Jarmo Laitinen

Model Based Construction Process Management

KUNGL TEKNISKA HÖGSKOLAN
Royal Institute of Technology
Construction Management and Economics

Thesis for the degree of Doctor of Technology to be presented with due permission for public examination and criticism in the Kollegiesalen at the Royal Institute of Technology on the 14th of September 1998, at 10 am.

Respondent:	Jarmo Laitinen, M.Sc.
Opponent:	Prof. Martin Fischer
Examination committee:	Prof. Martin Betts Civ.ing. Carl-Erik Brohn Prof. Jan Bröchner Prof. Rob Howard Prof. Jerker Lundequist
Supervisor:	Prof. Bo-Christer Björk

Cover page picture is drawn by my son Henri Laitinen, 13 years.

Stockholm 1998 KTH Högskoletryckeriet

ISBN 91-7170-301-2

KUNGL TEKNISKA HÖGSKOLAN, Byggandets organisation och ekonomi,
The Royal Institute of Technology, Construction Management and Economics
Drottning Kristinas väg 30, S-100 44 STOCKHOLM, Sweden.
http://www.ce.kth.se/fba/cme.htm

Abstract

The purpose of this research was to study how the data management of a main contractor can be improved, in order to provide better client value and more cost-efficient production. The research focused on methods for reengineering the information management using product modelling as enabling technology. The methods were tested in pilot tests in which the developed cost and value engineering prototype application was used.

This thesis demonstrates an integration of design and production planning based on the product model approach. The final outcome is that the main contractor can utilise information coming from designers as input in its own tendering and cost estimation applications.

The key methodology used for describing the information management process throughout the building process life-cycle was IDEF0. The analysis of the current process (as-is), in the form of an IDEF0 model, helped in identifying the main problems of current practice. The target process (to-be) definition was based on product model utilisation and takes into account the possibilities for process reengineering supported by product data technology. One specific requirement was deemed important in view of the anticipated developments in the area of data exchange; the target system should be structured in such a way that it could easily be adapted to receive data according to the emerging IFC core model schemas.

The overall result of the research reported in this thesis is that the product model approach can be used for a substantially reengineered information management process of a main contractor, especially in design and construct type contracts.

Keywords: cost estimation, information technology, process model, building product model, reengineering, knowledge engineering

ISBN 91-7170-301-2

Preface

This dissertation is the final result of my long-standing belief that the construction industry ought to, more often than normally is the case, implement the results of scientific research into practice. The rapid developments of IT-technology in recent years have provided good possibilities for doing so. The research presented in this thesis has both had an industrial and academic viewpoint. Hopefully the results can convince some practitioners, in the usually very conservative construction industry, that using results from R&D for reengineering the way they work can be very beneficial.

The work started step by step from a number of research projects under my supervision, much thanks to the support of the Finnish Technology Development Centre (Tekes). I would like to thank all the people who have contributed to the work with their support, arguments, sharing their professional and practical views, time and friendship. There are a number of people I wish to name. First of all I would like to thank my innovative wife, Tuula who just threw the magic words in the air one day: “Why not draft a Ph.D. on the subject?” Secondly Prof. Bo-Christer Björk, who finally convinced me that writing a Ph.D. would indeed be a good idea and who has provided the academic comments which have been necessary for finally achieving it. Other persons I especially would like to thank are Veli-Pekka Saarnivaara from Tekes for his visions and strategical sense, Pekka Hämäläinen at YIT for his great support in my work and my colleagues Heli Väliharju and Hannu Peltonen and the others who have been understanding and not disturbing my concentration too much, my colleagues at VTT: “Modelling Guru” Matti Hannus for his mental and visionary friendship, my “Tutor” friend Kalle Kähkönen, experts Kari Karstila and Karl-Johan Serén (both at VTT at the time), my sister Marjukka Laitinen as “the computer scientist” in completing some of the details, my “Knowledge-Engineer” Heikki Kulusjärvi and my supporting friend Markku Salmi. Many thanks also to my Swedish colleagues for their innovative participation during the “Swedish-Finnish Ph.D. seminars” at KTH and at VTT. Thanks also to Professor Brian Atkin for his good advises. I would also like to thank all who have been involved somehow in this work during these years and whose name is not mentioned here.

The work wouldn't have been completed without the support of my caring family, my wife Tuula, who has been a good help with her stylistic ideas and in proof-reading. Great thanks also to my children Kirsi and Henri, who have been patient when having no attention from me. Special thanks to our dog, labradorian retriever Kassu, who has been supporting and awake with me during the dark nights abandoned while the others were in sleep already. Many times he gave a deep sigh for me: *"Just do IT"*.

People need buildings, buildings need engineering,
engineering needs processing, processing needs reengineering,
reengineering needs IT.

(The first thought by an unknown author, extension for my work by Tuula and myself.)

Espoo, August 1998
Jarmo Laitinen

List of Used Acronyms or Abbreviations

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

ABCM	Apartment Building Core Model
ABS	Abstract supertype (in EXPRESS)
AEC	Architecture, Engineering and Construction
AP	Application Protocol
ARM	Application Reference Model
BCCM	Building Construction Core Model
BPM	Building Product Model
BPR	Business Process Reengineering
CAD	Computer-Aided Design/Drafting
CASE	Computer Aided Systems Engineering
CMM	Construction Method Model
COM	Component Object Model
CORBA	Common Object Request Broker Architecture
COVE	COst and Value Engineering application
CPR	Construction Process Reengineering
CSTB	Centre Scientifique et Technique du Bâtiment [French for Centre for Building Science and Technology]
CVE	Cost and Value Engineering
DWG	AutoCad Drawing File
DXF	Data Interchange Standard
EDI	Electronic Data Interchange
FM	Facilities Management (Facility Management)
FTP	File Transfer Protocol
GARM	General AEC Reference Model
HTML	HyperText Markup Language
HVAC	Heating, Ventilation and Air Conditioning
IAI	International Alliance for Interoperability
ICON	Integration of COnstruction Information
IDEF0	ICAM Function Definition Model
IFC	Industry Foundation Classes
IRMA	Information Reference Model for AEC
IT	Information Technology
KBE	Knowledge-Based Engineering
LAN	Local Area Network
NIAM	Nijssen’s Information Analysis Method
NICC	Neutral Intelligent CAD Communication
OXF	Object eXchange File
PDT	Product Data Technology

QFD	Quality Function Deployment
RATAS	RAkennusten Tietokone Avusteinen Suunnittelu [Finnish for “Computer-Aided Design of Buildings”]
SDAI	Standard Data Access Interface
SGML	Standard Generalised Markup Language
SQL	Structured Query Language
STEP	STandard for the Exchange of Product Model Data
TALO 90	Construction 90 [Finnish calassification system]
TCP/IP	Transmission Control Protocol/Internet Protocol
TNO	Nederlanse Organisatie voor Toegepast Natuurwetenschappe lijk Onderzoek [Netherlands Organisation for Applied Scientific Research]
TQM	Total Quality Management
UML	Unified Modelling Language
UoD	Universe of Discourse
VTT	Valtion Teknillinen Tutkimuskeskus [Finnish for Technical Research Centre of Finland]
WAN	Wide Area Network
WWW	World Wide Web

Contents

1 INTRODUCTION

1.1 Background

The construction industry is one of the largest sectors of the economy of any industrialised nation. The value added of the construction industry (including construction product manufacturing and related services) constitutes over one quarter of the industrial sectors and over 10% of GNP [Salmi 1995], [Tupamäki 1997]. Consequently the efficiency and competitiveness of the construction industry is a major concern for society as a whole. While other industries, such as the car industry, have been able to achieve very significant improvements in productivity and quality over the last few decades, the construction industry seems to have been at a standstill.

The current problems of the construction industry are quite well known to researchers and to practitioners participating in national R&D programmes aiming to improve the performance of the industry [European Commission 1994], [ELSEWISE 1997], [Allweuer et al. 1996]. The construction industry is suffering from fragmented organisation, traditional and local practices, poorly developed supply networks and missing competitive mechanisms. The industry has not been able to combine high quality with productivity, customer satisfaction and flexibility. Other related problems are lacking industrial practices, unsafe working conditions and insufficient ability to evaluate environmental impacts of building materials, products and production methods. Competition remains mainly focused on lowest cost and offering capacity instead of quality, sustainability and customer perceived value. What has been particularly significant for the problem formulation of this thesis work is the fact that the construction industry is lagging far behind other industries in using modern technology as a major catalyst for improving its processes.

The information management methods used in current construction processes are inadequate [Atkin 1995]. In particular, the traditionally almost ”water-tight” separation of design and production causes problems in the form of duplication of work, inconsistent documentation etc. Similar problems occur also at other inter-enterprise interfaces and even at inter-department interfaces within companies. According to a study carried out in the UK [Latham 1994] 30% of the total building costs should be saved when information problems such as repeated work, overlapping work, false information, redoing etc., are solved. Improved data exchange and the overall managing of the information will be a key solution to this. These problems can not be solved by more advanced IT tools alone. Reengineering of the process itself is necessary [Betts 1997], [Davenport 1993].

Some problems which characterise the current way of working are:

- Prevailing ways of organising the process do not encourage technical innovation and process change.
- The client's requirements are not adequately taken into account.
- Cost optimisation is too focused on minimising production cost only.
- Design is often carried out with insufficient consideration for constructibility issues.
- Contractors lack the means to take into account sustainability of the materials they use.
- The methods for decision support are ad-hoc and unsystematic.

In current practice, a team of architects and engineers develop a detail level building design which is sent by the client to a number of contractors for tendering. The pre-defined technical solutions included in the design, such as pre-cast concrete building frame with hollow core slabs, do not encourage contractors and suppliers to develop, evaluate and propose alternative, potentially more optimal solutions. Incentives for product (~ buildings and subsystems) and process (~ business and production) development are inherently hampered.

The original intent and needs of the client are often lost in the process. The industry has poor capability to extract client needs, transform them into formalised performance requirements and assure compliance to these requirements throughout the delivery process.

Economy is by the clients often seen only as low production cost. Still as the performance driven process is evolving life cycle performance assessment is gaining more importance. The industry - including contractors, their supply chain and the client - does not have the capability nor tools to identify the impact of the produced value based on life-cycle performance on the competitiveness of the company.

Production and construction requirements are often not taken into account or misunderstood in the design stage due to the separation of design and construction. This causes waste: the product specification is often far from the easiest possible to build, and it does not take into account the possibilities that the supplier's capabilities offer. Traditionally the consideration of constructability requirements is based only on the designers' personal experience from construction [Lautanala 1997].

Sustainability is gaining continuously growing importance in construction. Many building material producers are creating life cycle assessment databases for their own products, but the contractors, or any other partners in the process, are not able to make life cycle assessments for the whole building process.

Decision making in the construction industry lacks systematic methods based on solid performance measures. Usually decision making is based on personal intuition and experience from similar previous projects.

1.2 Possible solutions to the problems

Management philosophies as a basis for change strategies

In order to tackle some of the problems outlined above a few pioneering companies in the construction industry have during the last few decades tried to apply a number of management philosophies, often using IT as an enabling technology [Yamazaki 1990], [Miyatake et al. 1992]. Examples of general management philosophies which in principle could be applied to construction are value engineering, total quality management, just-in-time production, life-cycle costing, business process re-engineering, lean production. Other methodologies for process improvement which are more specific to the construction industry are performance driven construction, open building [Lahdenperä 1995] or the use of contractual forms such as design-build (often also called design and construct) contracting [Konchar et al. 1997].

In the following three of these approaches, which have had a particular relevance for the research presented in this thesis, are presented.

Value engineering - Value engineering originated during World War II time in the USA, due to the needs for optimising industrial production in a time of shortage of key materials. The systematic method nowadays known as value engineering was developed over the ten years following the war. According to its traditional meaning value engineering is mainly concerned with optimisation i.e. achieving a given function at minimum cost. Nevertheless, nowadays value engineering has a wider conceptual meaning concerning the meaning of the term 'value'. The primary concern is to develop a common decision framework around which the project participants can think and communicate [Green, 1992].

Within value engineering the basic phases followed at several stages in the development of a project are [Dell'Isola, 1973]:

1. Information phase: determination of the objectives and functional requirements of the project
2. Speculative phase: identification and development of alternatives
3. Analytical phase: selection of the best value alternative by examining the cost and value of each alternative
4. Proposal development: development of the best value alternative to more detailed design proposal

Typically the value engineering process is organised as workshops where representatives of all project stakeholders participate. Green for instance has used a two workshop approach where the first one is organised during the concept stage of a building construction project in order to establish clear project objectives and value-for-money criteria understood by all parties [Green 1994]. The second workshop takes place after the feasibility study to analyse design alternatives and select the outline design proposal with the appropriate value-for-money criteria. Another practical approaches to carry out value engineering processes for building construction has been described in Barrie & Paulson [1992].

An important overall objective for value engineering is to ensure that the decision making process is accountable. Within the workshops several techniques are applied e.g. *value trees* to structure objectives and decision making criteria, *brainstorming techniques* for studying possible design solutions, the *ratio method* to assign importance weights for each individual value-for-money criterion and *decision matrices* to reach quantitative evaluation of design proposals [Miles, 1972].

The term value management has been given even a broader meaning compared with the value engineering process described above. Value management is used to address all processes relating to value improvement. This covers all tasks from project concept development to feedback information from clients throughout the life of the facility [Institution of Civil Engineers, 1996]. The relation with design and build contracting is reported by Kirk [1998].

Both the research problem and proposed solution of this thesis are related to the general value engineering approach as described in chapter 1. In particular, the client service process for the briefing phase is concerned with the challenge of design value improvement. The new concept of *cost and value engineering* has nevertheless been used in this thesis having in mind a possibility to provide a new type of supplementary solution to earlier developed value engineering techniques. Within the context of this thesis ***Cost and value engineering*** is defined as the contractor’s evaluation of the design solution in terms of scope, efficiency, cost and functionality.

Process reengineering – Process Reengineering is a term coined by a number of researchers in the early 1990’ies [Davenport 1993], [Betts et al. 1997]. Reengineering attempts to change the mind-set, attitude and behaviour of organisations by fundamentally re-thinking and re-designing business activities, structures and working relationships in order to maximise added value and achieve sustainable improvements in all aspects of business performance [Love et al. 1997]. The construction industry is predominantly project based, and thus needs an alternative approach to reengineering. According to Love there are fundamental components associated with Construction Process Reengineering

(CPR): Concurrent Engineering [Turk et al. 1997] and Lean Construction [Koskela 1992], [Koskela 1997].

Fowler and Palmer [1997] emphasize the supporting business systems and the improvement of operating effectiveness through redesigning critical business process and supporting systems. This involves both a detailed analysis and the re-design of key processes, ultimately focusing upon an examination of the process' ability to add value. Mohamed [1997] defines CPR: ”*a customer focused approach to progressively develop an integrated project delivery process focusing on optimising process predictability and enhancing the value of the final product*”.

There are few reported cases of construction companies which have carried out systematic business process re-engineering projects [for an example cf. Bacon 1997].

The Performance approach -As an effort to promote innovation and free competition there is a trend to change the emphasis of building codes and standards towards performance rather than prescriptive requirements. The main motivation for this is the assumption that performance specifications will reduce barriers for process innovations and add incentives to use new technologies [Tiula 1993]. The designer should only state the performance criteria and leave the contractor the freedom to choose the materials and assembling methods within these specified limits, assuming that the contractor is able to analyse the differences between alternative solutions. In practice the use of the performance concept is, however, only in its infancy, and there is a need to develop methods supporting its use [Wittenoom 1995].

IT-tools that support change

Early developments in construction computing provided support for activities where information was created. Good examples are the use of CAD-systems for drawing production and spreadsheets for cost calculations. During the last few years new emerging IT-technologies have increasingly been used to facilitate information management and transfer in the construction process. Computer networking, document management systems, the Internet, database technology and interoperability standards provide examples of such technologies. The potential of these for data sharing has, however, not been fully utilised in the construction industry, but has rather been used for exchanging traditional documents in a digital format.

One promising technology for data exchange and sharing, the commercial use of which is still in its infancy, but which has been the subject of quite intensive research during the last decade, is product data technology. In product models the information about a product (in our case a building) is stored as information objects in databases, according to data structures which have been standardised. In contrast to today's practice information is stored only once and the needed documentation is produced from the product model using applications (this is illustrated in fig 1.1). Many European research projects, such as CIMSteel [1998], ATLAS [Tolman et al. 1994] and COMBINE [Augenbroe 1994] have developed methods for product model based information exchange. The development of some fundamental standards needed for building product data exchange is currently going on both as formal standardisation through the ISO STEP committee [ISO 1993a], and through active industry participation in the Industry Alliance for Interoperability [IAI 1997], which is developing object-oriented building descriptions, so–called IFCs.

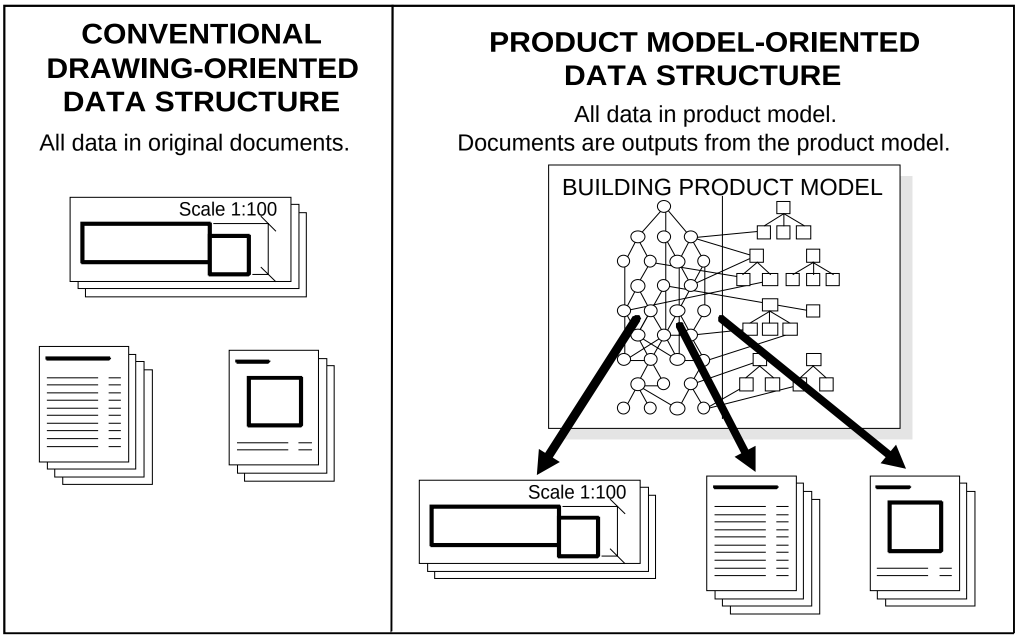


Figure 1.1. An illustration of the difference between the current document oriented approach for data exchange and the proposed product model oriented approach [Björk 1989].

Current CAD tools are oriented towards specification of design solutions in terms of geometric and material properties while the design intent, functional or performance requirements remain uncaptured. Some stand-alone methodologies, eg. QFD - quality function deployment [Huovila et al. 1995], [Serpell and Wagner 1997] exist to support systematic customer needs analysis and requirement specification. In the domain of product modeling some theoretical research has been carried out also concerning the inclusion of performance requirements [Gielingh 1988] and this has also been considered in this study. In general, however, systematic management of this type of information and knowledge throughout the delivery process is largely non-existent.

Research priorities in construction industry

At a recent conference on ”Computers and Information Technology in Construction”, some research priorities for information technology in construction were defined [Grilo et al. 1995], [Augenbroe 1995], [Eastman et al. 1995]:

- The focus of research is moving from product modeling towards process modeling.
- The effective management of the interdependence of the construction process will require that construction companies re-engineer their business processes and networks in order to form IT-enabled networked firms [Yusuf et al. 1997].
- Improved IT-tools and methodologies are needed to support new process organisation modes (e.g., ”Design and Construct”), which provide a more optimal division of decision making and responsibilities.
- There should be effective use of the performance approach as a basis for project definition.

Based on the above discussion one promising solution lies in transforming construction processes in such a way that the incentive mechanisms which are the consequences of different contractual arrangements encourage product and process improvements and innovations. Companies offering services and products to construction projects should be given performance requirements rather than prescribed solutions [Laitinen 1995].

Since 1985 the problems and possible solutions discussed above have in Finland been in focus in the planning and execution of a number of large publicly funded R&D programmes. The major programmes, their objectives and duration, are shown in the table below.

The research effort described in this thesis should be seen against this background. It has been strongly influenced by the RATAS programme and can be seen as a forerunner to the types of projects currently being initiated within the VERA programme [VERA 1998].

Table 1.1. Major publicly funded R&D programmes in Finland.

R&D programme	Objective	Duration
BEC	Standards and tools to support CAD and product model data exchange in the precast concrete industry	1984-1994 (several projects)
TAT	A comprehensive and open system for building design and construction	1984-1989
RATA2000	New process for construction and practice for contracting	1985-1990
RATAS	Specifications and models for computer inte-grated construction using building product model	1985-1995 (several projects)
VERA	The utilisation of product information techno-logy and information networks within construction processes	1997-2002

1.3 Some features of the Finnish construction market

In order to set the context for this study it is useful to go through some key characteristics of the Finnish construction industry and how it differs somewhat from the overall European picture. Some characteristics are listed below:

- The contracting and building materials industry is quite concentrated to a few large players which work in an international market.
- At times major contractors and design firms have done quite a significant amount of export work. The former Soviet market was a significant market due to bilateral trade agreements.
- From the 60ies to the end of the 80ies the best way to make profits in construction was to buy land cheaply, develop it, and sell it for a good price. The influence of production effiency on company profits was secondary to marketing and other issues (including negotiations with local authorities).
- The use of precast concrete elements is widespread (the market share in building frames is 60-70%) compared to other countries.

In the early 90'ies the Finnish economy went into the worst recession during this whole century, with unemployment reaching a record high of 19% in 1996 [RTS 1997]. This had catastrophic consequences for the construction industry, which has a tendency to react even stronger than the economy as a whole to business cycles. The development of the volume of building construction in figure 1.2 illustrates this situation.

Figure 1.2. Construction market development in Finland [RTS 1997].

The Finnish construction industry has consequently undergone a very severe crisis, including several bankruptcies and take-overs by foreign companies, from which it has started to emerge only from 1996 onwards. In order to stay in business construction companies now have to focus much more than in earlier decades on re-engineering their production processes, providing more value for their clients at a lower cost. This has been a major motivation for this research.

Contracting forms in Finland

The most frequent contracting forms in Finland are (by percentage of total project numbers) [Tiula 1993]:

• General contract	35%
• Divided contract (split contract)	45%
• Design and construct contract	20%

Other forms, e.g. target price or unit price contracts, occur only seldom in special cases.

In a ***general contract, also called bid and construct***, the client has only one contractor (main contractor), who generally himself takes care of the construction. The contract is based on a lump sum, which may be corrected by unit prices. The general contractor has several sub-contractors. Usually subcontractors execute earthworks, mechanical, electrical and similar specialised works.

