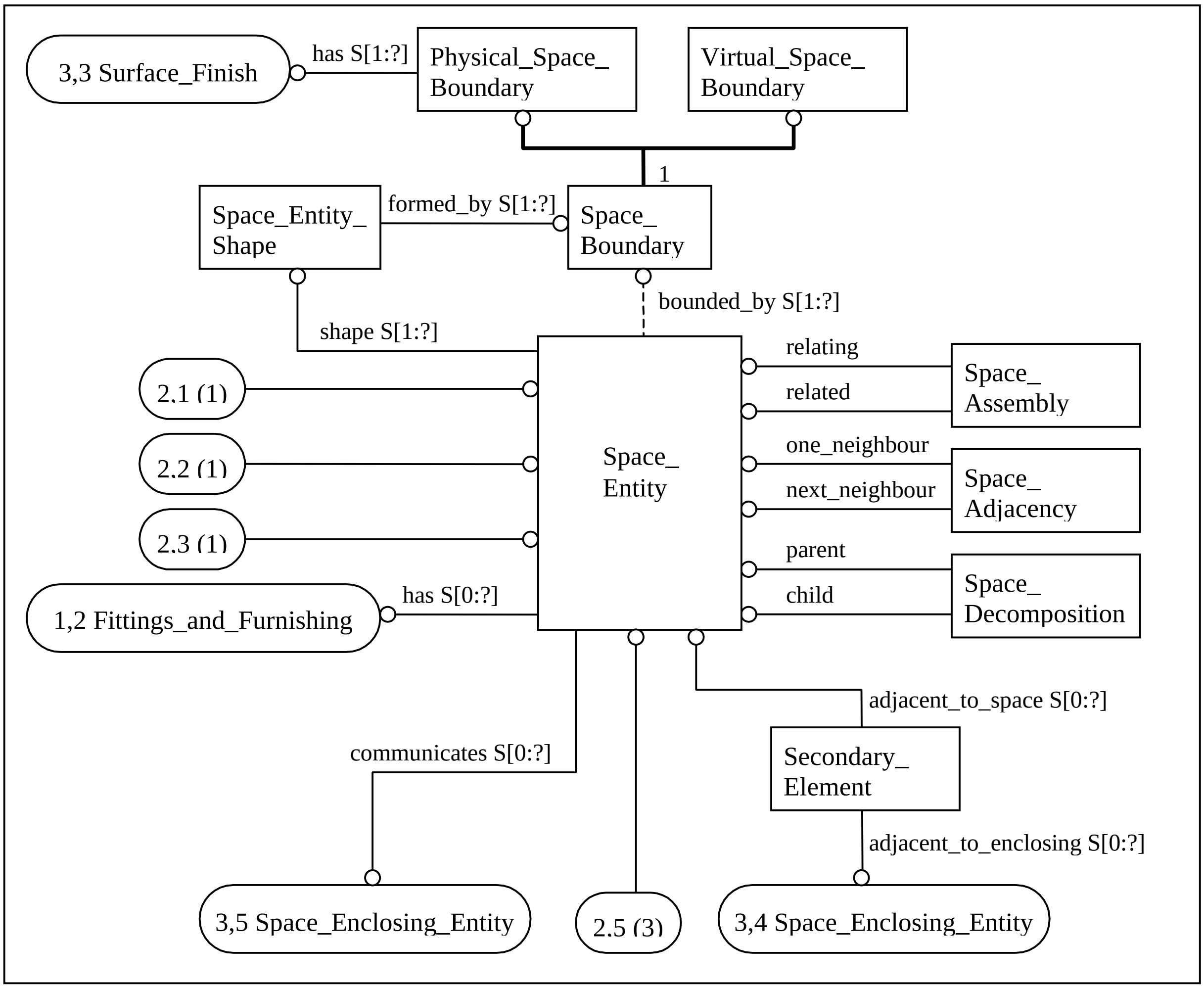


Figure 4 The space entity part model

The space enclosure part

Together with the space object the most dominating entity of the spaces and space enclosures model is the space enclosing entity. This entity represents all the different physical building objects that enclosure the spaces in and around the building. The space enclosing objects are basically parts of either the enclosure system or the structural system of the building or of both. Information about the physical enclosing objects is the most frequently exchanged information during the design process.

There is also a need for a decomposition hierarchy for space enclosing objects. The decomposition is done mainly along the main direction of the enclosing objects their self. This decomposition can refer either to the physical structure of the enclosure object or be based on the adjacency to individual spaces or group of spaces. Decomposition across the main direction of the enclosure object could probably be handled with library functions.