In **D*esign and construct contracting*** the client employs a general contractor, who is responsible also of design activities (can usually choose the design consultants). This form of agreement has not been popular so far in Finland, compared to other European countries, especially in Middle Europe where the share of Design and Construct is 30-45% [Lahdenperä 1995]. In the ”Open Building” approach e.g. in performance driven construction, this contractual form seems to be the most suitable [Konchar et al. 1997].

1.4 The Case company YIT Corporation

YIT Corporation’s roots extend back to 1912 when the company began operations in Finland as a contractor for urban, municipal and industrial water supply and waste water treatment projects. During the next decades the company’s operations extended step by step to infrastructure contracting, industrial construction as well as building construction and housing. Today YIT is Finland’s largest contractor, a privately-owned limited company with approximately 1,500 shareholders. The company’s net sales in 1997 were FIM 5,597 million with the number of personnel averaging 6,531.

YIT provides a full range of construction services including housing and building construction, industrial construction, civil engineering, mechanical contracting and maintenance. YIT Building Construction is the biggest business division with a 46 % share of overall production. YIT Building Construction is the leading contractor for residential, office and industrial facilities in Finland, with residential buildings constituting 55 % of its total production. The operations also cover design control, the purchase of plots and other services such as renovations.. Various forms of contractual relations and implementation are used, with over 60 % of the production being carried out in design and construct projects [YIT 1998].

YIT Building Construction has an internal R&D -department, which focuses on customer decision supporting systems, quality systems and business process reengineering supported by enabling IT-technology. One of the division’s main development projects in 1998 is to develop new tools and comparative methods for establishing the environmental impacts of construction over the entire lifecycle of buildings. The author of this thesis works in YIT’s Building Construction Division and is in charge of the development of business processes supported by information technology.

1.5 Aim and objectives of this research

Against the background described above ***the overall aim of this research was to study how the data management of a general contractor, who mainly aims at working in design and construct projects, can be improved, in order to provide better client value and more cost-efficient production***. For the client the key issue lies in the information provided for decision support. For the contractor the major improvements can be foreseen in the tendering activities as well in cost and value engineering management.

In order to achieve such improvements the operational target was to be able to manage requirements information, design and production information in an integrated manner throughout the construction process. In essence this meant that ***the research focused on methods for re-engineering the information management of the main contractor, using product modeling as major enabling technology***.

On a more detailed level the objectives of the study were:

- Identify the ways in which design information can be made amenable to computer interpretation.
- Define the structure and content for a cost and value engineering management system.
- Demonstrate the working parameters of a cost and value engineering management system.

1.6 Methods

The starting point of the research was in analysing the construction process chain throughout the whole life-cycle from the briefing phase to the use and maintenance phases. The analysed phases were: client briefing, design, production planning, construction and building use & maintenance. There are actually three different processes which were considered from the information management point of view:

- the customer service process, how to provide decision support and services to the customer throughout the building project,
- The teamwork between designers and contractors in design and construct type projects and
- the construction materials and subcontracting supply process

These construction process chains are illustrated in figure 1.3.

The main focus of the study is in the contractor’s activities, especially in design and construct -type projects. The key process stages are design, production planning and construction. The information transfer between the actors and across different phases of the process as well as the overall management of information are the key subjects in this research.

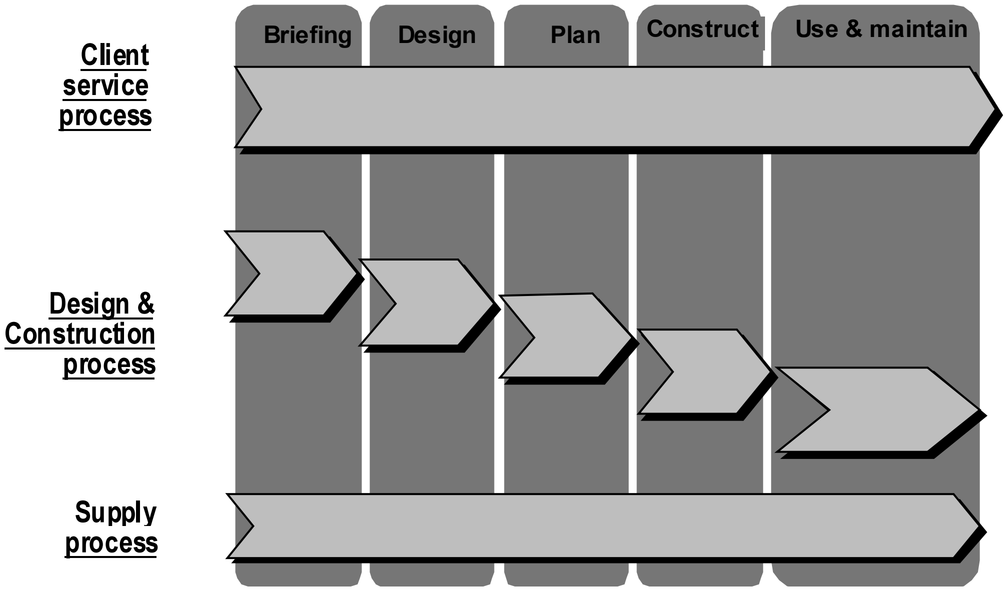


Figure 1.3. Construction process chains, three viewpoints.

The proposed solution is the use of so-called model based information management. Instead of managing the traditional paper or CAD-drawings the target is to manage the information using the product model approach. In practice this means that the contractor has the ability to create a production model from the designer's data (which could be available either as paper drawings, CAD-files or in the future as product model objects). After creation the model can be integrated with the contractor's applications for cost estimation, scheduling etc. and can finally be used to provide services for the customer. The increase of the value of the manageable information is illustrated in figure 1.4.

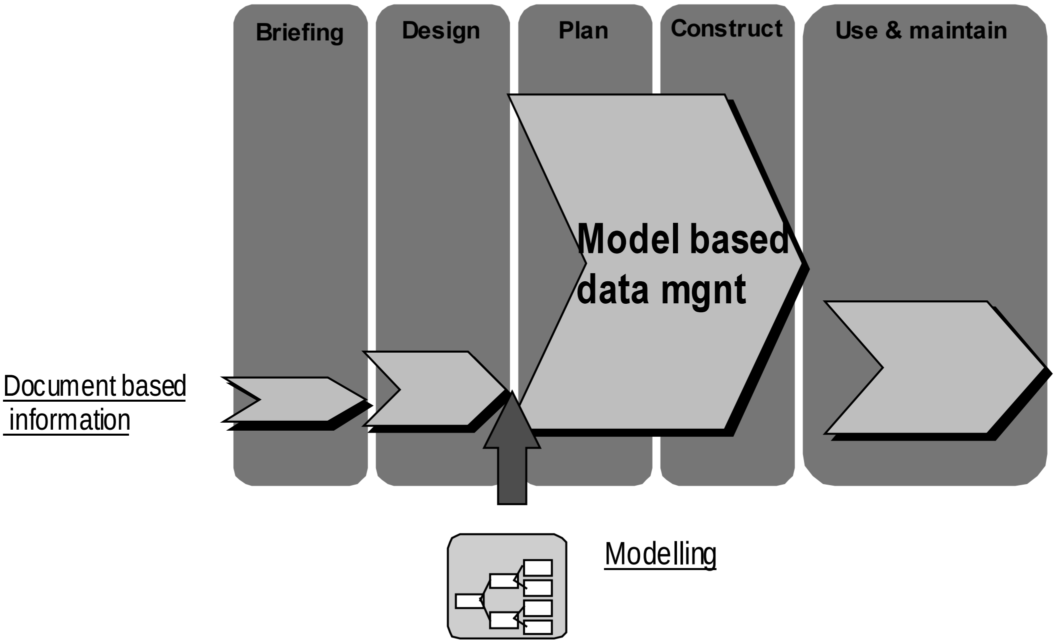


Figure 1.4. Construction process chain from the information management point of view in the model-based target process.

This study has been accomplished through the definition, pilot testing and implementation of an integrated information management system for a main contractor. It is important to remember that the study, the individual projects in which it was done and the results can be viewed from a number of different viewpoints:

- From the viewpoint of the company involved (initially Haka, later YIT) the individual projects, rather than the study as a whole, were development work, which was expected to yield tangible results in the form a working prototypes and methods which can be further developed to be used as a part of the company's IT system.
- From the viewpoint of the public bodies, which have provided part of the funding, the projects can be categorised as applied research. The primary aim has been to provide proof of concept that product modeling technologies, which to some extent have been developed also in earlier Finnish projects, can be made to work within the framework of an individual company. A major motivation has thus been that the possible successful results would inspire other construction industry companies to start similar efforts which would have positive effects on the industry as a whole.
- From the viewpoint of academic research, that is KTH's viewpoint, the study taken as a whole has, through its emphasis on business process reengineering and testing in an industrial setting, provided an interesting contrast to the bulk of academic building product model research reported during the last decade, which usually has been conducted as conceptual modeling supplemented by quite limited prototype work. It is also worth mentioning that this study has been conducted as one of several Ph.D. studies concerning product modeling [Svensson 1998], [Tarandi 1998], [Jägbeck 1998] carried out simultaneously at the department of construction management and economics at KTH. This has offered good opportunities for cross-fertilization of ideas between projects with partly similar aims conducted in two different countries (Sweden, Finland).

The basic overall development approach of this study was to work from a higher abstraction level step-wise down towards a detailed, implementable level. This involved first defining a framework methodology for how cost engineering activitites should be integrated with design, and then formalising the methodology as process and data models. From these models generic concepts and functions were extracted in order to define general purpose software components. Finally this enabled concrete exploitation through a collection of specific software applications. The development process has not been strictly sequential but has included feedback, in the sense that the final process and data models have been taken into account experiences gained during the testing phase.

The development methods used throughout this study are based on commonly accepted software engineering practises, official international or draft international standards as well as de facto standards. For process modeling IDEF0 (also known as SADT [Marca and McGowan 1987]) has been used. Product modeling has been accomplished using ISO/STEP [ISO 1993a] methods. EXPRESS and EXPRESS-G [ISO 1993b] were used for data modeling, and the STEP data exchange format was one of the methods used for actual data transfer.

The bulk of the research reported in this thesis has been carried out in two interrelated Eureka projects in which the author acted as international co-ordinator. The first was Eureka 520, CONCIM (1991–1993), where the basic analysis of the construction process was carried out. The main result was in the form of IDEF0-models describing the information flows between activities and a first draft definition of the re-engineered process. The other project was Eureka 1077, COCON (1994–1996). The main result of this latter project has been the definition and implementation of the enterprise model and cost and value engineering management tools for the YIT-Corporation. During the project a real pilot test using the product model approach and involving all disciplines (designers and contractors) has been carried out. In addition part of the theoretical work has been carried out outside the above mentioned projects as part of the Ph.D. studies at KTH, involving literature studies, regular seminar work with the rest of the research group at KTH and participation in international conferences. Figure 1.5 illustrates the research framework.

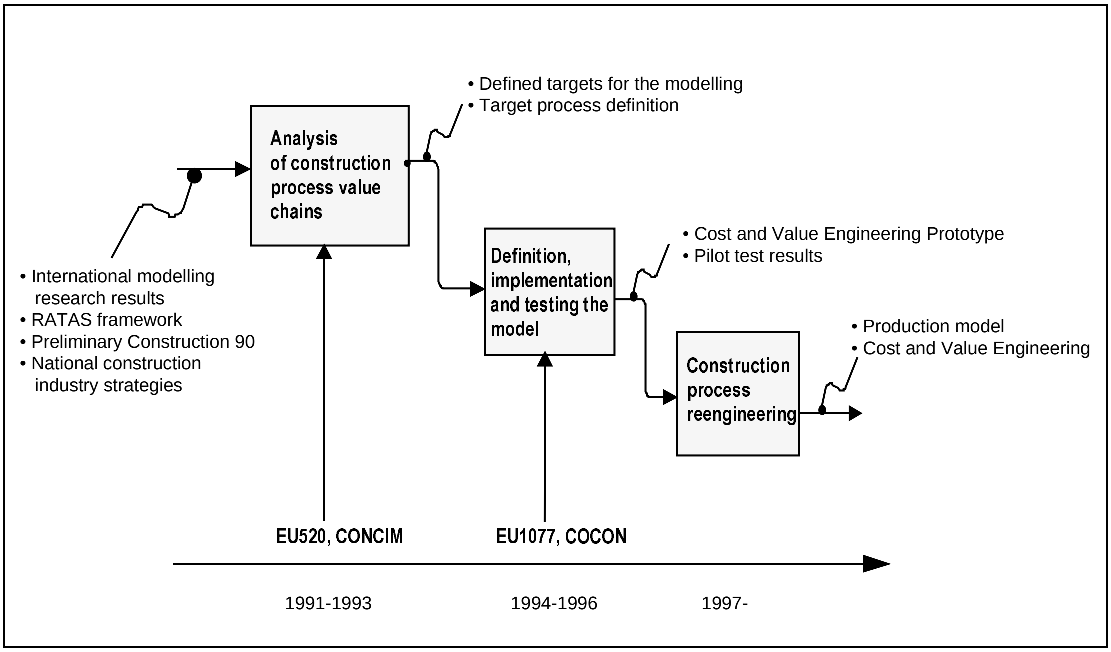


Figure 1.5. Research framework of this thesis.

The research reported in this study belongs to the general category of case studies, which is one type of research discussed in the standard textbooks on research methods [Walker 1997], [Seymour et al. 1997]. Although this type of research is quite common in fields such as management studies or construction economics and management, it seem rare in conjunction with the application of a technology such as product modeling. Most of the reported research on product modeling has discussed conceptual schemas of buildings or parts of them and has included only small scale prototyping in a research setting.

This kind of research, which includes wide scale testing of changed business processes can only be possible to carry out in close co-operation with industrial companies in order to follow the strategic business targets of the companies and to verify the results in real projects. The first Eureka project was done within the HAKA Group. After the bankrupcy of HAKA in 1994 the work has been continued in the YIT-Corporation where the author is currently employed.

1.7 Structure of the thesis

This thesis comprises eight chapters covering the main stages in the research.

- Chapter 1 has described some overall problems of the construction industry and a number of business management philosophies and supporting technologies, which seem to offer solutions to solve these problems. It also shortly presents the aims of the study.
- Chapter 2 studies the problems and shortcomings of current information management methods in construction, with an emphasis on an analysis of the current process within the case company.
- Chapter 3 studies current technologies and developments within construction product and project modeling, i.e. the available supply of tools. Enabling technologies are surveyed and other research related to this study is reviewed.
- Chapter 4 defines the requirements for better information and process management for the main contractor as well as a proposed ideal target process based on these. The target process is described using the IDEF0 modeling technology.
- Chapter 5 describes the technical solution for the target model. The chosen knowledge based engineering tool which was used for the creation of the model is described.
- Chapter 6 presents the material used for testing the proposed model in real building projects including the integration of the model with a tendering/cost estimation system. Internet has been used as the mechanism for data transfer between actors.
- Chapter 7 discusses the results of the pilot tests and describes the experiences which have been acquired. The research results are evaluated against the objectives of the study. The scientific validity and weaknesses of the study are

discussed and some future developments are proposed and some conclusions drawn.

2 ANALYSIS OF THE CURRENT PROCESS MANAGEMENT

2.1 Typical problems in construction process management

In this study the construction process used today by the case company, YIT, has been analysed throughout the whole life-cycle of the process. The analysis has been carried out through interviews with experts in the company, through studies of existing project documentation and internal company guidelines as well as a study of the software tools currently used in the company. The analysis work has partly been carried out using the formal IDEF0 modelling tool.

The focus has been on the main contractor's viewpoint and on information and process management. Quality management plays a minor role in this context. Some of the findings could, no doubt, be generalised to the processes in the construction industry in general, but such claims are not made since no empirical studies have been made outside the two companies involved in the different phases of the research (HAKA and later YIT).

According to the study the main shortcomings of the information management methods used by the contractor, either in "bid and construct" or "design and construct" type projects, may be summarised in two main points:

- From the customer's point of view; the contractor cannot provide sufficient decision support throughout the process.
- From the contractor's own point of view; poor information and data management, especially concerning the integration and sharing of data.

In the following this study focuses on the contractor's information management and exchange activities, especially in design and construct type projects. The focus on this contractual type has to do with an overall aim within the company to increase the share of this kind of contracts. The analysis covers the whole building process life-cycle, from briefing to hand over. Solving some of the contractor's own information management problems should also indirectly improve the customer service process. Customers are more concerned with what information is provided and exchanged - not so much with how it is exchanged [Bacon 1997].

Using the construction process chain description from chapter 1, some major current problems which were identified were:

In the client service process:

1. There are no tools to create enough information in the briefing phase to adequately support decision making and no capability to use information from reference projects as cases effectively. Other researchers have reported similar problems [Bindorf et al. 1997].

2. Hand over and as-built information for users and owners is poor.

In the design & construct process:

3. The information exchange between designers and between designers and suppliers is usually limited to paper drawings and is thus slow.
4. The information flow between designers and the contractor is mainly based on drawings. Contractors are not able to efficiently use design information as basic data in their own applications. This type of problem has also been discussed by Luiten who points out that this causes too long tendering lead times and inaccurate cost estimations [Luiten 1994].
5. The contractor’s systems do not work together (no internal integration). Information which has been input into one application cannot be transferred to other applications.

6. In general the feedback mechanism is poor. There is no upstream feedback from the use phase to briefing at the start of later construction projects. A consequence of this is that estimations for life-cycle economy and other assessments are based on very limited knowledge.

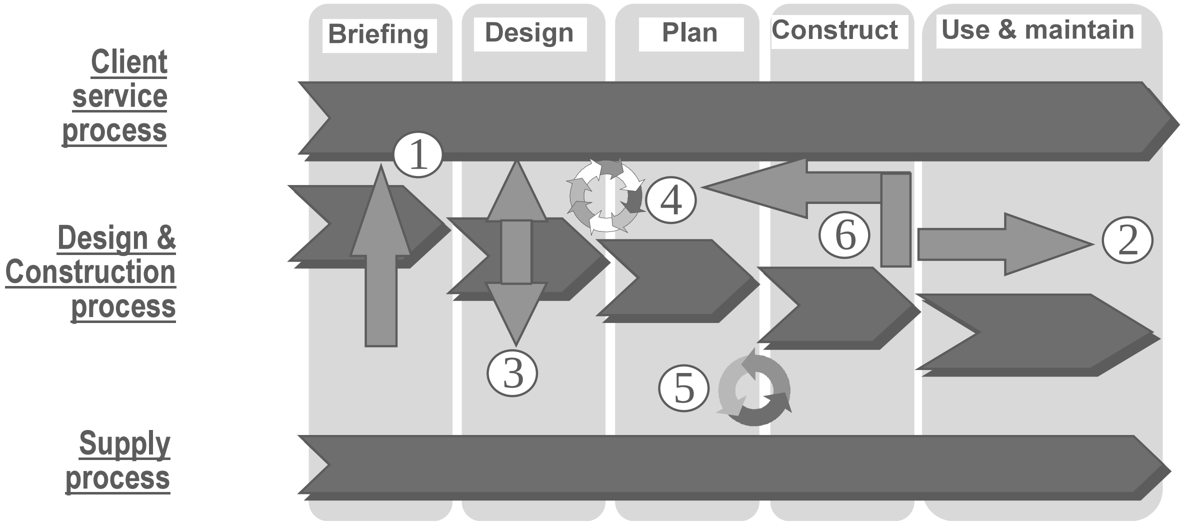


Figure 2.1. Identification of shortcomings in the information management across the construction process. The numbers in the diagram refer back to the main text.

In summary there is lack of IT-supported systems that are able to integrate the information management process both horizontally and vertically [Laitinen 1995]:

- Vertically in the sense of managing the creation, revision and exchange of information carried out simultaneously by several partners.
- Horizontally in the sense of transferring information across the process from one phase to another.

- Longitudinally, from project to project, as defined by Ferguson and Teicholz [Ferguson and Teicholz 1993].

2.2 Description of the building process (as is)

The description of YIT's current building process below is presented as IDEF0 diagrams [Marca and McGowan 1987]. Since the process description is based on YIT's viewpoint, the activities of owners and designers are in a minor role. A more general analysis of current Finnish practice can be found in the generic present-state systematisation done by VTT [Karhu et al. 1997]. The focus in the model presented here is in the co-operation between designers and contractors (in Finland contractors do not have in-house design departments at all nowadays) and on information flows and their contents. The model is focused on design and construct type of projects, where the contractor has the responsibility for the design activities.

The top level of the IDEF0 model consists of one single box (Figure 2.2) which illustrates the whole construction project. The major outputs are a building ready for use by the client or other end users and the documentation about the building, which according to today's practice is in the form of paper documents, such as drawings.

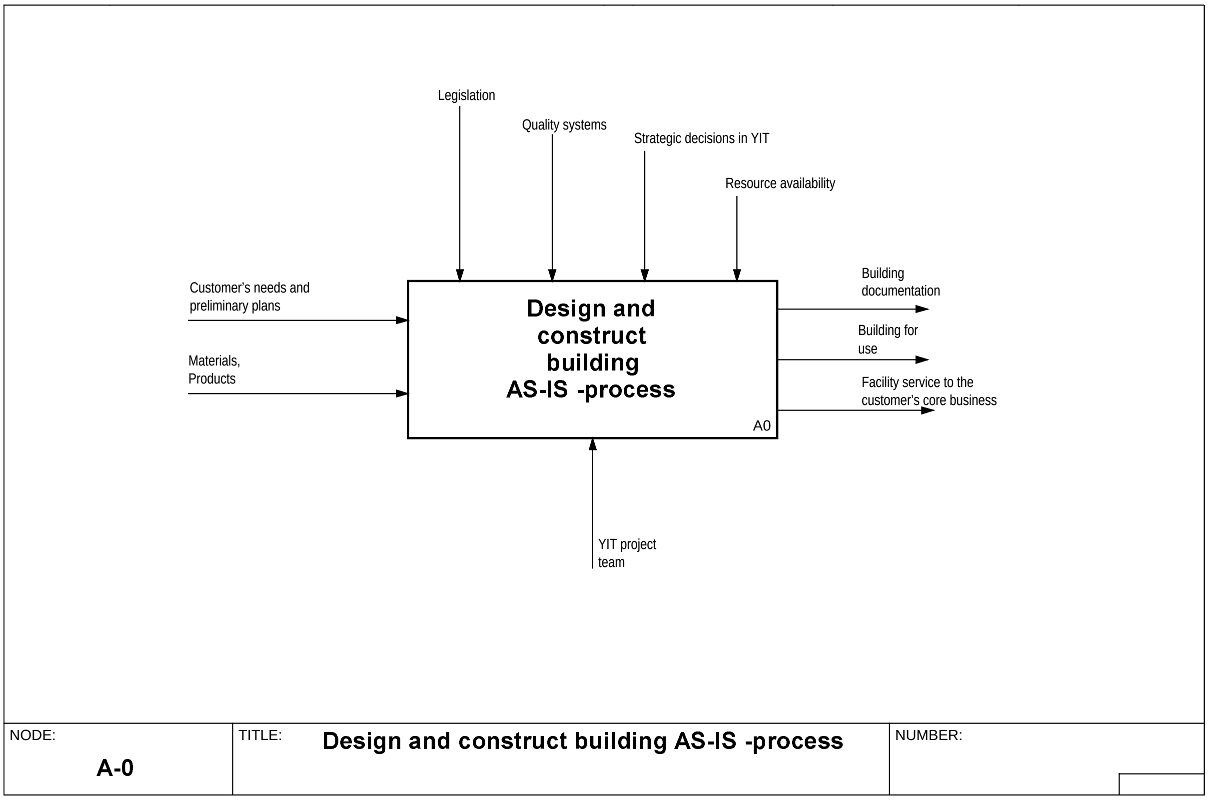


Figure 2.2. A-0, Design and construct building, as-is process.