Both the space entities and the space enclosure entities have shape. The explicit shape of both the space entities and the space enclosing entities could be described by STEP AP 225 [*ISO*, 1996a].

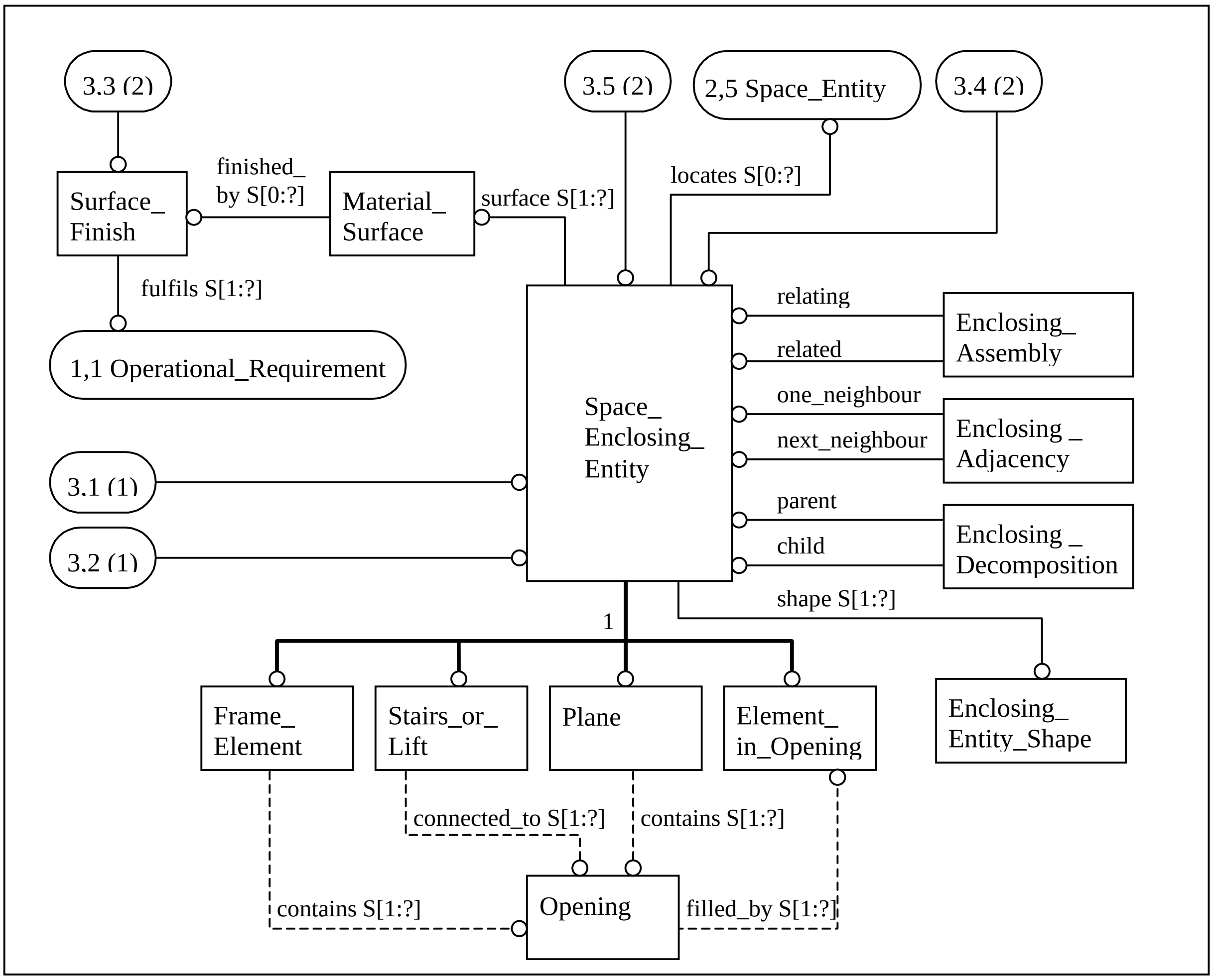


Figure 5 The space enclosure entity part model

The complete proposed model

There are several different relationships between spaces and space enclosing objects as described in figures 4 and 5. Physically the space and each of its space enclosing objects surrounding the specific space meet at the surface of the space enclosing object. With the locate relationship it is possible to locate different enclosing objects to specific spaces. Sometimes a relationship between a space object a an enclosing object is accomplished through a secondary building element like a balcony. Finally, with the communicate relationship different physical communications between space objects could be described. For instance, two space entities communicate through a door. These different relationships are best described by showing the complete model which is shown in figure 6 below.