On the second level (A0) a wider view of the life cycle construction process is described using four different activities (figure 2.3). The activities are the customer's own purchasing process, the main contractor's design&construct process, the maintenance of the knowledge libraries and bases of the contractor and the use and maintenance of the building. In the activity, *Manage procurement* (A1), the customer's procurement process is defined. The main outputs are decisions and contracts which are controlling the contractor's activities, and more detailed requirements and rough plans as input for the contractor. The second activity, *Manage design and construction process* (A2), focuses on YIT's information management process throughout the life cycle of a building. The main outputs are building documentation and information to support the customer's decision making , which is on a very general level and should be improved. The other outputs are the building ready for use and production process documentation for YIT's knowledge base, which should have a strong feedback mechanism to the process management. This study focuses mainly on this activity (A2). The third activity, *Maintain YIT's knowledge libraries* (A3), describes the maintenance of the company knowledge of on-site construction which forms the basis for production planning. The main output is the knowledge of production methods, recepies (production structure including labour and required equipment to complete a construction element) and related recources (e.g. prices). The fourth activity, *Use and maintain building* (A4), focuses on the user's activities during the life-cycle of the building. This is today poorly supported by IT systems.

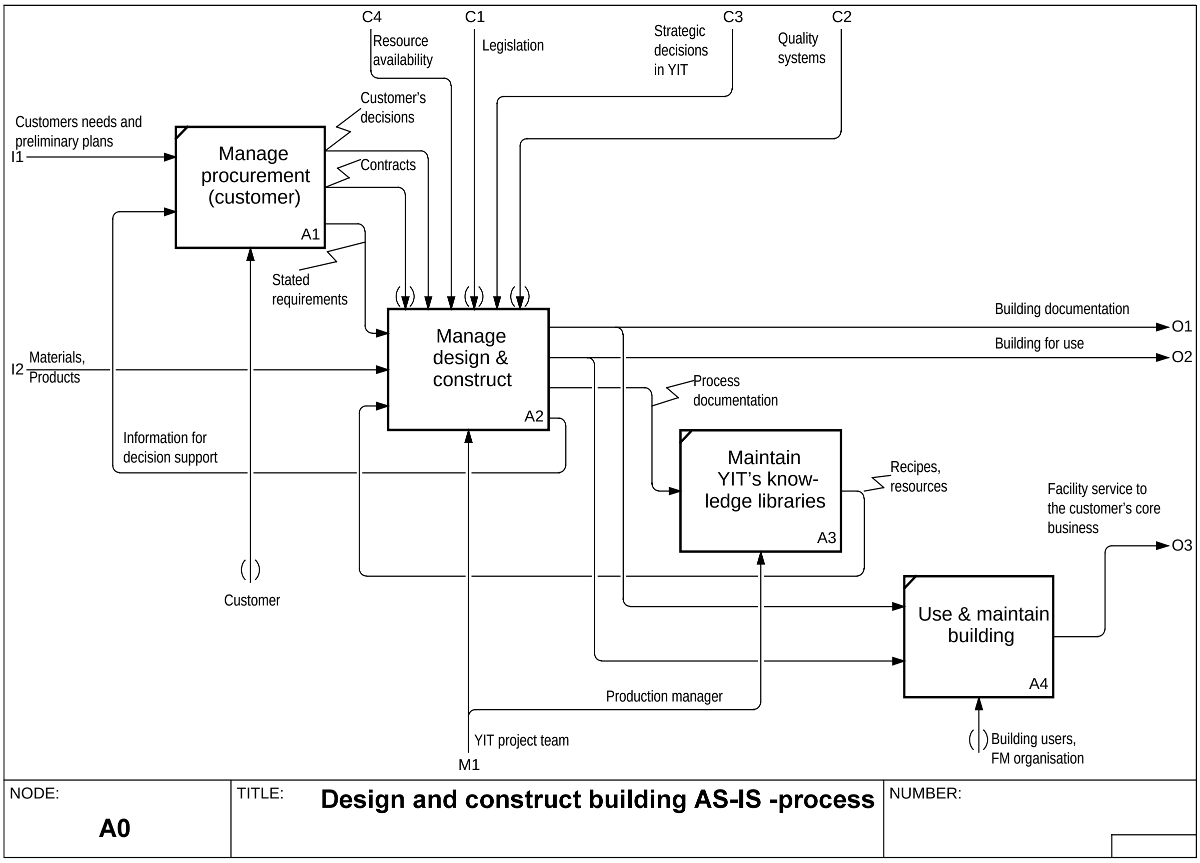


Figure 2.3. A0, Design and construct building, as-is process.

On the next level of (A2) (Figure 2.4) the aggregated main activity *Manage design and construct* has been split up into 6 different activities and is modelled throughout its life-cycle from defining the brief for the customer (A21) to hand-over to the user (A26). The inputs and outputs are still the same as on the previous level, but there are several intermediate outputs, such as the room schedule resulting from the briefing activity, which are used as controls or input for later activities.

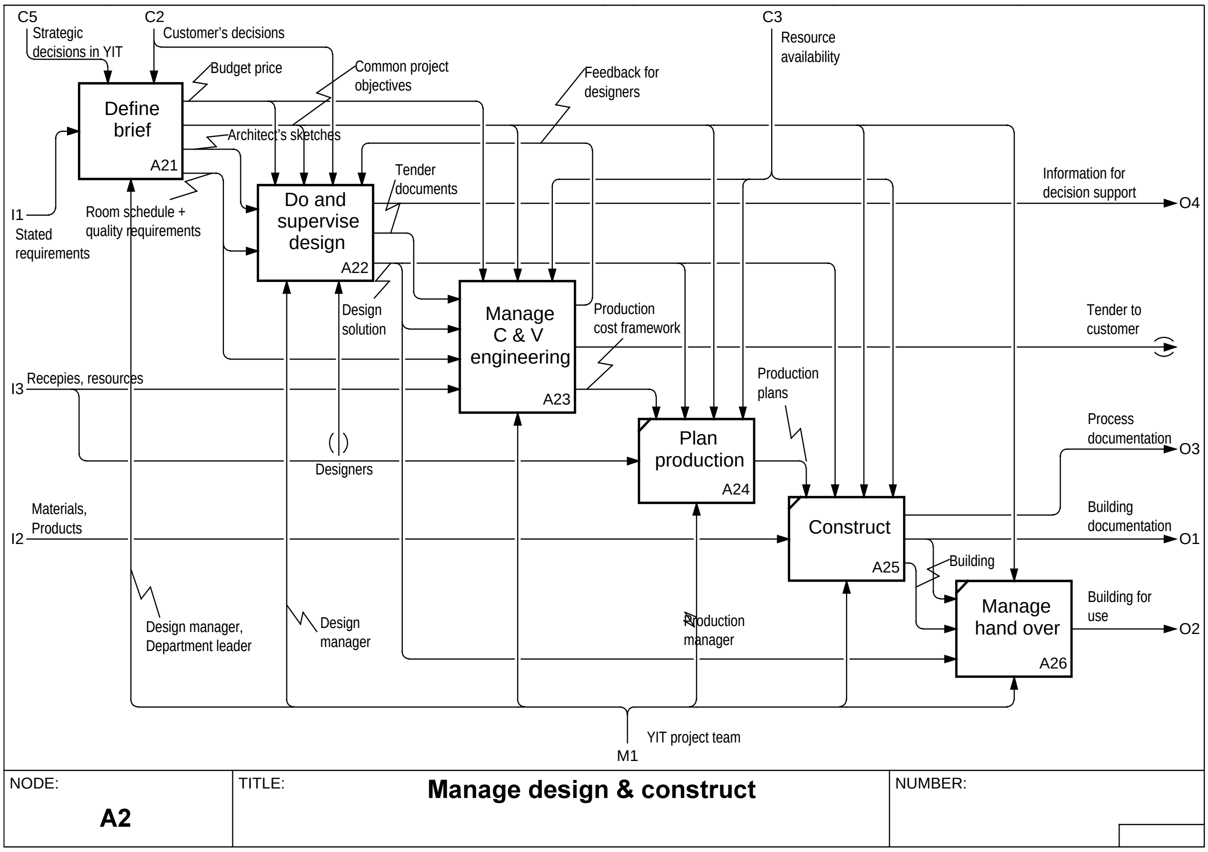


Figure 2.4. A2, Manage design and construct, as-is process.

The activities included in the design&construct are: *Define brief to the customer* (A21*), Do and supervise design* (A22), *Manage cost and value engineering* (A23), *Plan production* (A24), *Construct* (A25), and *Manage hand over to the customer*(A26). (Cost and value engineering means the contractor's evaluation of the design solution in terms of scope, efficiency, cost and functionality.)

The process shown is straight forward; the information flow is clear but not easy to manage due to the format of it (documents) and thus deliberation of alternative solutions and analysis of their influence are missing.

Based on the interviews and analyses of the IDEF0 models the support for the decision making of the client as well as of the contractor is needed the most in the briefing phase. In the designer-contractor collaboration the biggest needs and problems are in tendering phase. **The contractor should be able to use information coming from the designers as it is as input data, and to merge with it**

his own construction know-how. Another key issue is cost and value engineering i.e. the ability to analyse design solutions from the perspective of accomplishing the construction, as well as to examine alternatives and the impact they will have on the overall costs. In the following these three issues are discussed.

- Decision support for the customer
- Information exchange between the designers and the contractor in the tendering phase
- Support for cost and value engineering during construction planning

2.2.1 Decision support for the customer

In YIT's current practice, the customer's needs and demands are not in general specified in sufficient detail, and they are not presented in the form of measurable attributes. The checking of quality requirement fulfilment, is based on the design supervisor's own viewpoint and judgement. Design solutions that fulfil the customer's needs and demands, being yet cost effective and easy to construct, are difficult to find.

In residential construction projects, the customer is presented few alternatives with little choice. The contractor has difficulties in knowing of the alternatives or their impact on the total costs or on the project process. Use and maintenance cost assessment (life-cycle costing) is hardly carried out in the design stage, especially so in residential construction projects.

The following figure 2.5 illustrates the discrepancy between the client's initial expectations and the end result he finally gets. The different factors that contribute to this discrepancy are further explained below.

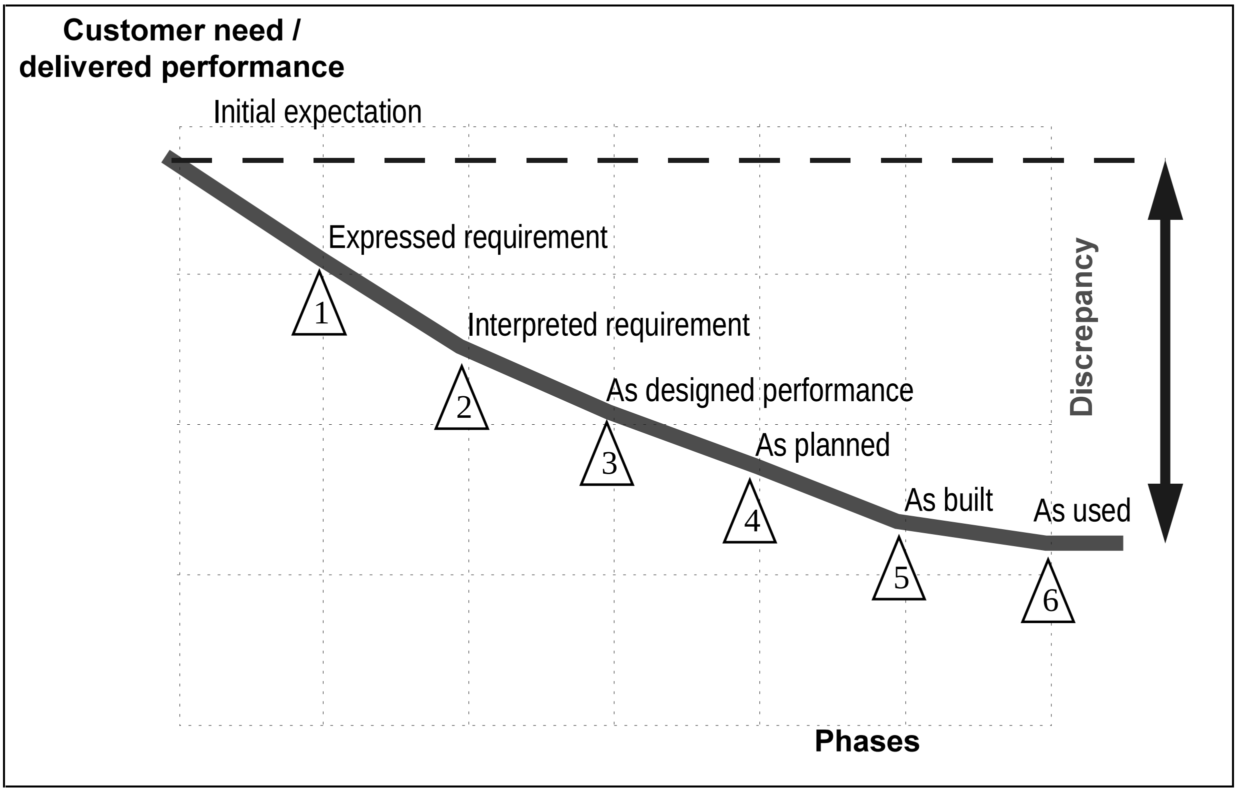


Figure 2.5. An illustration of the origins of the discrepancy between initial customer expectations and the final result. The figure is based on answers to questionnaires from owners and users.

1. The customer is not able to express his expectations in a formal or verbal way.
2. The designer interprets the requirements in a different way that the customer assumes.
3. The technical solution chosen does not fulfil the requirements.
4. The contractor takes into account constructability issues in planning the execution, which may be in conflict with the client's or designer's intentions.
5. The actual work is carried out differently from the plans, due to poor quality assurance etc.
6. The building is not operated and maintained according to the instructions.

The overall conclusion is that there are two main causes of this discrepancy: inadequate information management and the inherent conflict between customer and supplier.

In figure 2.6 the briefing phase is described in more detail. The lack of decision support is the biggest problem in this phase which causes the first discrepancy. The budget price is based on the room schedule, the architect's sketches and YIT's general information of costs per space (chapter 3). There are not available

IT-systems that support e.g. case based reasoning [Schmitt 1993], [Smith 1996], so it is difficult to use previous building projects as cases.

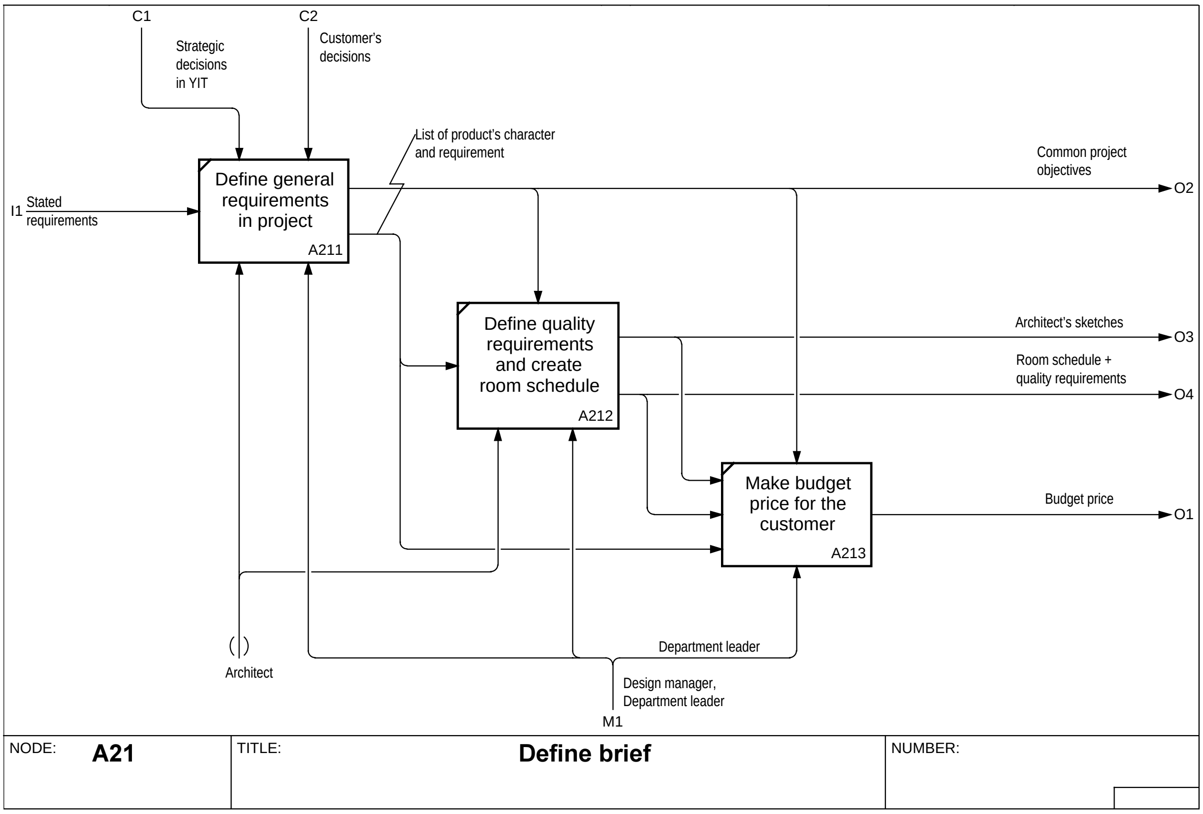


Figure 2.6. A21, Define brief, as-is.

2.2.2 Information exchange between the designers and the contractor in the tendering phase

A prerequisite for integrating the design and construction management is a conflict-free exchange of design data between the partners and from system to system. Today it is very rare that all the partners use the same type of IT-application or have the same requirements for the content of the data to be processed.

In figure 2.7 the activity, *Do and supervise the design process* (A22), is split in to six activities. The transfer of design data between the various partners is currently predominantly based on 2D -drawings, which mainly are exchanged as paper documents, even though they are increasingly CAD-produced. The exchange of paper documents is quite slow. Particularly in the early design stages, the other designers participating in the design process (structural-, building services- and other specialised consultants) have to wait for the architect’s designs and changes before they can proceed with their own work.

The same design information appears in several documents and there is too much redundant information, so updating data is problematic. For this reason, design documents are often mutually conflicting. In current practice much of the formalised procedures deal with the management of whole documents, not so much the management of the information within the documents.

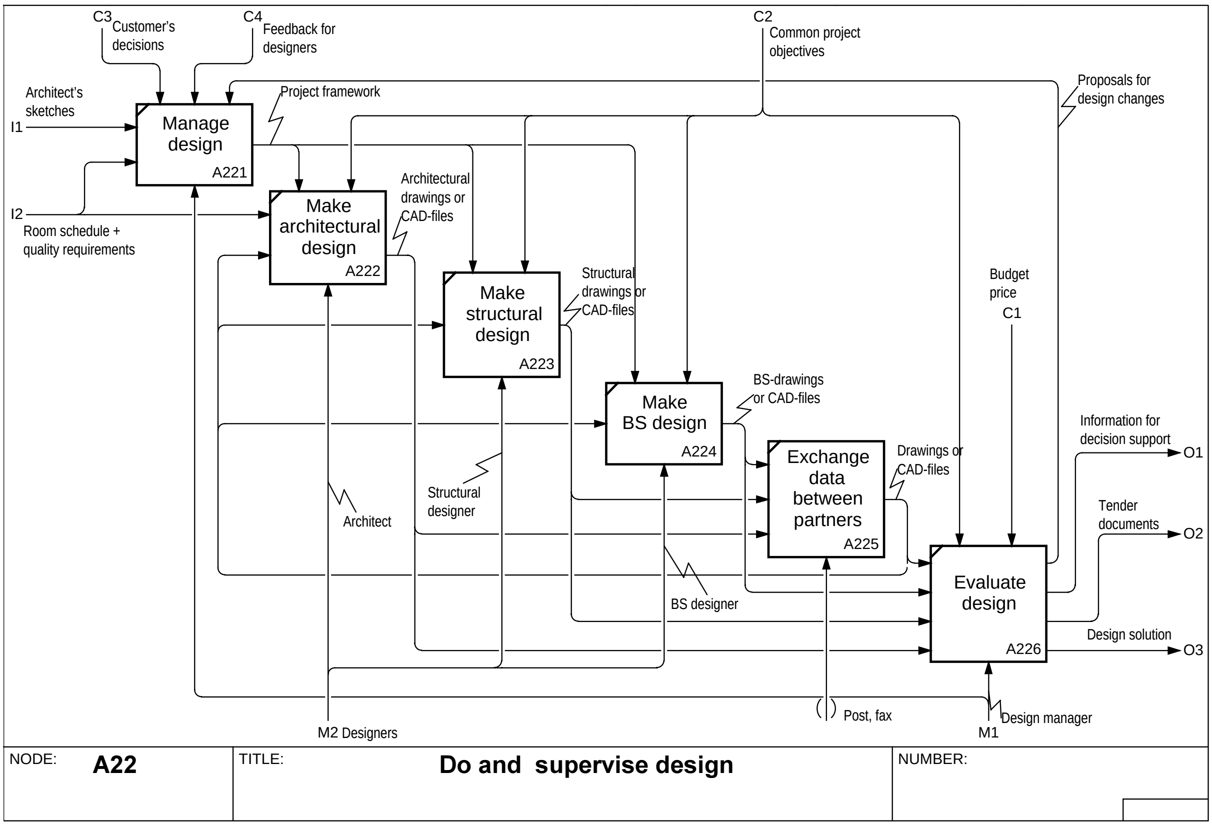


Figure 2.7. A22, Do and supervise design, as-is.

It is difficult to integrate the IT applications used by the various partners. Design information is transferred on paper documents or by diskettes, from which the other partners input the needed data into their own applications. Even if designers are using CAD-systems, the data structures they use (symbol libraries, layers, reference files) are usually company-specific. There have been a few pilot projects in Finland where all designers have used AutoCad in an organised way [Vahala 1997]. Still this type of integration has only facilitated the exchange of the graphical aspects of design data, for instance using low level standards such as DXF. The lack of standards concerning the layering of CAD-files has been the major problem, although a draft international standard for structuring layers in computer aided design has been published recently [Björk et al. 1996]. Transferring design information from one phase of the project to another is mainly based on paper documents. For this reason, actions are often duplicated in the course of the project.

To summarise, the problem lies in the methods for data exchange; the data should be in usable form for all parties involved. This problem is due to the lack of either standardisation or suitable methods supported by IT tools.

2.2.3 Support for cost and value management during construction planning

In present-day design practice attention is focused primarily on describing the building using documents, not on specifying data describing the building in models which are directly interpretable by computers applications. The process has been divided into clearly successive design phases, in which decisions of various levels are made and the decisions are documented in the form of drawings, specifications and schedules.