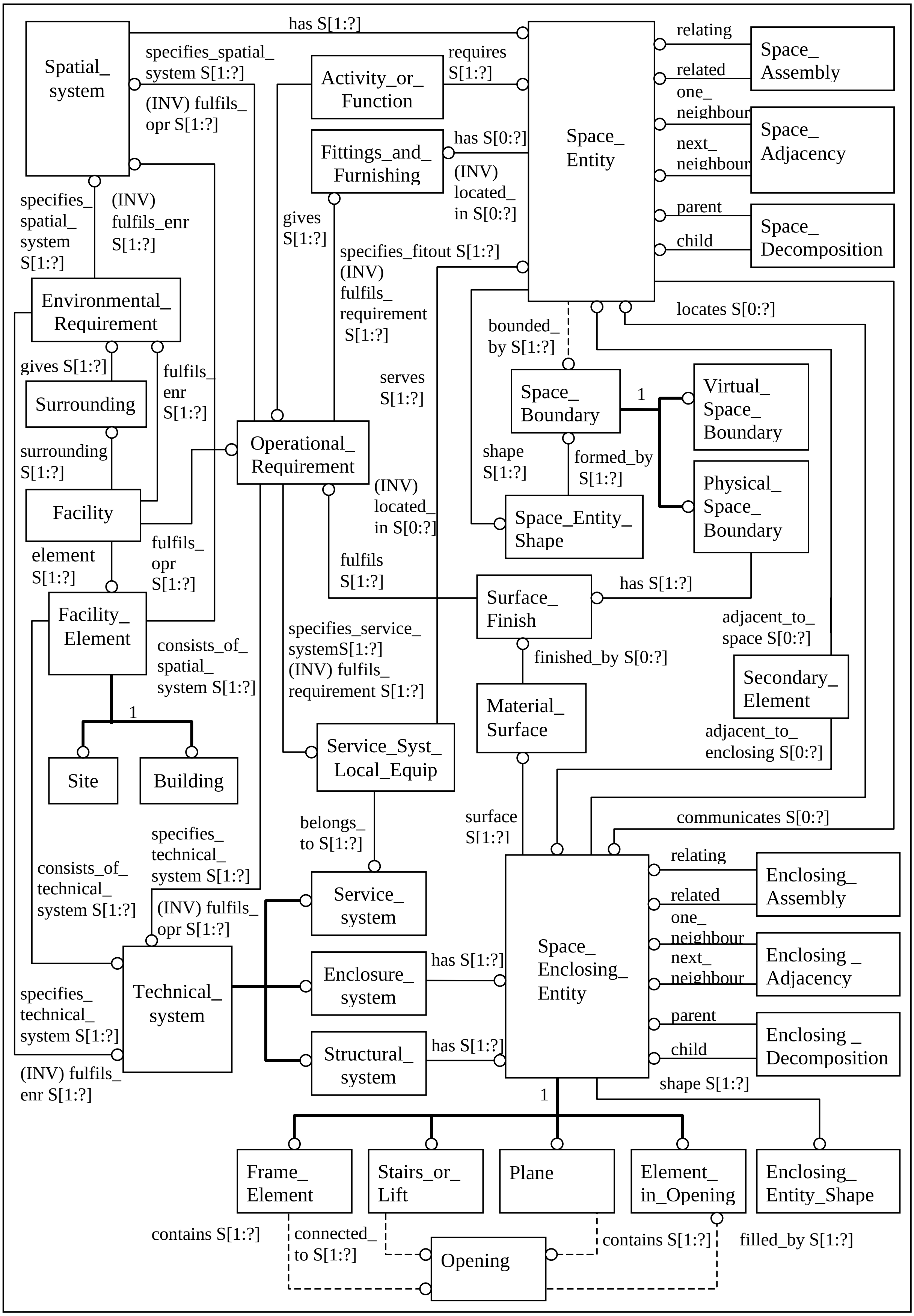


Figure 6 The complete spaces and space enclosures model

Appendix 9: The Spatial Arrangement Model described with EXPRESS

This appendix contain a textual EXPRESS description of the Spatial Arrangement Model described in appendix 8.

```
SCHEMA SpatialArrangement;

ENTITY Activity_function;
            gives : SET [1:?] OF Operational_Requirement;
            requires : SET [1:?] OF Space_Entity;
END_ENTITY;

ENTITY Building
 SUBTYPE OF (Facility_Element);
END_ENTITY;

ENTITY Element_in_Opening
 SUBTYPE OF (Space_Enclosing_Entity);
END_ENTITY;

ENTITY Enclosing_Adjacency;
            one_neighbour : Space_Enclosing_Entity;
            next_neighbour : Space_Enclosing_Entity;
END_ENTITY;

ENTITY Enclosing_Assembly;
            relating : Space_Enclosing_Entity;
            related : Space_Enclosing_Entity;
END_ENTITY;

ENTITY Enclosing_Decomposition;
            parent : Space_Enclosing_Entity;
            child : Space_Enclosing_Entity;
END_ENTITY;

ENTITY Enclosing_Entity_Shape;
 INVERSE
            geometry : SET[0:1] OF enc_geometry FOR item;
END_ENTITY;

ENTITY Enclosure_System
 SUBTYPE OF (Technical_System);
            has : SET [1:?] OF Space_Enclosing_Entity;
END_ENTITY;

ENTITY Environmental_Requirement;
            specifies_technical_system : SET [1:?] OF Technical_System;
            specifies_spatial_system : SET [1:?] OF Spatial_system;
END_ENTITY;

ENTITY Facility;
            surrounding : SET [1:?] OF Surrounding;
            element : SET [1:?] OF Facility_Element;
            fulfils_opr : SET [1:?] OF Operational_Requirement;
            fulfils_enr : SET [1:?] OF Environmental_Requirement;
END_ENTITY;

ENTITY Facility_Element
 SUPERTYPE OF (ONEOF(Building, Site));
            consists_of_technical_system : SET [1:?] OF Technical_System;
            consists_of_spatial_system : SET [1:?] OF Spatial_system;
END_ENTITY;

ENTITY Fitting_furnishing;
 INVERSE
            located_in : SET[0:?] OF Space_Entity FOR has;
```

```
            fulfils_requirement : SET[1:?] OF Operational_Requirement FOR
             specifies_fitout;
END_ENTITY;

ENTITY Frame_Element
 SUBTYPE OF (Space_Enclosing_Entity);
            contains : OPTIONAL SET [1:?] OF Opening;
END_ENTITY;

ENTITY Material_Surface;
            finished_by : SET [0:?] OF Surface_Finish;
END_ENTITY;

ENTITY Opening;
            filled_by : OPTIONAL SET [1:?] OF Element_in_Opening;
END_ENTITY;

ENTITY Operational_Requirement;
            specifies_spatial_system : SET [1:?] OF Spatial_system;
            specifies_technical_system : SET [1:?] OF Technical_System;
            specifies_service_system : SET [1:?] OF Service_Syst_Local_Equip;
            specifies_fitout : SET [1:?] OF Fitting_furnishing;
END_ENTITY;

ENTITY Physical_Space_Boundary
 SUBTYPE OF (Space_Boundary);
            has : SET [1:?] OF Surface_Finish;
END_ENTITY;