According to the Finnish practice, the design process can be sub-divided into brief design, conceptual design and main design. In addition, additional design is performed during the construction preparation stage and even throughout the construction work. The cost estimates required during the various design stages are the target cost calculation, the building element estimate, and the product structure estimate. Much of the cost information generated in a particular design stage is lost when moving on to the next stage. The linkage between design stages and cost estimation is shown in figure 2.8. The figure also illustrates the accumulation (and subsequent loss) of cost information.

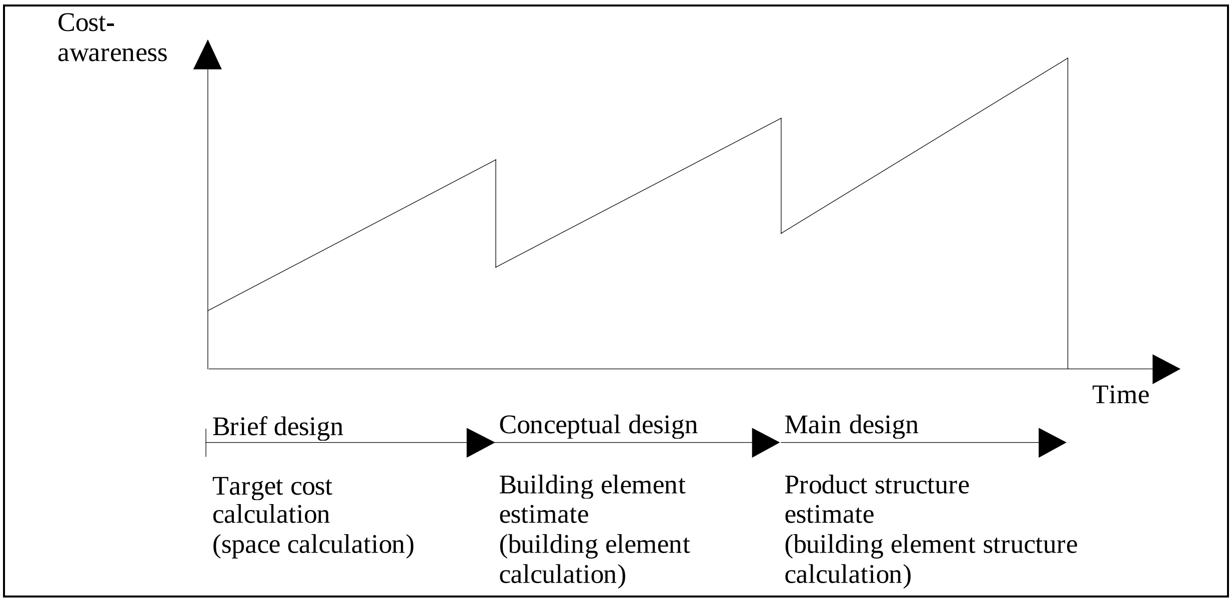


Figure 2.8. Cost-awareness as the design work progresses.

Design cost control in Finland is based mainly on the comparison of characteristic figures of the effectiveness of the design solution and on scope calculations. The cost estimates in the functional design stage are usually based on statistics in the annually published ‘Kustannustieto-kirja’ (‘Cost Information Book’). A cost estimate based on building elements is normally not made before the working drawings have been produced (conceptual design stage). This being the case, the real cost impact of the decisions and choices made, based on the previous experience of the contractor, are not known in the design stage. **At the stage in which the cost impact of the solutions chosen is at its highest, decisions are frequently based on guesswork and assumptions.**

2.2.4 Cost and Value engineering, prevailing practice in YIT

YIT Building Construction’s cost and value engineering (CVE) management constitutes a part of the company’s quality system, which has been awarded ISO-9001 certification. According to YIT’s quality system, the aims of systematic cost and value engineering are:

- Decisions affecting design solution should be made on the basis of true, researched information, in the right order and at the right time.
- Any need to revise a design solution should not to be caused by inadequate co-ordination or poor management.
- The viewpoints of production and of the client should be reconciled, taking into account the aspects of functionality and aesthetics, into an economically feasible product.

The procedure used currently by YIT is based on the cost and value management principles defined in the annually published “Talonrakennuksen kustannustietokirja”. These have been defined by the Construction 80 group originally in the 1970’ies, and follow international construction cost engineering practice relatively well. The analysis of designs at the draft phase is largely based on the comparison of characteristic figures. The most frequently used indicators are square meters of gross/net floor area and net/gross leasable area which describe extent. The management of the main planning is based on the building element system in accordance with the Construction 90 classification tables (see chapter 3).

The temporal management of design is based on the project schedules of the various phases which are revised as the project progresses. Excel applications or Planman-Project management software is used as a tool for time schedule planning.

The qualitative management of design can be divided into two different subtasks; the management of the quality of the drawings (clear, unambiguous documentation etc.) and the management of the quality of the design solutions themselves. The management of design quality is based on reviews of compliance with the objectives set in the project briefing phase.

Figure 2.9 illustrates how one of the most important of the contractor’s activities, cost engineering, is done in a traditional way. *The quantity survey* (A231) from tender documents is done either by hand or digitising and it’s also possible to use outside Quantity Survey (QS)-companies. Alternatively the client may provide the quantities.

Usually the documentation is on paper, altough the tendency is towards getting cad-files also. CAD-files in a digital form are, however, usually not a sufficient basis for automated quantity take off, due to a lack of standarisation. In traditional CAD, drawings consist of a vast number of lines arranged to describe a building. It is not easier to collect data for cost estimating from a conventional CAD image than from a hand-drawn drawing. Some remedy is offered by well-structured layering schemes, which enable the selective viewing of different building elements one at a time.

Once the quantities have been determined it’s a rather straight-forward process to produce a cost estimate and a bid. However, systems which enable the rapid generation of alternative design solutions or the comparison of alternative production methods as a basis for bidding are not available. The current process is so labor-intensive and slow that there usually is no time to study alternatives.

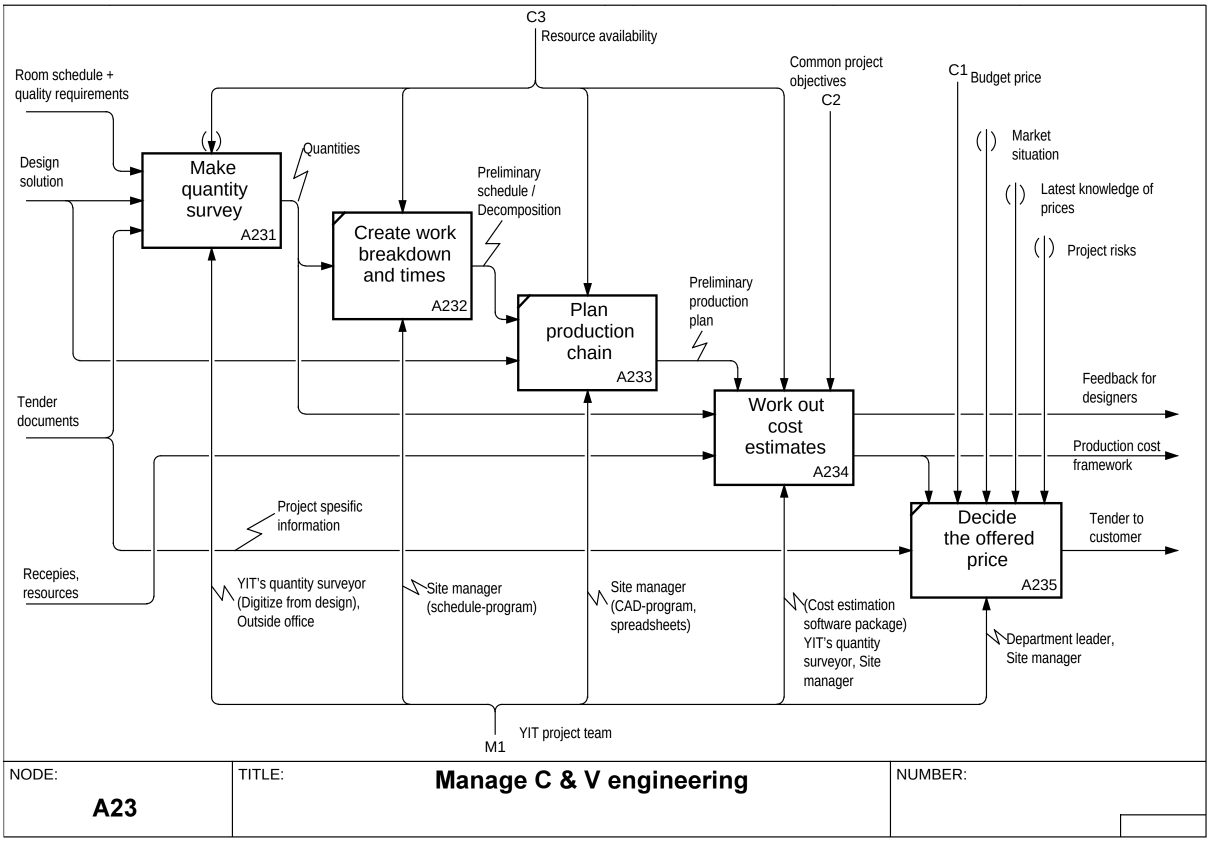


Figure 2.9. A23, Manage C&V (cost and value) engineering, as-is.

The success of a detailed cost estimate is critically affected by the success of the quantity surveying activity. Quantity surveying involves a lot of work, depending on the size and type of the building. The amount of quantity surveying work is also influenced by the calculation methods chosen and the available tools, such as a digitising board. Quantity surveying is the most time-consuming part of a contractor's tendering process.

In quantity surveying the same data value will often be determined at least six times during the project. **Information produced in the bidding or planning stage is not usually structured in such a way (building element or work section breakdown, measurement rules etc.) that it could be used directly for purchasing or production purposes. Also, part of the project-specific data is not transferred from one phase to another**.

The use of resulting quantities during the construction process is as follows:

- Tendering; check the methods and resources, prepare tasks for quotation
- Scheduling; check the tasks and determine them
- Quotation planning; prepare quotations
- Task planning; budgeting according to tasks, quantities for final cost estimation, planning of the delivery lots
- Quotation tenders and orders; quantities according to assemble partitions/ delivery lots
- Production control; as built quantities

In the following IDEF0 diagrams (figures 2.10 and 2.11) this repetitive action of quantity take off during the construction process is illustrated. After each design phase similar actions will take place for almost the same purposes. The created information is not used in the next phase.

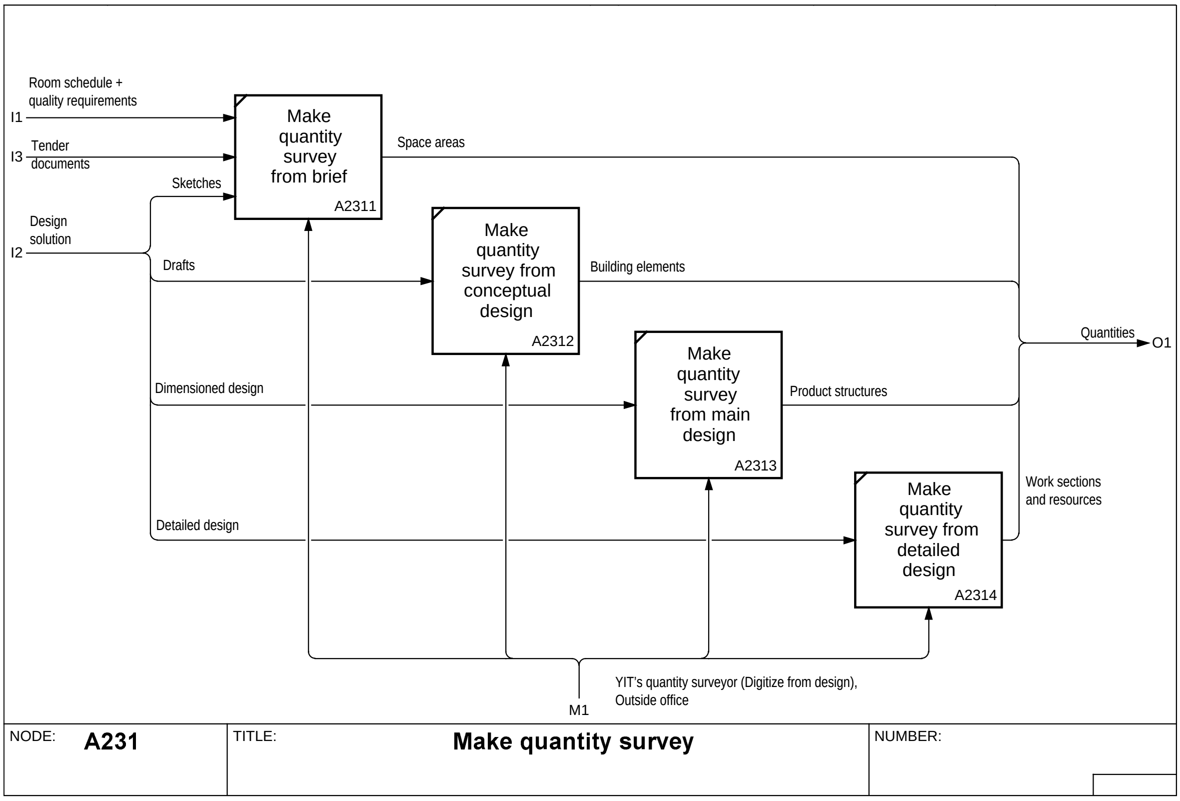


Figure 2.10. A231, Make quantity survey, as-is. Quantity surveys are carried out repeatedly based on design documentation in each different design phase.

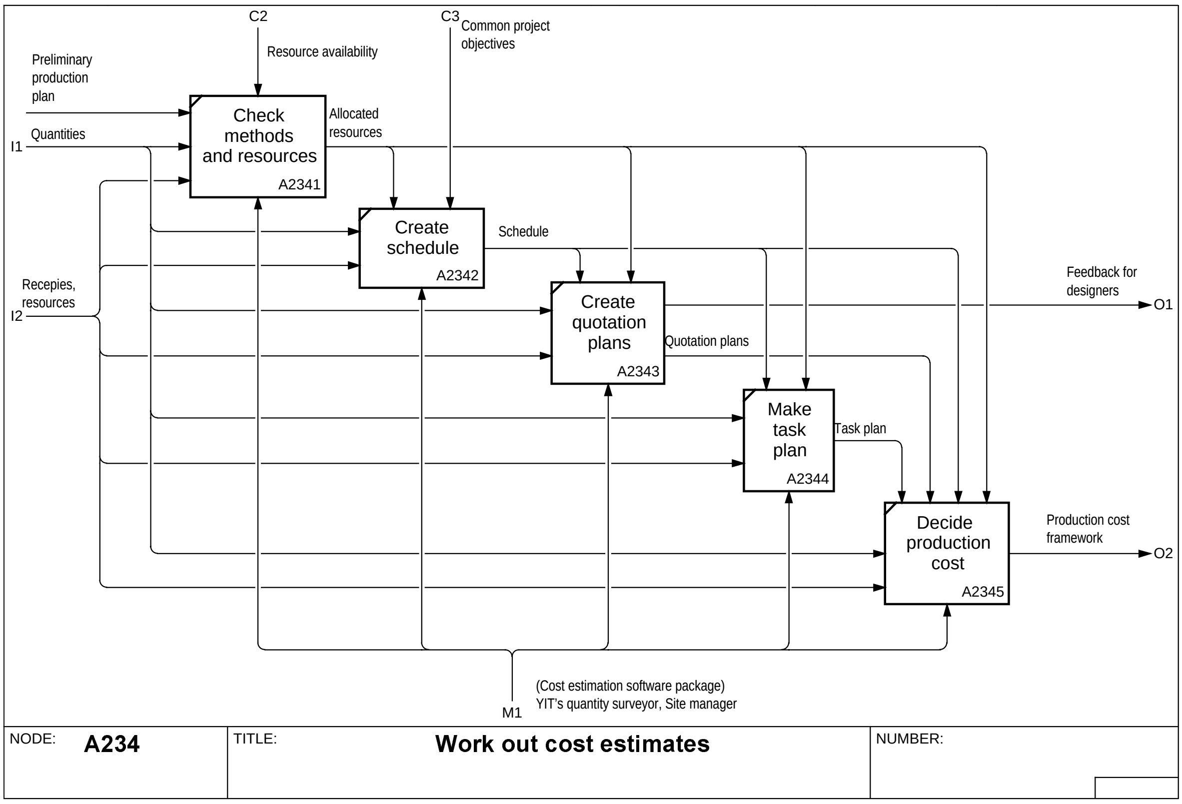


Figure 2.11. A234, Work out cost estimates, as-is. In each phase the information has different contents. Repetitive actions characterise the process.

2.3 Summary of shortcomings

The shortcomings in the building information management process are concentrated in two key areas: customer decision support and contractor’s information management. From the customer’s point of view the design team together with the contractor have a weak ability to serve him/her and provide decision support throughout the process. This is due to the lack in creating enough information to adequately support decision making and lack of capability to use information from reference projects effectively as cases. Another key issue is the hand over and as-built information for users and owners which is poorly defined and documented.

From the contractor’s information management point of view a crucial shortcoming is the difficulty to manage data. Another is the poor integration between different applications (tendering, production planning etc.). Information which has been entered into one application cannot be transferred to other applications. The contractor is not able to effectively use design information as basic data in their own applications, because the information flow between designers and contractor is mainly based on drawings. This especially causes too long tendering lead times and inaccurate cost estimations.

The contractor should be able to use information coming from the designers as it is as input data, and to merge with it his own production knowledge. Another key issue is cost and value engineering, i.e., the ability to analyse design solutions from the perspective of accomplishing the construction, as well as to examine alternatives and the impact they will have on the overall costs.

In all the above problem areas, the key issue is efficient data management, which the IT applications used by the case company cannot adequately support.

3 STATE OF THE ART

3.1 Information Management Methods and Technologies Supporting Construction Process Management

Some key areas of construction information management and IT technology that are particularly relevant to the topic of this study are discussed below.

Traditional methods used to create and manage the construction management information include:

- Classification systems for construction information. [Giertz 1995]
- Methods for construction cost estimation and process planning.

The key new information technology area is

Product data exchange, i.e., data exchange based on formal representations ranging from aspect models in specific product areas to large scale integrated product models [Eastman and Augenbroe 1998]. The ultimate goal is to gain all the benefits that information sharing on a large scale can bring to the industry. Examples and characteristics of shared project models can be found in [Fischer and Froese 1996].

3.2 Classification Systems for Construction Information

Classification is a means to facilitate communication among the different parties in the construction field. It has impact on the structuring of information that is essential in data exchange between for instance designers and contractors, irrespective of if this data exchange is done in the form of traditional documents such as drawings and written specifications as in the current practice or in the form of models intended directly for use in computer applications as in the envisaged future practice. Logical structures of classification systems are discussed for instance by Bindslev [1995].

At present there are many national classification systems for building elements, work sections and construction products. Many of these are, nevertheless, relatively similar in their overall structure, although they may differ a lot in their detailed categories and coding principles. Examples of national standards include:

- The SfB system which originally was developed in Sweden, and from which national variations have been developed in countries such as the UK and Denmark.
- The BSAB system which currently is in use in Sweden. [SB-Rekommendationer 1997]

- The North American MASTERFORMAT classification and number system developed by the Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC).
- The British SMM7 (Standard Method of Measurement).
- The German StLB (Standardleistungsbuch).
- The Swiss NPK (Normpositionenkatalog).
- The Finnish Classification System Construction 90 [Tiula 1993].

A working group of the International Standardisation Organisation has recently issued a draft international standard called “Framework for Classification of Information” [ISO 1997]. One goal of the draft is to establish principles for the classification systems of the building sector, including definitions of concepts such as building element, space, work section etc. as well as the interrelationships between the concepts. No work on the development of a full international standard has, nevertheless, been launched. Ekholm discusses concepts of the draft in a paper [Ekholm 1996].

In the following one of these national standards, the Finnish Construction 90 system is discussed, since it has been particularily relevant for this research.

3.2.1 The Construction 90, Element Classification in Finland

In Finland there is a tradition to control the cost and the quality of construction using a building element breakdown. The preliminary cost appraisal systems, construction master specifications, procedures for cost calculation during tendering and construction cost follow-up are all based on using the same national element table [Tiula 1993].

The element system has its origin in the early 1970s, when the construction industry published a classification system to be used in electronic data processing. The system was developed further in cooperation with public builders and contractors. A new version has been published once a decade. The latest version is called Construction 90.

Construction Elements

An element of construction is a functional part of the building fabric, designed and built as a distinct unit. An element is identified in the design process by breaking down the building fabric, to the level where a distinct functional part is found. That part has an individual production structure, i.e., it is built of specific construction products using specific skills.

There are two main types of building elements, those which *enclose* the spaces and those which *link* the spaces with technical services. The space-enclosing elements may be called *constructive elements*. They are composed of more or less ‘traditional’ building products, such as bricks, concrete, timber, building boards, etc. Setting up a constructive element may involve several work sections. For instance, a partition is built of a steel skeleton, mineral wool filling and plasterboard linings on both sides. The way an element is composed of work sections is in Construction 90 terminology called its *production structure*. A production structure, including the labour and equipment required to complete the construction element is called a *recipe*.

The space-linking elements may be called *service elements*, which also have a production structure. A space heater, for example, may consist of a radiator, brackets, sockets, sealers and a thermostat valve.

The constitutional relations between the different concepts introduced above are thus:

- A building consists of spaces (void) and elements (material).
- The elements consist of work sections.
- The work sections consist of products and labour.
- In addition to a classification of building elements the Construction 90 classification system also includes other classification facets which can be used to describe the different phenomena in a construction project. They are:

- A classification of spaces to be used in the planning and programming phase.
- A work section classification to be used in production planning and subcontracting.
- A (physical) resources classification to be used in trading commodities (construction products, machinery).

Table 3.1 contains an extract from an element based cost estimation, classified according to the Construction 90 classification system.

Table 3.1. An extract from an element based cost estimate, classified according to the Construction 90 classification system.

Building Element Code	YIT-Code	Building Element Description	Total Quantity
Building Element Code	Method Code	Method Description	Quantity
	Resource Code	Recourse Description	Quantity
F27	**VP11**	**Intermediate Slab / Hollow Core Slab**	**1 414 m^2**
F27	**25 0005**	**Hollow Core Slab Element Assembling with Tower Crane**	**184 unit**
	1 25001	Element Assembling	185,9 h
	2 315000004	Neoprene Tape 4*40 mm	485,9 m
	4 211201	Derrick Boom	4,6 d
F27	**25 0265**	**Hollow Core Slab Jointing 265mm with Steel, no Work**	**1 534 m**
	2 311300012	Reinforcing Bars A 500 HW 12 mm	1 090 kg
	2 311300900	+Transportation	1 090 kg
	2 312100056	Ready-mixed Concrete K25/8 mm 2-3sVB	21,2 m^3
	2 312190514	+Transportation / Ready-mixed Concrete	169,4 m^3km
	2 342110152	Timber 19*100 pl/kl	168,7 m
	2 342110279	Timber 50*100 vs/vl	210,9 m
F27	**25 0903**	**Casting on Site h=265**	**97 m^2**
	1 21001	Concrete Formwork	43,6 h
	1 22001	Reinforcing	34,8 h
	1 23001	Concreting	19,4 h
	2 311300008	Reinforcing Bars A 500 HW 8 mm	967,8 kg
	2 311300900	+Transportation	967,8 kg
	2 312100056	Ready-mixed Concrete K25/8 mm 2-3sVB	26,9 m^3
	2 312190514	+Transportation / Ready-mixed Concrete	215,4 m^3km
	2 342110279	Timber 50*100 vs/vl	243,9 m
	2 342110900	+Transportation / Timber	0,5 load
	2 361300344	Plywood Board 12 mm I	7,3 m^2
	2 361300900	+Transportation / Plywood	0,5 load
	4 112010	Supporting Poles 1.75-3.40 m	483,9 d
F27	**25 2265**	**Hollow Core Slab 265 mm, Purchasing**	**1 348 m^2**
	2 315330266	Hollow Core Slab h=265 mm	1 348 m^2
	2 315330800	+Precast Hole	134,8 m
	2 315330912	+Transportation / Hollow Core Slab 120 km	485,3 ton
F27	**26 1001**	**Finishing of Concrete Element Surface**	**1 348 m^2**
	1 99001	Work	43 h
	2 335100050	Correction Mortar (40 kg)	1 483 kg
	2 335100900	+Transportation / Mortar	1 483 kg
	31 000000X	Subcontractor's Work	80,9 h

3.3 Methods for Construction Cost Estimation and Process Planning

Over the decades a number of methods for cost estimation and project planning for different stages in the construction process have evolved [Fischer and Aalami 1995], [Aalami and Fischer 1998]. These methods rely quite heavily on having information classified according to some classification system structured as discussed above, including company-specific specialisations. Rather that discuss such practices internationally the following discussion concentrates on prevailing Finnish practice.

The recommended national quantity surveying and cost calculation practice is based on the following conventions which lend themselves to different stages of the construction process:

- Cost calculation by spaces for the preliminary design stage.
- Cost calculation by building elements for the tendering stage.
- Cost calculation by work sections and resources for the production planning stage.

The first cost estimation during the early part of the design process, the target cost, is based on information about the required spaces and their overall qualities, as specified in the room schedule. The cost for these spaces is estimated using historical data on per square meter costs in similar projects. The procedure involves a method, which allows to take into account the project specific qualitative features.

In the design stage the building costs can be calculated from the quantities of different building elements, calculated from the architectural drawings. An updated general price list of elements, both as a printed yearbook and as a data file ("Talonrakennuksen kustannustietokirja") is available. The target cost and the building element cost are comparable.

The next step is the building specification. The specification is arranged according to element types, writing an individual clause for every different production structure of an element.

In the tendering phase the building element system is widely used. In cases when the tenders are requested on the basis of the client's bill of quantities, they are always based on quantities of elements. Most contractors have detailed price files for the production structures of common elements according to their company's methods of production. For exceptional elements, the unit cost can be calculated by breaking down the production structure into work sections and, if necessary, further into resources.

Typical IT tools used today for cost estimation include spreadsheets, relational databases and dedicated scheduling software. A crucial feature in current best practice is the contractor’s ability to link experience data from past projects (for instance what work sections and what amounts of resources are typically needed to build particular types of building elements) to data for new projects emanating from the designers. The classification codes offer significant support for this, but nevertheless a substantial part of the process is manual and laborious. This has to a large extent to do with the fact that the IT tools generating the designs (essentially building elements) and the ones used for processing the cost calculations are rather incompatible.

3.4 Product Data Exchange

3.4.1 Data Exchange As Documents Versus Models

The traditional way of exchanging information in the construction industry could be called document centred. Designers and other participants in the process have produced documents on paper such as drawings, written specifications, bills of quantities etc. Although computers offer substantial help today in the production of these documents the data exchange and management procedures are still very focused on documents, which have an important legal status. The emerging product data technology offers a radically different way for the exchange and sharing of information, making full use of the potential offered by computer networking and data base technology. It is the ability to share information in digital format throughout the building process, that would take the utilisation of information technology in building construction to the next level with greater benefits, not the small enhancements in the features and functionality of individual computer applications, inside discipline areas.

Figure 3.1. depicts the reduction of redundant communication in product data exchange. Shared data is stored only once, in a product model from which the different participants in a construction project can retrieve data and to which they can add data. An integrated approach for a model based document production and management has been proposed by Rezgui and Debras [1996]. The CONDOR approach [Rezgui et al. 1997], describes the shift from construction product information to consistent project documentation. Law [1992] discusses design information management in a shareable relational framework.

Product data technology can be defined as a set of IT methods, tools and standards for the development and implementation of applications for the management, exchange and sharing of product data. The central effort in the development of the product data technology has been the international standardisation work in ISO TC184/SC4 *Industrial Data* committee. The main result from the work so far has been the so-called STEP-standard, officially known as *ISO 10303 Product data representation and exchange* standard.

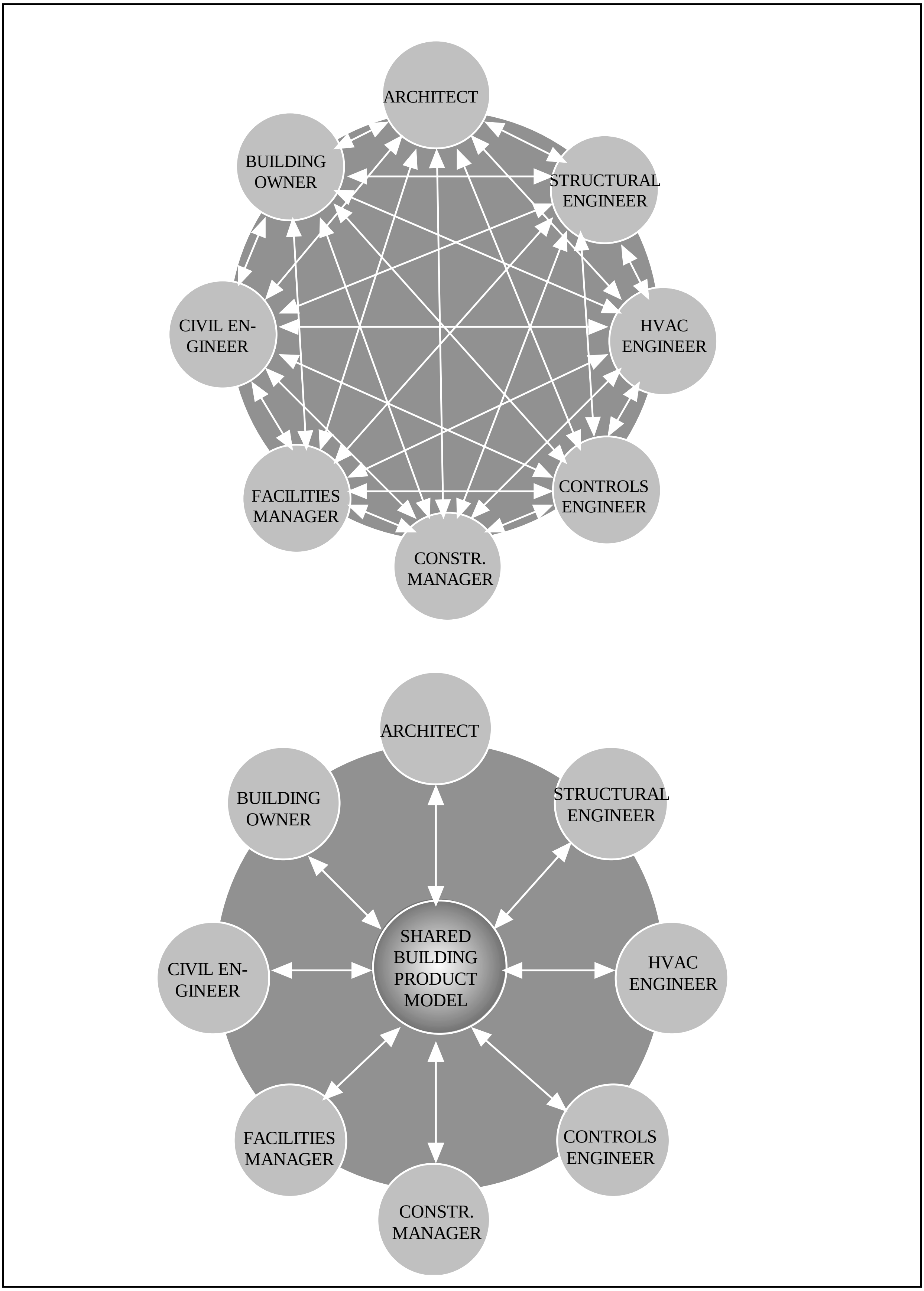


Figure 3.1. In product data exchange, shared data is stored only once, in a product model, from which the different participants in a construction project can retrieve data and to which they can add data.

The development of product data technology and standards over the last decade and new emerging information technologies (IT), such as object-oriented technologies, World Wide Web etc., has resulted in a situation where methods, tools and data exchange standards are available for real applications of product data exchange in a computer-interpretable form between a heterogeneous set of computer applications [Karstila 1997]. A comprehensive application of product data can be supported, and requires a combination of a number of methods, standards, tools, and applications as illustrated in figure 3.2.

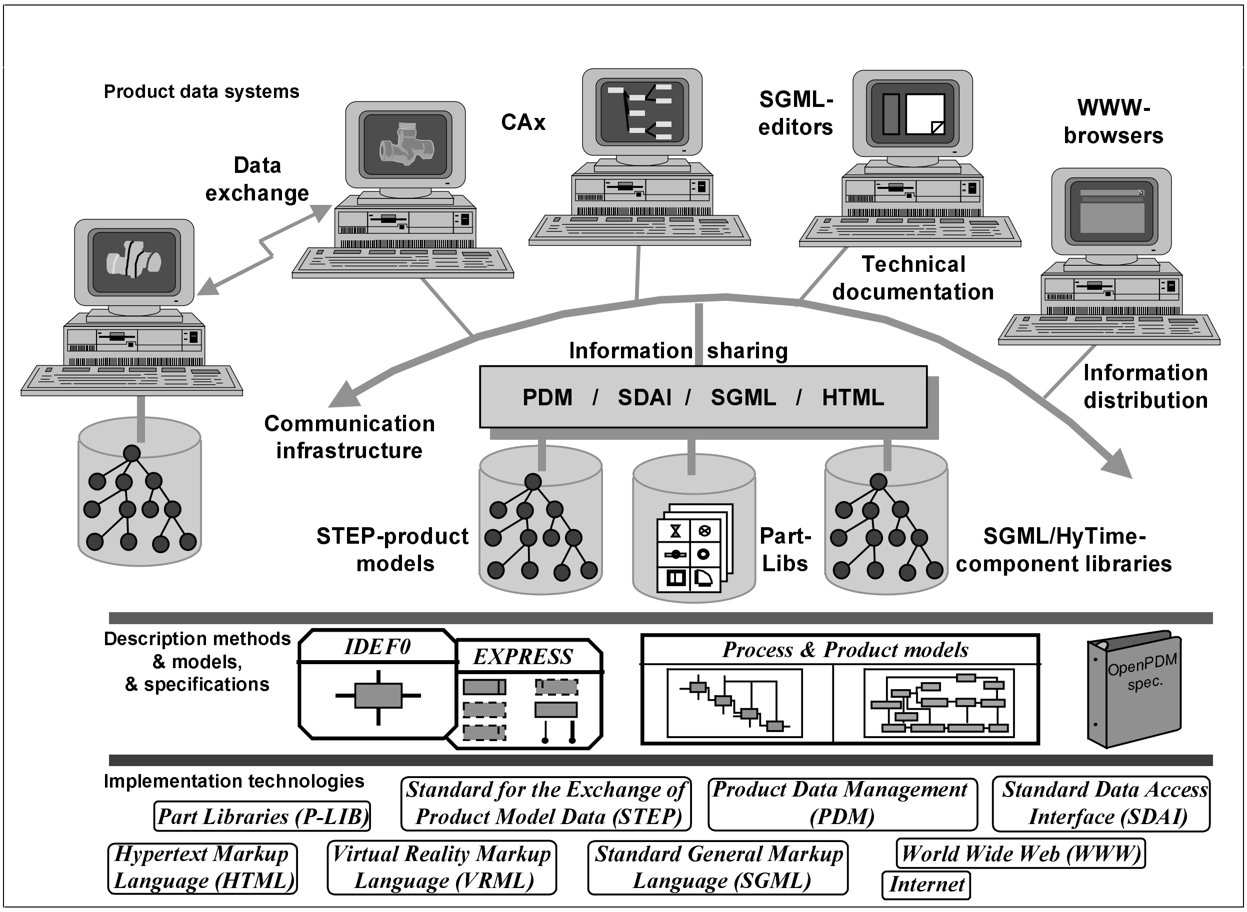


Figure 3.2. The components of product data technology. [Karstila 1997].

The kernel of the STEP technology includes:

- Methods for modeling the product information to be exchanged.
- Integrated resources as a set of reusable product data constructs to be used in the development of application domain specific data exchange standards.
- A formalised standardisation process according to which data exchange standards (Application Protocols) for new areas can be developed.
- Application protocols (AP) which are typically industry specific data exchange standards to support specific data exchange needs.

- Implementation methods providing the definition for a neutral data exchange format for file based data exchange, and a standardised data access interface for product data repositories.
- Methods for the conformance testing of implementations.

The formal methods of STEP technology have also resulted in commercial toolkits for the development of STEP implementations, e.g. product model browsers and CAD pre and post processors. Using the formal product data descriptions the tools provide library functions e.g. for parsing data and data access. [Karstila 1997]

Several authors have discussed the benefits of the product model based data exchange compared to the document based [Björk 1989], [Tolman 1991], [Augenbroe 1992]. Possible benefits include:

- The information is stored only once, avoiding data redundancy, and thus avoiding also conflicting information, which typically appears in the document centred approach.
- All the relevant design information is stored in a uniform way, which eases data access for applications. Today it is difficult to extract relevant data from heterogeneous sources such as cad-files, word processing files, spreadsheets etc.
- From a product model it is easy to produce tailor-made traditional documents for various purposes. Today the producer of the information decides what types of document are being exchanged. In the product model approach, the receiver himself can, based on the model, define what sort of documents he may need.
- The following table 3.2 describes the main differences between the document centred and the product model based approach [Kulusjärvi 1996]. The viewpoints are on the usage of information when exporting and importing the information, and on information flow management.

Table 3.2. The main differences between the document centred and the product model based approach. [Kulusjärvi 1996].

	USAGE OF INFORMATION	
EXPORT		*IMPORT*
The person designing the process visualises the plan in tables, drawings and reports. Although all the information is documented, it is placed in separate documents.	***Document***	*All the documents are interpreted by human experts*
All the information is captured in the product model and is passed forward as it is.	***Product Model***	*Information is used in the same context and format as it arrives*

3.4.2 Product Model Fundamentals

The fundamental basic building blocks of product data exchange are:

- An agreement on the semantic structure of the information to be exchanged.
- A physical data exchange format.
- The physical media for the data exchange.
- Sending and receiving applications capable of using the above standards.

Agreements on the semantic structure of the information to be exchanged deal with what concepts we use to describe buildings and how these are interrelated. For instance concepts such as space, wall and window. Spaces are enclosed by walls. Windows provide lighting for particular spaces and are located in walls. Such agreements are based on object-oriented conceptual models.

Physical data exchange formats are used for constructing the data exchange files which contain the objects of interest. These formats can include agreements on how to mark that a new object starts, what characters are allowed, etc.

In the area of physical exchange media there has been a tremendous development during the last few years. Where magnetic tapes sent by couriers would have been the most feasible solution fifteen years ago, the developments in computer networking make it technically possible today to share product data using electronic mail, the world wide web, shared database etc.

Concerning sending and receiving applications the trend towards increasing use of object-oriented software structures and general interoperability makes it increasingly easy for software for CAD, cost estimation, project planning etc. to export and import data.

In the following we shall in particular focus the discussion on conceptual models of buildings and construction process information as well as physical data exchange formats.

3.4.3 Conceptual Models of Buildings and Construction Process Information

Modeling is a means of conceptualising some well-defined part of the real world. A conceptual model will show the structure of information in these “mini-worlds”. Conceptual models provide formal definitions of the basic entities and relationships required to fully represent information about the domain in question. The term *conceptual schema* is often used for such a model.

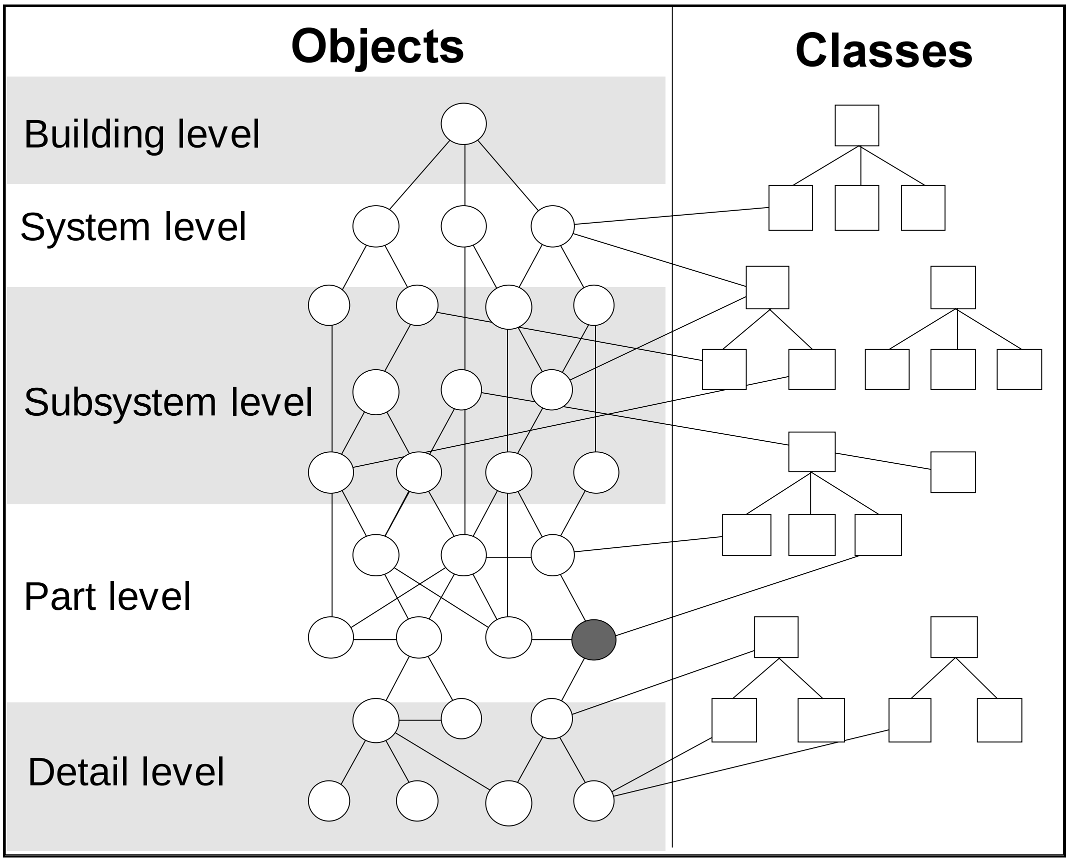
There are a number of formal languages available for conceptual modeling, including languages such as IDEF1X and NIAM. In the construction modeling area EXPRESS and its graphical subset EXPRESS-G [ISO 1993b], [Schenck and Wilson 1994] are the most frequently used conceptual modeling languages. Other object-oriented modeling methods exist, e.g., the OMT method [Rumbaugh et al. 1991].

A *product data model* can be defined as follows: “A particular type of conceptual schema, which structures the information needed to describe a physical artefact, designed and manufactured by man. The central object classes of product data models describe the functional parts of the artefact and assemblies formed by them, rather than concepts needed for representing the parts in different kinds of documents” [PM Glossary 1996].

A *product model* again is a computer-interpretable description of an artefact, structured according to some predefined product data model. A product model is thus an alternative to a wire-frame model or a miniature model of the same object.

A *building product model* is a subtype of a product model in general, a description of a particular building (i.e. the YIT corporate headquarters building). It must fulfil the data structures defined in a corresponding *building product data model* [PM Glossary 1996].

A building product model according to the RATAS framework can be used to illustrate these concepts. The left part of the figure 3.3 (Objects) illustrates the actual building product model, whereas the right part illustrates the underlying conceptual schema.



building product model *building product data model*

Figure 3.3. An illustration of the concepts of "building product model" and "building product data model" using the basic framework of the RATAS project [Penttilä et al 1991].

For the purpose of this thesis the following concept is also useful. This definition has been created for this thesis only and other authors may have used the same term slightly differently.

A ***Production model*** integrates the contractor's knowledge of production (methods, recipes and resources) with information in the building product model.

3.4.4 International and National Standardisation Efforts

Standard for the Exchange of Product Model Data STEP

STEP (The Standard for the Exchange of Product Model Data) is the working name for the standardisation of models for product data representation and exchange. Its aim is to define standards for the definition and exchange of computer-interpretable product information throughout the lifetime of a product [ISO 1993a].

The STEP standards are aimed for the whole life-cycle of product data including planning, design, erection, usage, maintaining, and demolition. STEP includes various implementation methods for handling, storing, exchanging, and archiving product information.

The first part of STEP, Overview and Fundamental Principles, covers general aspects. The structure of the rest of the STEP standards is divided into functionally similar parts called classes.

The cornerstone in the STEP development is the kernel which includes the following:

- Description methods for describing the product information to be exchanged, e.g., EXPRESS, EXPRESS-G.
- Integrated resources as a set of reusable product data constructs to be used in the development of domain specific data exchange standards, e.g., application protocols, see below.
- Application protocols which are typically industry specific data exchange standards to support specific data exchange needs. Application protocols are developed according to a formalised standardisation process.
- Implementation methods providing the definition for a neutral data exchange format for file based data exchange (SPF), and a standardised data access interface (SDAI) for product data repositories.
- Methods for the conformance testing of implementations.

STEP defines mechanisms for neutral data exchange, i.e. in the data exchange the product data is in the form defined by STEP standards and the sending and the receiving applications have pre and post processors to convert the data from their own data structures to this neutral format and vice versa. The product data to be exchanged must be formally described using information modeling techniques and the data specification language EXPRESS.

For the construction industry there is a Building Construction sub-committee. The main current results within that committee are:

- ‘Application Protocol AP 225. Building elements using explicit shape representation’ [ISO 1996a]. The status of the protocol is Final Draft International Standard (FDIS).
- ‘AP 230. Building structural frame: Steelwork based on Eureka CIMSteel’ [ISO 1996b]. The status of the protocol is Committee Draft (CD).
- ‘Part 106. Building Construction Core Model (BCCM)’ [ISO 1996c]. Due to the lack of resources this development has been moved under the IAI-umbrella (see below) for the next coming 18 months.

Industry Foundation Classes IFC

The International Alliance for Interoperability (IAI) is a recently founded industry effort whose goal is to develop product data models for sharing information between software tools which are utilised throughout the Building Industry [IAI 1998]. These models (or rather the class definitions that form them) are called Industry Foundation Classes (IFC). The IAI is a group of over 600 AEC related companies and organisations located throughout the world.