ENTITY Plane
 SUBTYPE OF (Space_Enclosing_Entity);
            contains : OPTIONAL SET [1:?] OF Opening;
END_ENTITY;

ENTITY Secondary_Element;
            adjacent_to_enclosing : SET [0:?] OF Space_Enclosing_Entity;
            adjacent_to_space : SET [0:?] OF Space_Entity;
END_ENTITY;

ENTITY Service_Syst_Local_Equip;
            belongs_to : SET [1:?] OF Service_System;
            serves : SET [1:?] OF Space_Entity;
 INVERSE
            fulfils_requirement : SET[1:?] OF Operational_Requirement FOR
             specifies_service_system;
END_ENTITY;

ENTITY Service_System
 SUBTYPE OF (Technical_System);
END_ENTITY;

ENTITY Site
 SUBTYPE OF (Facility_Element);
END_ENTITY;

ENTITY Space_Adjacency;
            one_neighbour : Space_Entity;
            next_neighbour : Space_Entity;
END_ENTITY;

ENTITY Space_Assembly;
            relating : Space_Entity;
            related : Space_Entity;
END_ENTITY;

ENTITY Space_Boundary
 SUPERTYPE OF (ONEOF(Virtual_Space_Boundary,Physical_Space_Boundary));
END_ENTITY;

ENTITY Space_Decomposition;
            parent : Space_Entity;
            child : Space_Entity;
```

```
END_ENTITY;

ENTITY Space_Enclosing_Entity
 SUPERTYPE OF (ONEOF(Frame_Element, Stair_or_Lift, Plane,
  Element_in_Opening));
            surface : SET [1:?] OF Material_Surface;
            locates : SET [0:?] OF Space_Entity;
            shape : SET [1:?] OF Enclosing_Entity_Shape;
 INVERSE
            identification : SET[0:1] OF enc_id FOR item;
            attribute : SET[0:?] OF enc_attribute FOR item;
END_ENTITY;

ENTITY Space_Entity;
            bounded_by : OPTIONAL SET [1:?] OF Space_Boundary;
            shape : SET [0:?] OF Space_Entity_Shape;
            has : SET [0:?] OF Fitting_furnishing;
            communicates : SET [0:?] OF Space_Enclosing_Entity;
 INVERSE
            identification : SET[0:1] OF spa_id FOR item;
            attribute : SET[0:?] OF spa_attribute FOR item;
END_ENTITY;

ENTITY Space_Entity_Shape;
            formed_by : SET [1:?] OF Space_Boundary;
 INVERSE
            geometry : SET[0:1] OF spa_geometry FOR item;
END_ENTITY;

ENTITY Spatial_system;
            has : SET [1:?] OF Space_Entity;
 INVERSE
            fulfils_enr : SET[1:?] OF Environmental_Requirement FOR
             specifies_spatial_system;
            fulfils_opr : SET[1:?] OF Operational_Requirement FOR
             specifies_spatial_system;
END_ENTITY;

ENTITY Stair_or_Lift
 SUBTYPE OF (Space_Enclosing_Entity);
            connected_to : OPTIONAL SET [1:?] OF Opening;
END_ENTITY;

ENTITY Structural_System
 SUBTYPE OF (Technical_System);
            has : SET [1:?] OF Space_Enclosing_Entity;
END_ENTITY;

ENTITY Surface_Finish;
            fulfils : Operational_Requirement;
END_ENTITY;

ENTITY Surrounding;
            gives : SET [1:?] OF Environmental_Requirement;
END_ENTITY;

ENTITY Technical_System