After having been started as a relatively independent effort, the IAI has increasingly taken into use techniques that have earlier been developed within STEP. Thus the EXPRESS language and the STEP physical file format are used and there is quite a lot of reuse of models or parts of models. Many of the leading experts who have earlier been engaged in the development of STEP building construction application protocols or the building construction core model are now active within the IAI. Discussions are also going on to reach an agreement ensuring that the duplication of effort is minimised and that the resulting standards – the STEP application protocols and the core model – and de-facto standards (IFCs) as far as possible are compatible or even the same.

The Finnish National RATAS Effort

There has been an on-going effort to develop the basis, methods and conventions in computer integrated building design projects in Finland since 1985 [Enkovaara et al. 1988], [Björk 1994]. The goal has all along been *open systems* between the various parties taking part in a construction project, common practices about the techniques of data exchange, standardised formats for the data to be transferred. Since 1988 recommendations concerning a number of areas have been published, including:

- The structure of a common general database in the construction area (Teleratas).
- Standards for data exchange for graphics, tables etc.
- General building product model principles.
- Definitions of information needs and outputs in the various phases of a construction process.
- Product identifiers and EDIFACT messages for building trade.

The RATAS work is organised by a committee under the Finnish Building Information Institute. The institute maintains a database of product models as description pages of object definitions. Information about them is delivered to developers, who themselves feed the delopment work by their comments and suggestions for change.

The RATAS work started very early on, before the industry was ready for product model techniques. A number of technical developments (for instance the Internet and the WWW, development of interoperability of basic software) have made some parts of the RATAS proposals outdated. On the other hand, the R&D which has been performed has produced know-how and results which currently are being channelled into international standardisation efforts.

3.4.5 The Architecture of Building Product Data Models

Building product data models can be defined on different levels of detail. As an example of a layered structure of different complexity and scope Björk defines five “layers” of representation in building product data modeling [Björk 1995]:

1. information modeling language,
2. generic product description model,
3. building kernel model,
4. aspect model, and
5. application model.

In the following a number of contributions to building product data technology are discussed using this layered model as a background.

The first three layers are generic models which cannot be used for meaningful data exchange on their own. They can have different scopes ranging from generic objects through products to buildings. Data structures from these upper layers can via inheritance be reused for more specialised data structures on the lower levels.

Information Modeling Language

The information modeling language layer deals with what constructs the conceptual schema language contains. As mentioned above the EXPRESS language is today widely used for this purpose and has also been used in this study.

Generic Product Description Models

The generic product description deals with data structures used for describing any products or product parts. A number of different solutions have been proposed for the generic product description level. In particular the OOCAD model [Serén et al. 1993], developed at VTT in Finland, has influenced the work included in this thesis. The OOCAD conceptual level model relies on the concepts of the RATAS-II project [Enkovaara et al. 1988] and the BEC-II project [BEC 1991] and was also influenced by the GARM model [Gielingh 1988]. It is based on object-oriented concepts. The neutral data exchange file format OXF maps the model as closely as possible to an ASCII file.

In the OOCAD model objects are composed of lower level objects with the part-of relationship. As design objects are composed of complex, prefabricated parts, the model objects form a composition hierarchy. A composition of instances is always a type, that may be instantiated at a higher level. For example, a window type can be described as a complex composition of instances of a frame, sheets of glass, a handle, etc. Several instances of this window type can occur in different positions in a wall panel. The wall panel is again a type, that may have one or several instances in the building, etc.

The entities of the model are thus as in figure 3.4:

- The abstract supertype *Individual*, which is the root of the model. It identifies the model defining unit by a unique identifier *Id*, which is composed of the individuals name and a sequential number.
- The *Type* object, a subtype of Individual. The types build up the skeleton of the technical solution of the design. Types have properties as *Attribute sets*. They are generic, application dependent and have values assigned to them. The benefit of defining in the Type all attributes with common values shared by all the instances of the Type is avoiding redundant definition. The Type *has parts* S[0:?] as Instances, the inverse of which states, that an Instance *is part of* a Type.
- The *Instance* objects are also subtypes of the supertype Individual, and they always belong to a Type object. In addition to their inherited attribute sets, instance objects optionally have instance properties of their own. These attribute sets have instance specific values. Also, the attribute *Position* is optional. It expresses the relative position of the instance object to a fixed origo in a three dimensional transformation matrix. Instance objects can be in *Relationship* with other instance objects and they may be members of *Groups*. A group may have another group as supergroup.

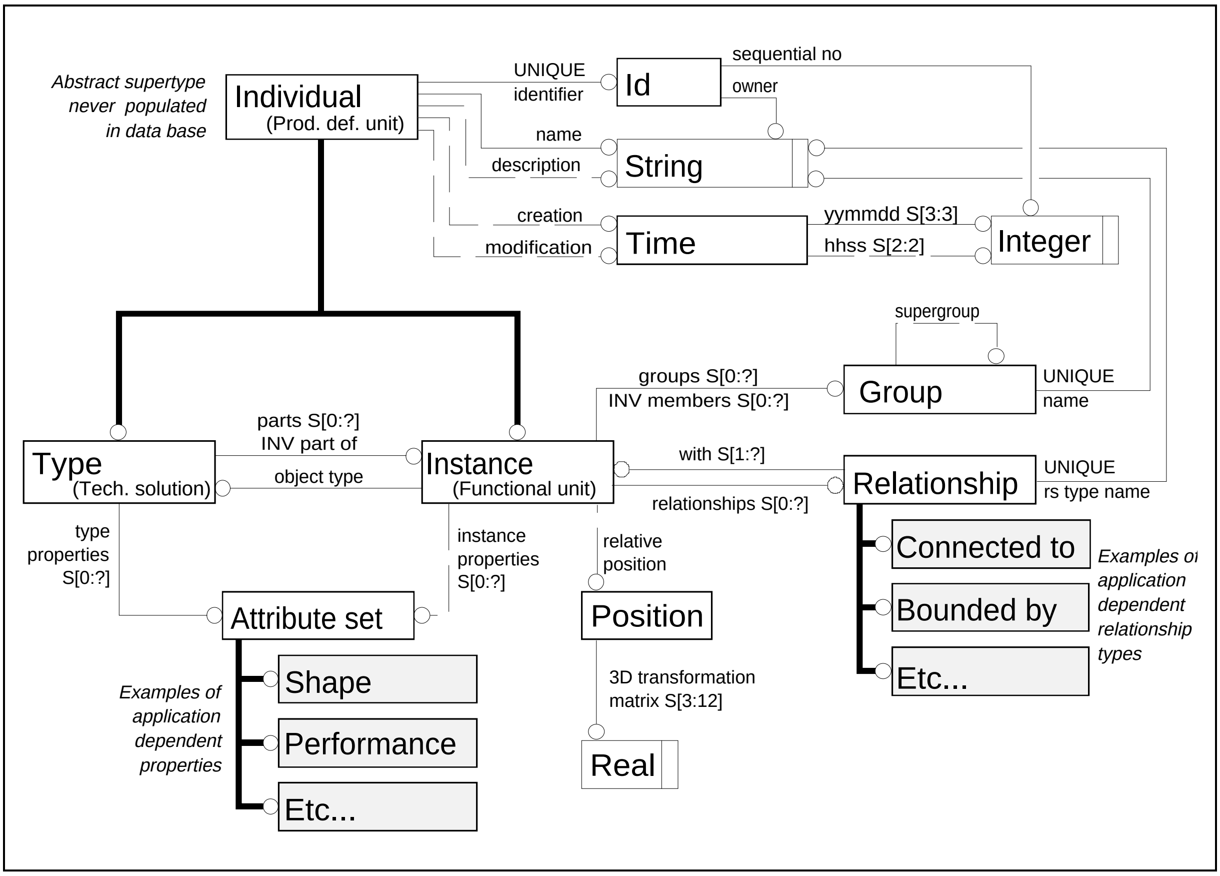


Figure 3.4. The Generic OOCAD model.

Another important model proposed for the generic level is the Global AEC reference model GARM [Gielingh 1988] which in particular contains a distinction between requirements data and the technical solutions chosen to fulfil these. A requirement could for instance be the acoustical properties of a wall and the technical solution the particular material layers chosen to build it.

The resource models of the STEP standard, which for instance deal with data structures for how geometry is to be represented using objects, could be seen as examples of generic level models.

Building Core Models

Here the term core model – rather than the kernel from above – is used. A core model typically models the relationships between the fundamental types of objects which are needed to describe buildings. For instance the relationships between buildings, building systems and components, elements and spaces can be modelled in a core model.

Core models are intended to be high-level models that provide a unifying reference for more detailed aspect or application models that will be constructed on top of them. The data constructs from the core model can then via inheritance be reused as part of the class definitions of models which for instance are specific to different design disciplines. The core models are generally not intended to be instantiated for representing actual data in the way that application models are, though they can be used for exchanging information between different application areas. Even though models such as ATLAS [Tolman et al. 1994] and ICON [Aouad 1994] are intended to directly support actual implementations, they can be described as model segments that play “core” roles for other, more specialised sections of the models.

This structure resembles a paradigm presented in [Van Nederveen 1993], where a Kernel Model is formed by the overlapping parts of different View Models as shown in figure 3.5.

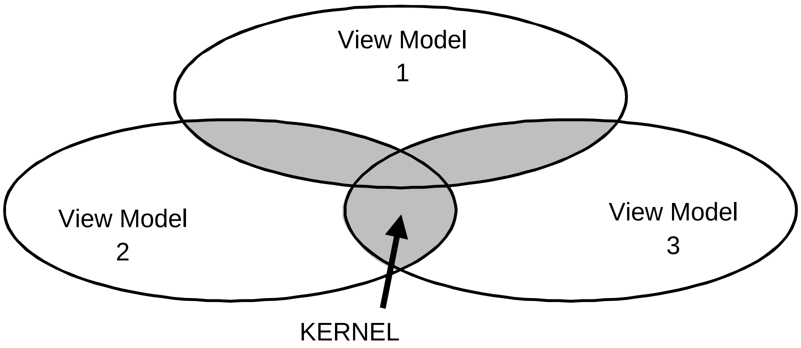


Figure 3.5. The Kernel Model concept description using a Venn diagram. All mutual intersections belong to the kernel model. The overall product model is the union of the View Models [Van Nederveen 1993].

In the following figure 3.6 the current IFC model structure is shown as an example of the role a core model plays. The STEP building construction core model, which has been under consideration since 1994, is more or less the same model.

The purpose of the IFC Object Model is to enable interoperability between AEC/FM applications from different software vendors [IAI 1997].

The IFC Object Model Architecture has been developed based on a set of principles which focus on basic requirements and can be summarised as:

- Provide a modular structure to the model.
- Provide a framework for sharing information between different disciplines within the AEC/FM industry.
- Ease the continued maintenance and development of the model.
- Enable information modellers to reuse model components.
- Enable software authors to reuse software components.
- Facilitate the provision of upward compatibility between model releases.
- Facilitate the provision of upward compatibility between model releases.

There are four conceptual layers within the IFC architecture, which use a strict referencing hierarchy. Within each conceptual layer a set of model modules is defined.

The first conceptual layer, shown at the bottom in figure 3.6, provides Resource classes used by classes in the higher levels. In our framework these could be described as belonging to the generic product description layer. The second conceptual layer provides a Core project model which contains the Kernel and several Core Extensions. The third layer defines a set of modules including concepts or objects that are common across AEC industry domains. This is the actual interoperability layer. The fourth layer in the IFC Object Model is the Domain/Applications Layer. It provides a set of modules tailored for a specific AEC industry domain or application type. (These could be defined as aspect models, see below.)

The architecture is based on a 'ladder principle'. At any layer, a class may reference a class at the same or lower layer but may not reference a class from a higher layer. References within the same layer must be designed in order to maintain modularity in the model design.

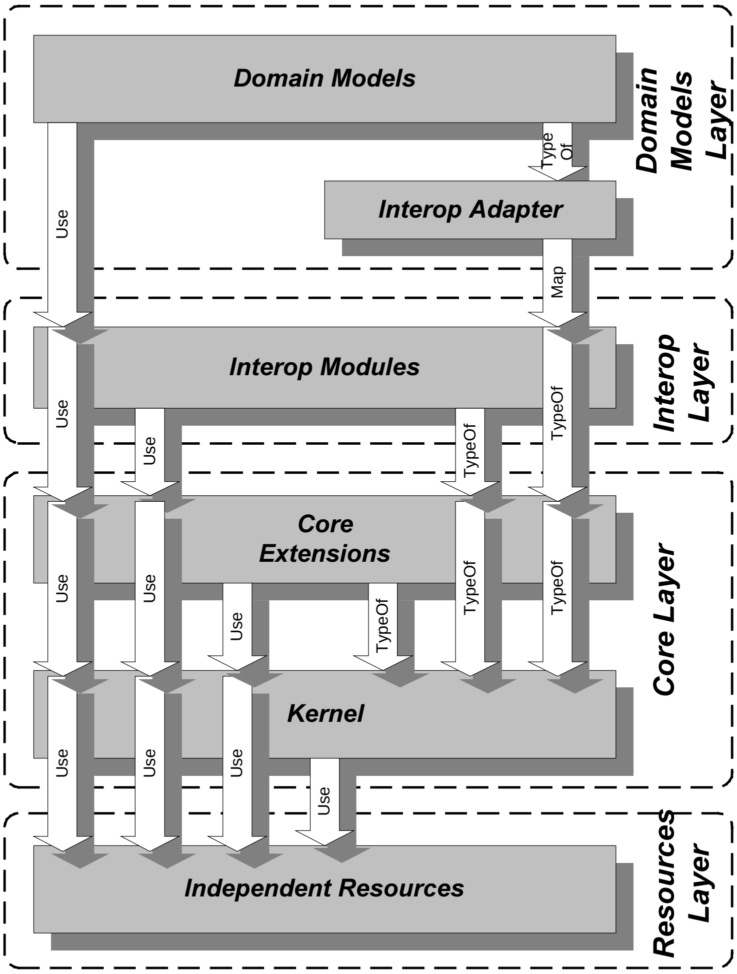


Figure 3.6. The layering Concept of the IFC architecture.

Aspect Models

Different names (aspect model, view model, application protocol) have been used for this type of models, which correspond to the data exchange needs of some restricted discipline or purpose and not to the needs of all the parties in the whole construction process. In STEP the Application protocol mechanism is used for this purpose.

As an example of an aspect model, an informal model of the data elements needed for data exchange concerning constructional steel work is shown in figure 3.7. (The model is EXPRESS-like but lacks definitions of attribute names and cardinalities). This model has been developed within the scope of the Finnish SteelBase project [Karstila 1997]. It is a draft of the information contents needed when transferring data concerning steel structures from designers to the manufacturers.

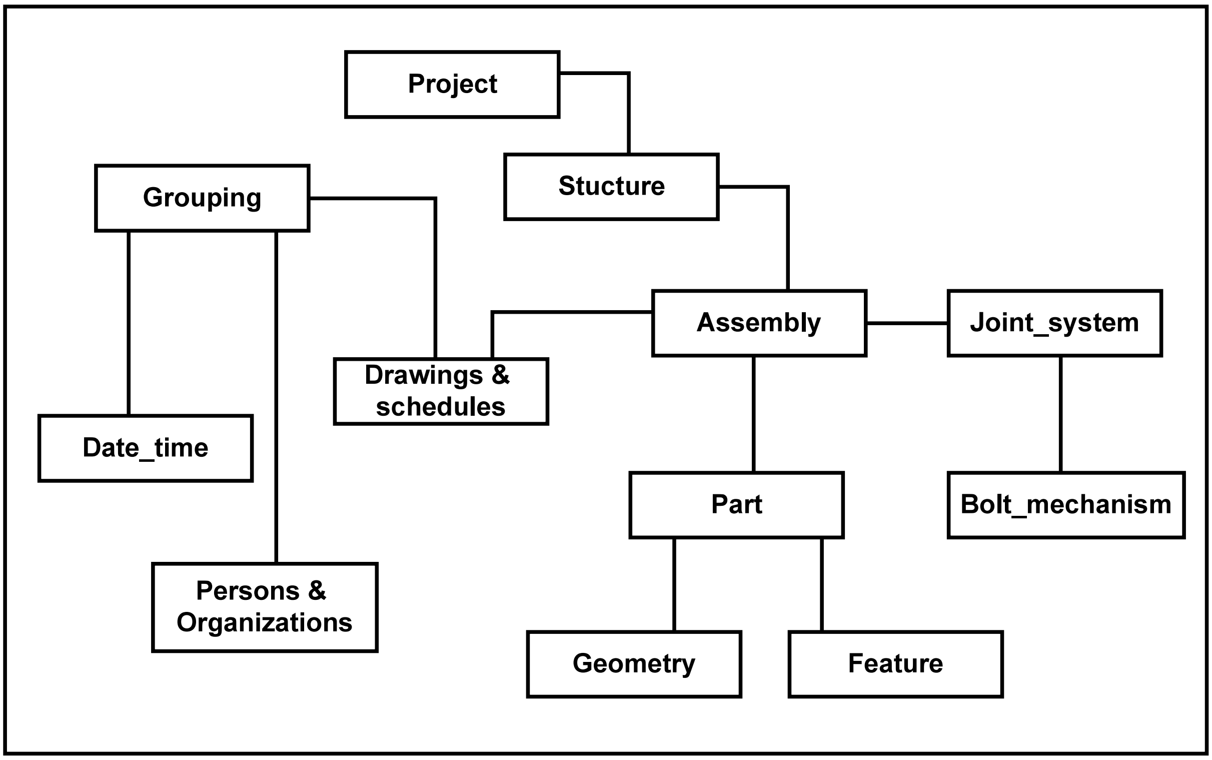


Figure 3.7. A rough information planning model from the SteelBase product data model (a subset of CIMSteel Logical Product Model LPM V4.0, Data Exchange Protocol DEP 4).

Application Models

Application models are embedded in application software, either explicitly having been modelled as a part of the software development process or implicitly. For instance the cost estimation software in use in YIT has an internal application model. Such models cannot be standardised, but it is essential to enable data conversion from the standardised models on the upper levels to and from these application models.

3.4.6 Physical Data Exchange Formats

The STEP Physical File Format

The STEP file exchange format is defined in the standard ISO/DIS 10303-21 [ISO 1993c]. This part of STEP defines the structure, i.e. grammar of the ASCII exchange file.

The definition describes the transformation of a conceptual schema represented in the EXPRESS language to an exchange file. The file contains in the header general information on the sender and on the contents of the file. In the data part there are objects that correspond with some STEP conceptual schema. The crucial point about this format is that objects corresponding to any conceptual schema that has been defined in EXPRESS can be sent. The format is in the form of a flat file, where each object occupies one row. Links between different objects are handled using the row numbers assigned to the objects. An example STEP physical file is shown in figure 3.8.

```
DATA;
#10=DSCENTITY(’PLAN’,#11,$,(#13,#18,#23),(#12));
#11=DSCCLASS(’floor_plan’,’arch_spaces_std’);
#12=DSCATTRIBUTE(’NUMBER’,’1’,$);
#13=DSCENTITY(’9B’,#14,$,(),(#15,#16,#17));
#14=DSCCLASS(’kitchen’,’arch_spaces_std’);
#15=DSCATTRIBUTE(’NUMBER’,’8’,$);
#16=DSCATTRIBUTE(’AREA’,’14.36 m2’,$);
#17=DSCATTRIBUTE(’CORNER_POINTS’,
’ 3946.75,1808.53,0.00 5454.73,5227.54,0.00 8915.36,5227.54,0.00 8915.3
6,1827.84,0.00 3946.75,1808.53,0.00 ’,$);
#18=DSCENTITY(’8D’,#19,$,(),(#20,#21,#22));
#19=DSCCLASS(’entrance’,’arch_spaces_std’);
#20=DSCATTRIBUTE(’NUMBER’,’9’,$);
#21=DSCATTRIBUTE(’AREA’,’17.19 m2’,$);
#22=DSCATTRIBUTE(’CORNER_POINTS’,
’ 2071.44,977.92,0.00 8915.36,977.92,0.00 8915.36,-2189.98,0.00 4681.41
,-2189.98,0.00 4681.41,-470.82,0.00 2071.44,-470.82,0.00 2071.44,977.92
,0.00 ’,$);
#23=DSCENTITY(’78’,#24,$,(),(#25,#26,#27));
#24=DSCCLASS(’room’,’arch_spaces_std’);
#25=DSCATTRIBUTE(’NUMBER’,’10’,$);
#26=DSCATTRIBUTE(’AREA’,’5.45 m2’,$);
#27=DSCATTRIBUTE(’CORNER_POINTS’,
’ 0.00,0.00,0.00 3217.22,4102.48,0.00 3217.22,4302.48,0.00 3217.22,4502
.48,0.00 3217.22,4702.48,0.00 0.00,0.00,0.00 ’,$);
ENDSEC;
END-ISO-10303-21;
```

Figure 3.8. An example STEP physical file used in the Isopurje data exchange pilot (chapter 5).

The OXF Format

The exchange format OXF for product data stands for Object eXchange File. It is a further development of the STD90 format from the BEC project. The so-called BEC standard was developed in Finland in the late 1980s [BEC 1991]. The OXF format was defined as part of the OOCAD project, mentioned above, to support the physical exchange of objects structured according to the OOCAD schema.

There are three kinds of structures in the OXF definitions: attribute set definitions, classes and groups. Design objects are either types or instances (called occurrences in an earlier version of OOCAD).

The structure of an OXF file resembles code written in the LISP programming language. Information is presented as lists surrounded by parentheses. The lists can be nested when the data is hierarchical. The meaning of the data is interpreted by reserved key words. An example OXF file is shown in figure 3.9.

```
; OXF 2.0
; Owner:     struai_tp
; 1995-10-17/12:27:02
...
(ATS PARTITION_WALL_in_STD_FRAME
   (ATT GEO_ARGUMENTS NIL NIL)
   (ATT GEO_COLOR NIL NIL)
   ... )
...
(CLS (PARTITION_WALL STD_FRAME)
   (SCL (WALL STD_FRAME))
   (ATS PARTITION_WALL_in_STD_FRAME))
...
(TYP struai_tp.18
   (NAM PARTITION_WALL)
   (CLS (PARTITION_WALL COCON1))
   (OCC struai_tp.19
      (NAM PARTITION_WALL.S9025 STRUAI_TP9025)
      (TYP PARTITION_WALL)
      (SCL (PREFAB_CONCR_WALL_ATTR STD_ATTRIBUTES))
      (ATV PARTITION_WALL_in_STD_FRAME "2800.0 2800.0
                                    ...")
      (ATV PREFAB_CONCR_WALL_ATTR_in_STD_ATTRIBUTES
                                 "VS201E" )
      (REL PARTOF "((STRUCTURAL_FLOOR.S10778
                 STRUAI_TP10778))")
   )
   (OCC struai_tp.20
      ....)
...
)
```

Figure 3.9. An example OXF file.

The OXF and STEP formats differ from each other in their syntax, but the capability for information exchange is practically equal. An important aspect is that the OXF format contains built-in support for the ‘type – instance’ construct in the OOCAD generic model in the form of a nested structure.