 SUPERTYPE OF (ONEOF(Service_System, Enclosure_System, Structural_System));
 INVERSE
            fulfils_enr : SET[1:?] OF Environmental_Requirement FOR
             specifies_technical_system;
            fulfils_opr : SET[1:?] OF Operational_Requirement FOR
             specifies_technical_system;
END_ENTITY;

ENTITY Virtual_Space_Boundary
 SUBTYPE OF (Space_Boundary);
END_ENTITY;

ENTITY enc_attribute
 SUBTYPE OF (ff_attribute);
            item : Space_Enclosing_Entity;
```

```
END_ENTITY;

ENTITY enc_geometry
 SUBTYPE OF (ff_geometry);
            item : Enclosing_Entity_Shape;
END_ENTITY;

ENTITY enc_id
 SUBTYPE OF (ff_id);
            item : Space_Enclosing_Entity;
END_ENTITY;

ENTITY ff_attribute
 SUPERTYPE OF (ONEOF(enc_attribute, spa_attribute));
            attribute_name : STRING;
            attribute_value : STRING;
            attribute_unit : OPTIONAL STRING;
END_ENTITY;

ENTITY ff_geometry
 SUPERTYPE OF (ONEOF(enc_geometry, spa_geometry));
            line : OPTIONAL ff_polyline;
            ref_point : ff_point;
            angle : REAL;
END_ENTITY;

ENTITY ff_id
 SUPERTYPE OF (ONEOF(enc_id,spa_id));
            id_number : INTEGER;
            source_name : STRING;
            code : STRING;
            complete_code : STRING;
            revision : STRING;
            date : STRING;
            id_type : STRING;
END_ENTITY;

ENTITY ff_point;
            x : REAL;
            y : REAL;
            z : OPTIONAL REAL;
END_ENTITY;

ENTITY ff_polyline;
            coordinates : LIST [2:?] OF ff_point;
END_ENTITY;

ENTITY spa_attribute
 SUBTYPE OF (ff_attribute);
            item : Space_Entity;
END_ENTITY;

ENTITY spa_geometry
 SUBTYPE OF (ff_geometry);
            item : Space_Entity_Shape;
END_ENTITY;

ENTITY spa_id
 SUBTYPE OF (ff_id);
            item : Space_Entity;
END_ENTITY;

END_SCHEMA;
```

Integrating
Facilities Management Information

The purpose of this thesis was to develop suitable information structures to support primary processes of facilities management (FM). The approach chosen was to develop a building product model and a generic FM process model to be used as central information structures in information systems for FM. The models developed were evaluated trough prototyping. Three different prototypes were developed. The prototype systems demonstrated that the product model developed (the KBS Model) fulfils the requirements of flexibility, stability, adaptability, comprehensibility and cost-effectiveness, which are discussed in this thesis. The generic process model provides better conditions for integration by capturing aspects of the essence of FM and by providing an structure for information handling within FM. The overall result of the research provides basic prerequisites for the development of commercial IT systems for FM as well as input to international standardisation efforts.

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