3.5 Integrating Product Model Data with Process Information

Since around 1991 a number of researchers have started to look at the problem of how to provide an infrastructure for integrating the possible future product models produced by designers with the software applications used by contractors for cost estimating and scheduling. The proposed solution has been to define conceptual schemas defining the relationships between building elements with the activities that produce them and the resources used. The term construction project model has for instance been used for such schemas.

As an example of modeling the construction project, one of the central schemas of IRMA is shown in figure 3.10. The Information Reference Model for Architecture, Engineering, and Construction (IRMA) was developed in a modeling workshop in Espoo in 1992 [Luiten et al. 1993]. The aim of the model was to establish a common understanding of previous work clarifying the basic modeling terminology and the concepts involved in modeling in the form of a reference model. The model provided a level of integration within modeling research work and has also acted as a basis for future work

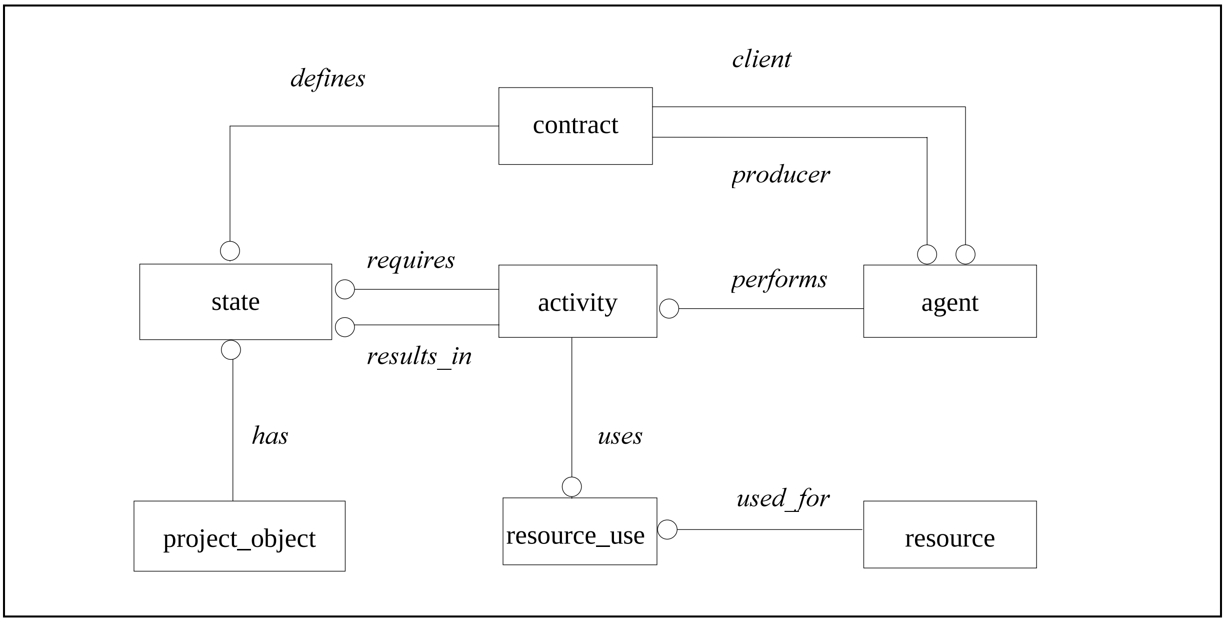


Figure 3.10. One central schema of the IRMA model [Luiten et al. 1993], defining the construction projess.

A number of other research efforts in this domain have been reported, including [Luiten 1994], [Froese 1992], [Jägbeck 1996]. Froese describes models of construction process information in [Froese 1996].

The research of Fischer [Fischer et al. 1995] focuses on formalising the representation of construction method models in the form of computer-interpretable construction method models integrating design descriptions, cost estimates, and schedules. In the paper Scheduling with Computer-Interpretable Construction Method Models [Fischer and Aalami 1995] they discuss the process of developing a schedule in practice today and establish the need for explicit construction method models. The writers envision a knowledge-based environment that integrates construction method and resource information with construction plans, schedules, cost estimates, and product models of a proposed facility at different levels of detail. Such a system would allow to evaluate the effect of design and construction planning decisions on project duration and cost, providing a basis for improving the constructibility of a design.

Currently there are a number of efforts where generic construction project models have a significant role to play. In the ISO classification report mentioned earlier some conceptual schemas on a high level are included. In the IAI development work the IFC core model already contains some generic classes related to construction activities. The project management domain group within the IAI has also started to develop more detailed models [Froese 1998].

3.6 Prototyping Product Data Exchange

Overall the state-of-the art survey has revealed that a lot of work has been done in the definition of building product data models on different levels, but that there are almost no reported cases of research where the models have been tested on a large scale in an industrial setting, which is one of the primary aims of this study. Most of the reported prototype work has been on a small scale and in research organisations. Nevertheless, there is an increasing number of reported research and development projects where the developed schemas have been tested in quite ambitious prototypes with data from real construction projects and/or with active industry participation in the prototyping process. In the following three illustrative cases; the StBrowser, KBS, and PreFacto projects are discussed.

3.6.1 The StBrowser for steelwork data

The Finnish R&D project SteelBase in the FINNSteel technology program deals with the development of data exchange for constructional steelwork design and manufacturing.

The SteelBase-project decided to use the data exchange specification from the Eureka/CIMSteel-project (WWW-CIMSteel) for the exchange of basic steel member, assembly, joint system etc. data. More precisely, the data exchange is based on a subset of CIMSteel Integration Standard (CIS 1.0), its Logical Product Model LPM V4.0, and Data Exchange Protocol DEP 4. The focus of the exchange is data transfer from the steel structure designer to the manufacturers.

As part of the data exchange scenario, developed in cooperation with the companies that participate in the project, a product model browser (called *StBrowser*) is currently being developed [Karstila 1997]. Its aim is to enable the utilisation of steel structure product model data in the receiving end, i.e. by the manufacturers when receiving STEP data from designers. The basic functionality of the StBrowser includes viewing, navigating in, and editing the steel structure product model, and generation of various reports (like bill-of-materials) from the product model (figure 3.11). The browser also supports some additional data exchange formats besides the basic SteelBase-format, and conversions between the formats. The purpose of the additional data exchange formats is to enable data migration from a simple format generated by e.g. CADD applications, and on the other hand to enable easy utilisation of data in the manufacturer's production planning systems.

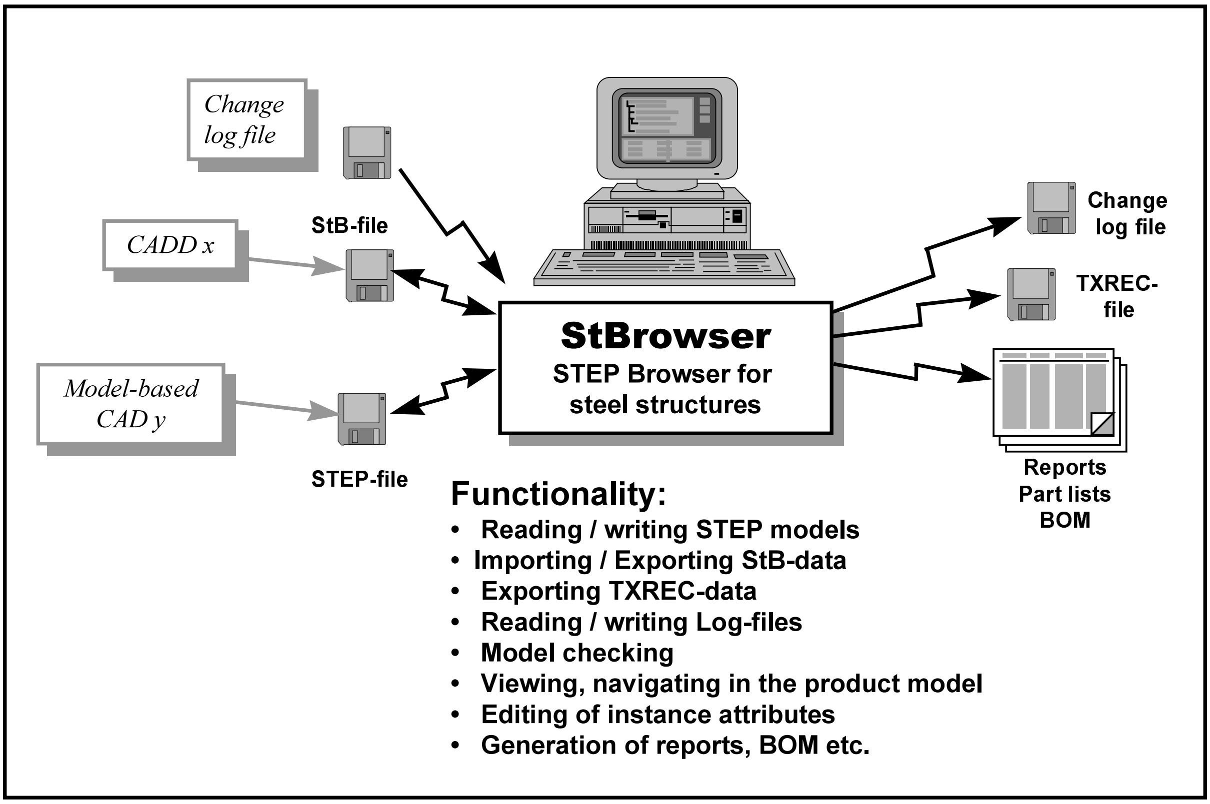


Figure 3.11. The StBrowser (a STEP Product model browser for steel structures) system overview.

The StBrowser, as well as the SteelBase project in general, is an example of technology transfer from research and standardisation to practice. Nothing fundamentally new is invented in the project, but rather, solutions which have already been presented and to some extent standardised, are being utilised in close cooperation with industrial end users. An important aspect of the project has been to choose the right level of ambition for the prototypes. It is considered more important to demonstrate usable results within a reasonable time-frame than to test too ambitious product data schemas in the prototypes. It has also been considered very important to take into account the current IT-maturity of the companies and personnel which will have to use the resulting applications.

3.6.2 The PreFacto System – A Construction Management Tool

The PreFacto production management system [Jägbeck 1996] was developed in 1994 – 1995 in Sweden for the Skanska construction company. It uses the product model approach throughout the construction management process. Design specifications are extracted from a product model of a building using the STEP physical file format and stored in an object-oriented database. During the process of managing production the product model is manipulated and augmented with tools designed to enhance production decisions. The PreFacto system is concerned with the production stage of the overall construction process life-cycle.

Some features of the Generic Building Model in PreFacto include:

- PreFacto uses a neutral core model solution influenced by STEP. The information about the product is imported from design documents and is used as a starting point for creating PreFacto's own aspect model, a Production Management Model.
- There are no high level building objects, such as building or building systems, but only building parts and projects.
- The product model can be imported to PreFacto in the STEP physical file format.
- The attributes of a building part include a building classification code, which uses the structure of the function-oriented national Swedish classification system, BSAB P2.
- The model has been defined in EXPRESS-G.

The approach and scope of the PreFacto project are quite close to the one taken in this study. It was also geared to the needs and the viewpoint of a large building contractor. The product model data was enhanced with the production knowledge of the contractor.

The prototype which was produced in PreFacto was tested with test data from Skanska. Although at least one practitioner participated in the testing, it was, however, never carried through to a real project, and the prototype work has not lead to any further development within the case company.

3.6.3 The KBS Facility Management Building Product Model

Kjell Svensson has for his doctoral thesis 'Integrating Facilities Management Information - A Process and Product Model Approach' [Svensson 1998] done development work on information structures to support the main processes of 'Facilities Management' (FM). A generic FM *process model* and a *building product model*, *the KBS,* were developed. Activity models and object-oriented conceptual schemas were defined for the life cycle of ordinary buildings. One main concern was to incorporate the *existing national classification system*, the BSAB/SfB-system, into the model structure. Thus, the process of defining the conceptual schema started from the existing classes within the national class tables of the BSAB-system.

The model development is not further discussed here, but can be found in [Svensson 1998]. Only the test results of model evaluation are here of interest.

The models were evaluated through prototyping simultaneously with being defined. The prototypes used data from real facilities. What was significant was that there were three different prototypes in which different subsets of the overall KBS model were tested. One of the three prototypes is reported to have lead to a commercial system which is still in use.

An important lesson of the KBS project was that the relationship between the individual efforts of a company and existing standards or on-going standardisation efforts must be given considerable thought. In addition to the KBS model the NICC model [Tarandi 1998] has consciously built on existing Swedish classification systems.

3.7 Conclusions

A number of conclusions could be drawn from the state-of-the-art review.

- There were at the time when the prototyping began no existing fully developed product data models or standards which as such and alone were sufficient for the data exchange needs of this project.
- Nevertheless, on-going research and standardisation could offer the general paradigm of a core model, supported by aspect models, as a framework for how the data exchange could be achieved.
- The national existing building classification system, in this case the Construction 90 classification system, should be used as far as possible as a basis for defining the object classes in the product data models which will need to be defined.
- For the physical data exchange, the STEP part 21 seemed suitable. In addition, the OOCAD/OXF data exchange facilities which had been developed by VTT, offered a short term solution which also could be integrated with the STEP technology.
- For integration with the production know-how of the contractor, the concept of a production model emerged. Some work has already been done by a number of researchers, as well as within the STEP and IFC core models, to incorporate some data structures which are useful in such production models.
- There were no reported cases of the use of product data technology as part of the process reengineering of a construction company (or design company for that) on the same scale as envisaged in this study.

4 PROPOSED NEW INFORMATION MANAGEMENT PROCESS

4.1 TARGET BUILDING PROCESS

4.1.1 New Approach

The new proposed approach is based on the application of product model technology, especially for the purposes of cost and value engineering. The utilisation of the product model covers all phases of the building project. The chosen approach is in line with the results from the RATAS project as well as Construction 90 activities, which aim to support product model and performance driven construction.

The description of the target process focuses particularly on the design process and on controlling it, with cost and value engineering as the basis for this. This is due to results of the analysis of the construction process information flow.

The aim is to integrate the information of the designers and the contractor in such a way that the data from the design work can be used as source data directly, without manual input, for calculating the tender as well as for production planning (i.e. the information produced by the designers is integrated with the contractor's know-how). Designers do not at the moment have appropriate modelling tools, so the contractor should have an IT-system that allows to build up a product model which contains production information, a so-called production model. Another objective is regular communication between the various partners, for example, to analyse design solutions or to generate alternative solutions to support decision-making in the earlier phases of the process. The basis for this new approach consists of enterprise specific information which has been stored beforehand, such as accepted good practice structural details as well as typical building cases.

There are three main requirements for the target process:

- Provide more information and alternative solutions to the customer and the other participants within the building construction process.
- Provide more accurate information in earlier phases of the process.
- Utilise information created beforehand (cases) and classified technical solutions embodying the contractor's knowledge.

The target process is from a decision support point of view illustrated by figure 4.1, which is based on the approach that key activities are shifting to earlier phases.

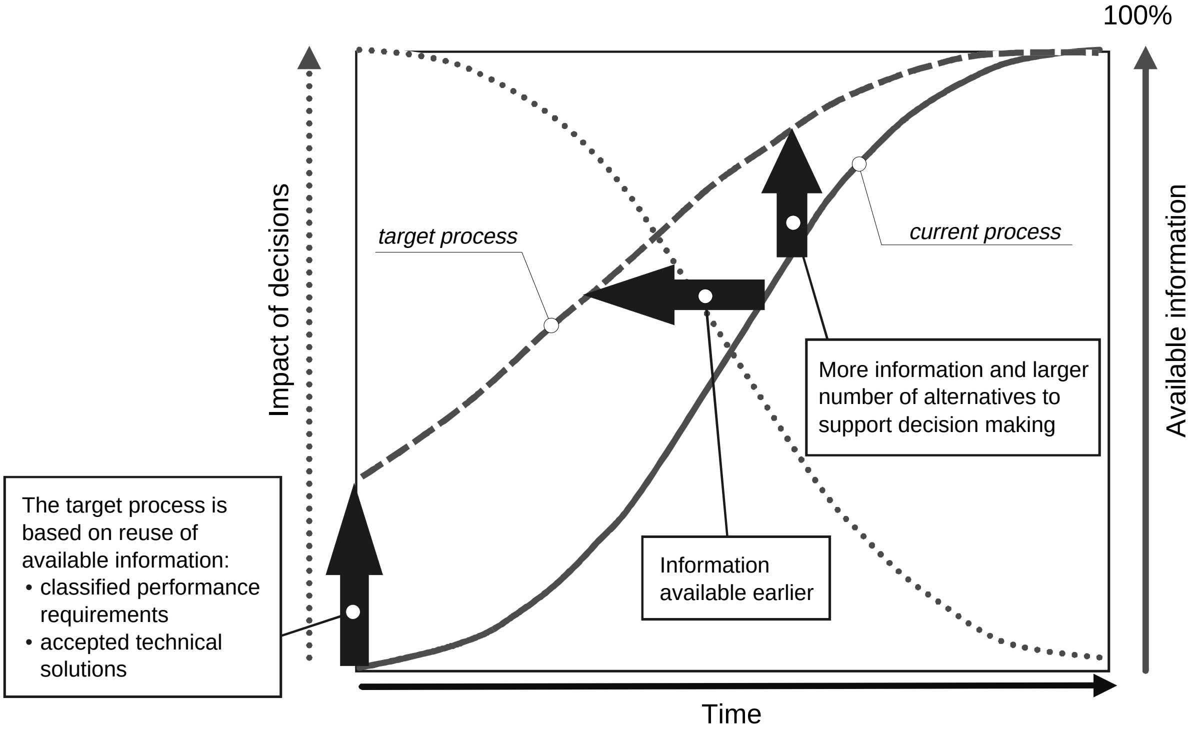


Figure 4.1. Decision making versus available information (Adapted from [Fisher et al. 1993]).

Using product modelling technology and Knowledge Based Engineering-tools (KBE) it should be possible to reach at least some of these targets. The model should be enterprise based, in terms of using the contractor's production knowledge, but yet open for other disciplines within the construction process. This means that one should first define the minimum "core" data to be shared by partners involved so that all the parties can get the data needed for their own usage and are able to share with the others the data the others need. This forms the basic framework for the production model development, and is in accordance with the latest knowledge of data exchange paradigms [Hannus et al. 1995].

In figure 4.2 the value of the information for the contractor from a data management point of view is illustrated. The basic documentation coming to the contractor is in paper or cad-file format which is not very useful for the contractor. To utilise the information coming from the designers the chosen solution is to create a production model (chapter 3) using product model and KBE technology, thus the information is in manageable form and has more value. After completing the construction it is possible to give more/better information for the user in the hand over phase.

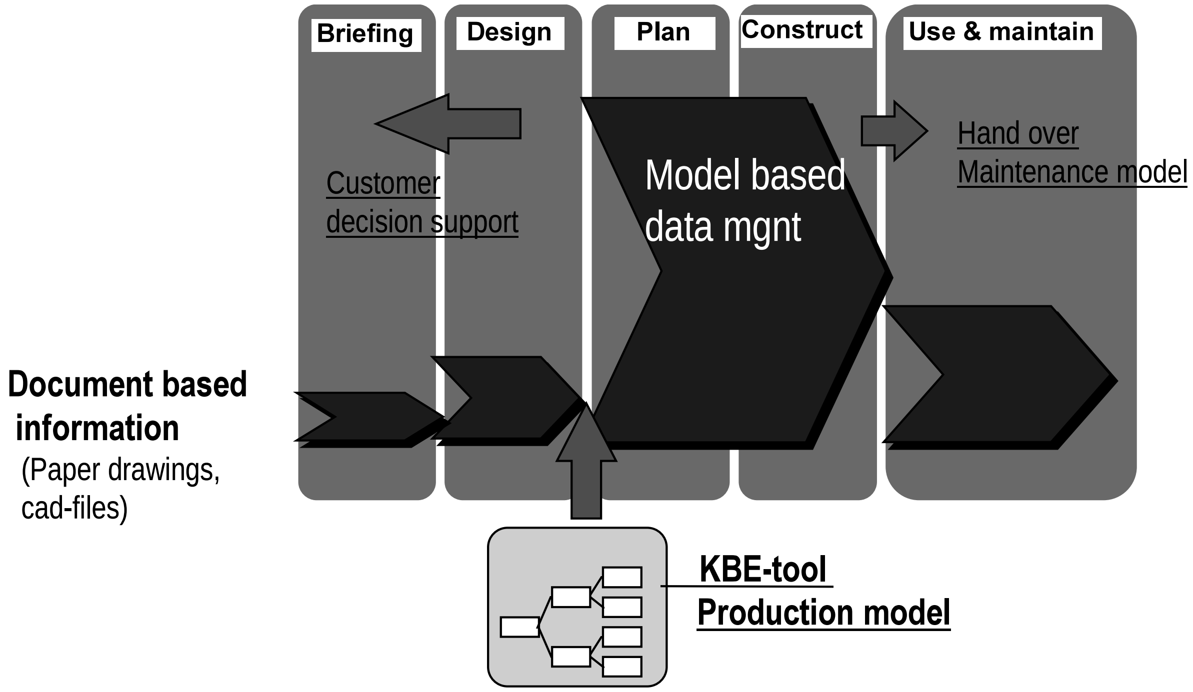


Figure 4.2. Information management value chain.

In this study the target situation for the management of the cost and value engineering process is presented. The basic information coming from designers can be based on document-centred design (based on the utilisation of designers' drawings, preferably in the form of CAD files) or on integrated product model-based design. The model based cost and value engineering process is suited to descriptions of both design processes unaltered. These two alternatives are illustrated in figure 4.3.

The transfer of non-conflicting design information from one partner to another and from phase to phase of the project requires standardised communication protocols between software packages. In describing the target situation of integrated design, the focus is on product model -based CAD and the utilisation of data communications.

The traditional design process is divided into different phases of design, starting with briefing and ending with the production of working drawings. **In integrated, model-based design, there is no such clear distinction between the phases: instead, the phases of the design process constantly interact and complement each other.** The data content of the artefact being designed becomes more detailed and data accumulates continuously as the process advances. All new data are produced once only and are used as input data for the next 'phase'.

The traditional demarcations between phases of design vanish and are replaced by new e.g. **'decision points'**. It is characteristic for the new way of working that decisions may be made in smaller parts and earlier, so that design and decision-making are interactive.

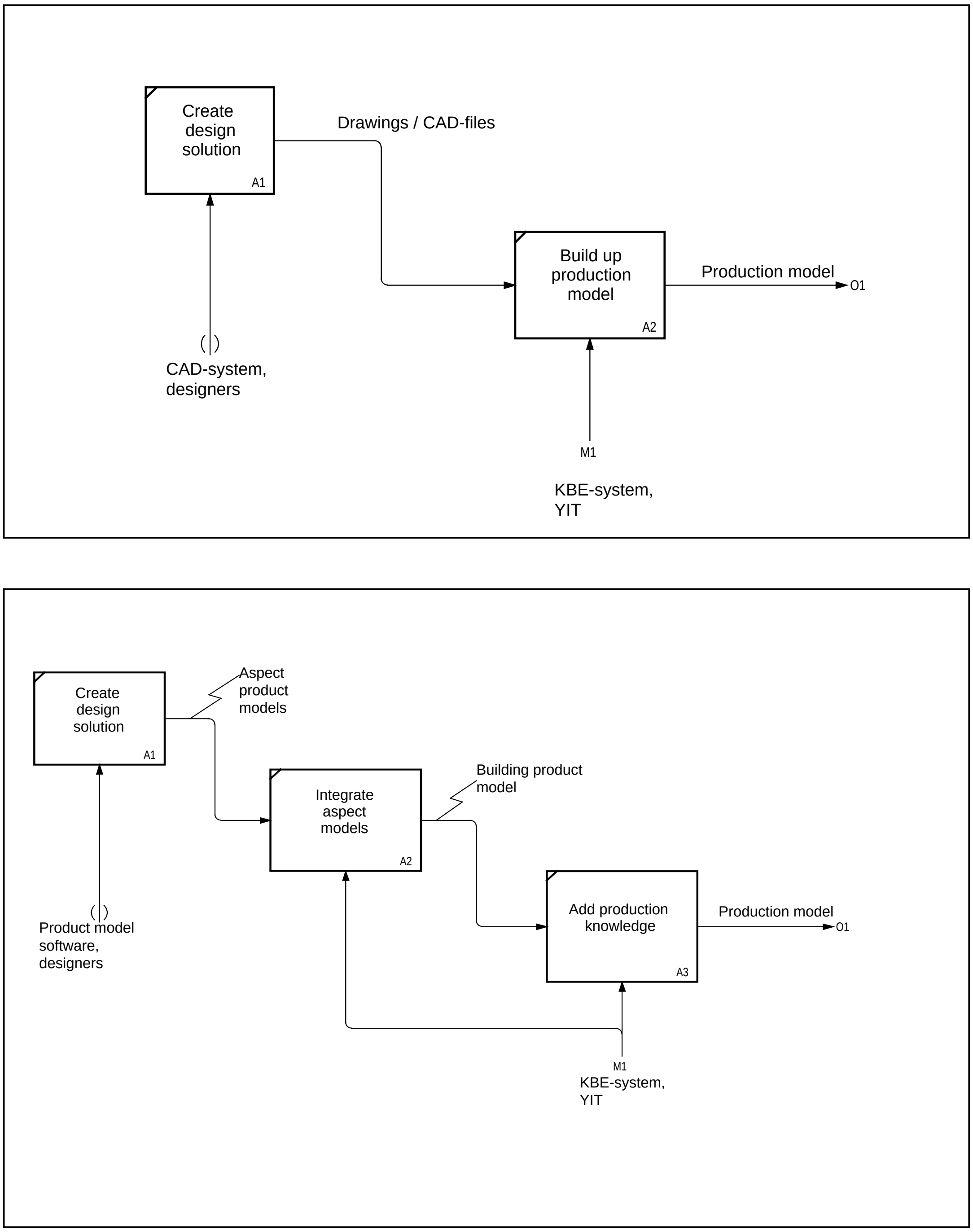


Figure 4.3. Two target situations are dealt with: document-based and model-based, integrated design. In the document-based design process, plans are presented either as paper documents or as CAD files, on the basis of which the contractor builds up the production model. The model-based, integrated design process is based on aspect product models made by the designers; these are used to put together the integrated building model and later integrated into the contractor's production model.

4.1.2 Design and Construct Building Process

The target IDEF0-model is focused on model-based, integrated design, but is suitable for the traditional drawing based way of working with some minor changes as described in figure 4.3 above.

On the top level of the IDEF0 model for the target construction process is one box (figure 4.4) which defines the entire building project as in chapter 2. **The main difference is that in the target process one of the outputs is building documentation in model form**.

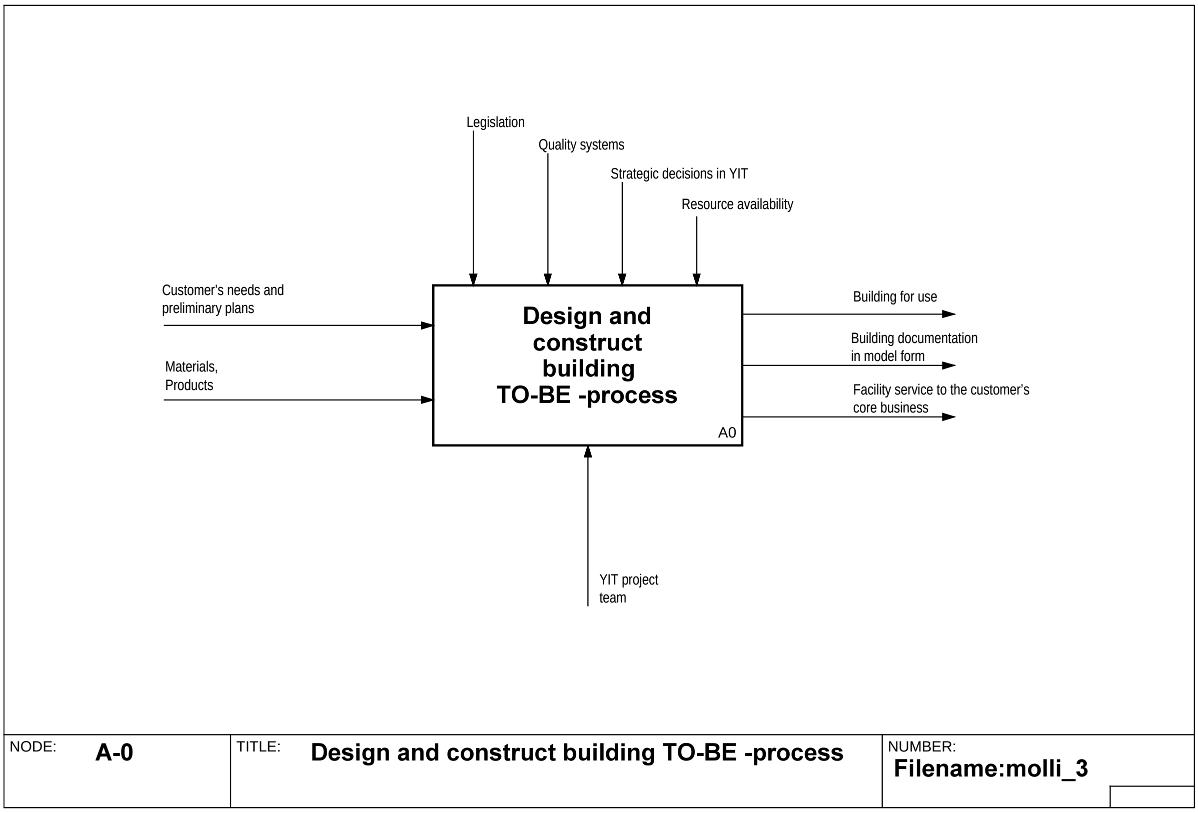


Figure 4.4. A-0, Design and construct, to-be process

The second level (A0) again is a wider view where the model based construction process approach is described from the customer's, contractor's and building user's point of view. Now the information management is organised in a systematic manner and discussion, feedback and self learning is enabled (figure 4.5).

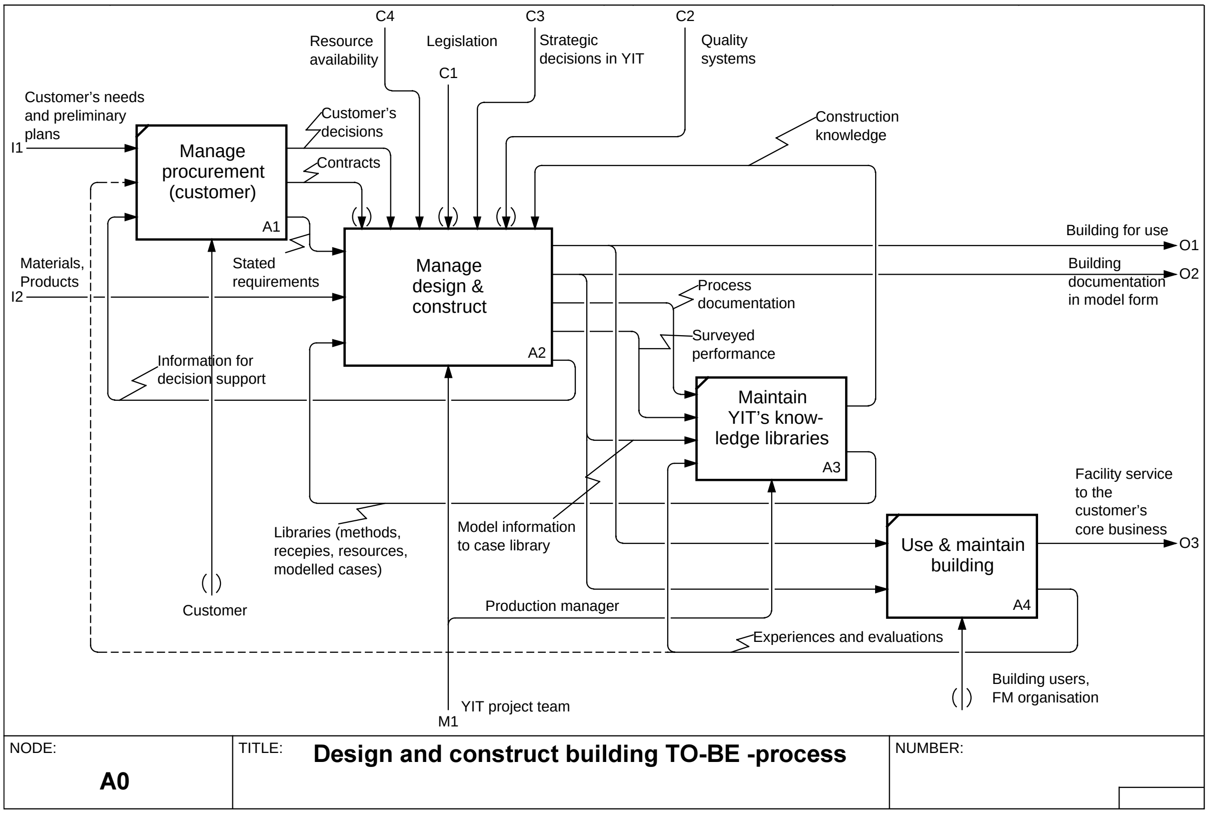


Figure 4.5. A0, Design and construct, to-be.

The customer's procurement process, activity (A1), is as modelled in chapter 2, but the decision making process is based on more accurate information for decision support coming from the contractor's activity, *Manage design and construction* (A2).

The contractor's activities, M*anage design & construction* (A2) *and Maintain YIT's knowledge libraries* (A3), are supporting each other better than in the as-is process. The main inputs for the knowledge libraries are model information to case library, process documentation and surveyed performance. The libraries are organised according to the building type (e.g. apartment buildings, office buildings) so they can be used as cases and as construction knowledge to control future projects. There are approved YIT-solutions for systems, production methods and structural details. The evaluation of the production performance improves the accuracy and reliability of recepies and methods which are inputs (libraries) for design and construction management and thus forms the basis for constant/standard work unit scheduling. The feedback from the *Use and maintain activity* (A4) improves the life-cycle performance knowledge in the YIT-libraries (for a discussion of such a feature cf. [Bröchner 1995]).

On the second level (A0) there are the following main differences compared with the as-is process:

- In the activity box, *Manage design and construct* (A2), the to-be process utilises the knowledge libraries of modelled cases (case based reasoning). Another major change is the output “building documentation in model form”, which provides basic data for facility management.
- From the *Use and maintain building* (A4), one output is feedback in the form of evaluations and experiences, which can be utilised in maintaining the knowledge libraries.

4.1.3 Manage design and construct

The activity model of the contractor’s main activity *Manage design and construction* (A2), is described from YIT’s viewpoint and generally follows the phases of a traditional construction project. It covers all the phases of the project from briefing to the final occupation.

The *manage design and construct* (A2), to-be, is shown in figure 4.6.

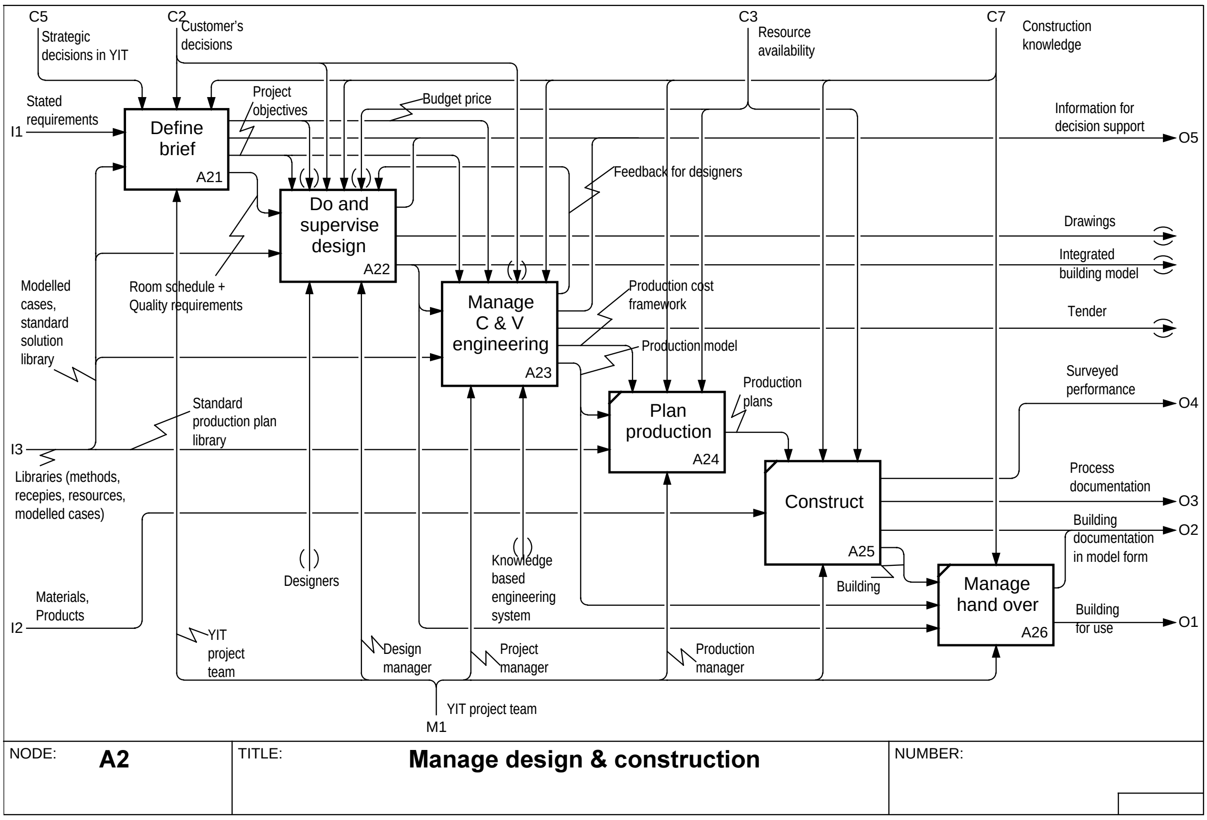


Figure 4.6. A2, Manage design and construct, to-be.

In the briefing phase, a space utilisation plan (in the form of a room schedule) and quality requirements are determined for the project on the basis of the client's needs and wishes. The objectives for the costs and the yield from the investment and for the buildings life-cycle economy are set. The client's needs and the contractor's production resources are the basis for determining the time scheduling objectives of the project. The briefing phase, *Define brief* (A21), results in a space utilisation plan together with quality requirements, the expression of which in model-based design is a preliminary architect's aspect model (see picture 4.7, define brief) including quality specifications on a per space basis. This serves as the basic data for the integrated building product model to be made in the design phase.

In *Do and supervise design* (A22), the designers each make their own part of the product model, which the contractor evaluates and gives feedback on. The integrated model based design process starts out with the architect's draft aspect model, which models the building's shape, spaces, structural allocations (enclosing walls, ceiling/roof and floor) and the quality standard. After that, the structural engineer models the structures on the basis of the architect's allocations, possibly suggesting necessary modifications to the architect. Similarly, the installation designer models the technical conduits and furnishings according to the architect's space model.

The building product model grows and becomes more detailed throughout the design phase. At the *Manage C&V engineering* (A23) stage, the model contains all the design data for the building and the basics for design solutions as well as the planned production methods. After the integrated design phase, the production model data are used in the production planning and construction phases.

In the *Production planning* (A24) phase, data is used for planning time schedules, purchases and logistics. In this phase especially the knowledge of quantity and location data of building elements is used. Data specified once need not be measured again as they can be downloaded from the production model in the desired form, for example as partial outputs of wall panels or building frame structures. The production model can be considered from various perspectives and on different levels of depth.

The feedback from the phases *Construct* (A25) and *Manage hand over* (A26), serves as a guiding factor for the early activities in upcoming projects. These are modelled as outputs of the *Manage* d*esign & construction* activities, and are used as input in the *Maintain YIT's knowledge bases* activity. Experience data is also stored in the case library of modelled projects in YIT's knowledge bases. Final output is not only the building ready for use but also an as built model for owners and occupants.

The main differences compared with the as-is model (on third level in this study A2) are:

- In *Draw up brief* (A21), the budget price is based on a rough production model which is composed from the architect's sketches using predefined "standard" solutions. This enables to use the contractor's knowledge in the early design stage and provides reliable information for the customer as well.
- In *Do and supervise design* (A22), the integrated design is based on the product model approach. The design solution and the building product model grows and becomes more accurate throughout the project. Data exchange is based on the Internet and time lags due to the data exchange are minimised.
- In *Manage cost and value engineering* (A23), the differences and advantages are the biggest. The product model enables to use the designers' solutions as basic information for the contractor's activities. Knowledge based software systems allow to analyse, provide alternatives, evaluate their impact, calculate and create decision support for building process participants. The product model approach enables the effective use of cases and predefined (modelled) standard design solutions. Once the information is created as a production model, it is in useable form as basic data for construction process management in later phases of the process.
- In *Manage hand over* (A26), there is a possibility to provide the "as-built" and maintenance model for the customer and occupants (this is out of the scope in this study).

The subactivities of the briefing phase, *Define brief* (A21), are illustrated in figure 4.7. The architect's aspect model should be accurate enough to describe the building to the customer for decision-making and to the contractor for making estimates. This kind of approach is appropriate to performance driven construction, which is defined using standard tasks, technical solutions and structural details with proven methods according to building types. This information should be in YIT's knowledge bases (according to good, approved construction practice), which is available for designers also.

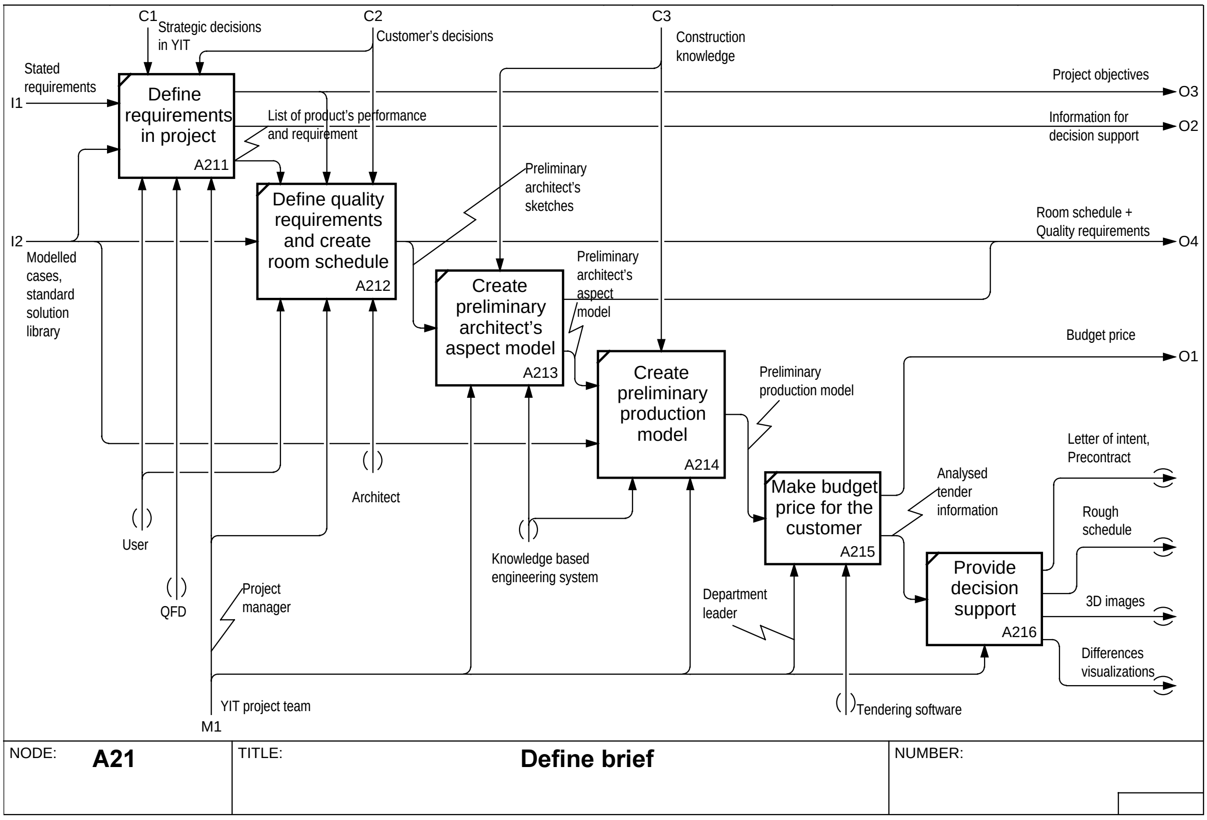


Figure 4.7. A21, Define brief, to-be.

In the activity *Define requirements in project* (A211), and *Define quality requirements and create room schedule* (A212), the user is in a major role and the QFD (Quality Function Deployment) methodology is used in the definition of check lists for required characteristics of the building.

The following activities, *Create preliminary architect's aspect model* (A213*), Create preliminary production model* (A214) and *Make budget price for the customer* (A215), differ much from the as-is model. The architect's aspect model creation is based on the architect's sketches and previous building project cases and done by YIT using a KBE-system. The preliminary production model covers all design disciplines; structures and building services are based on a standard solution library and project cases. A more detailed description of the composition of the production model is in the *Compose production model* (A232).

In the *Make budget price for the customer* (A215) activity, it is possible to do reliable estimates already at this point using the contractor's tendering software. A more detailed description is in the activity *Manage C&V engineering* (A23). From the activity *Provide decision support* (A216), the main output is a rough schedule, 3D images and visualised differences of alternatives.

On the activity level the differences with the as-model are the creation of the preliminary architect's aspect model and preliminary production model both, by

YIT. On the information process level the utilisation of YIT's production knowledge as input provides reliable decision support. This is done traditionally using general statistics.

4.2 Target cost and value engineering process

4.2.1 Do and supervise design

The *Do and supervise design* (A22), diagram 4.8, is divided into functions according to the way design data are handled. The activity, *Manage design* (A221), describes the management, production, transmission and utilisation of data. The activities, *Make architectural design* (A222), *Make structural design* (A223) and *Make BS* (building services) *design* (A224), generate design data in a product model form. The activity*, Exchange data in neutral form* (A225) transfers data from one partner to another and the activity*, Evaluate design and compose product model* (A226), evaluates all the design data and processes in the integrated building product model and gives feedback to designers.

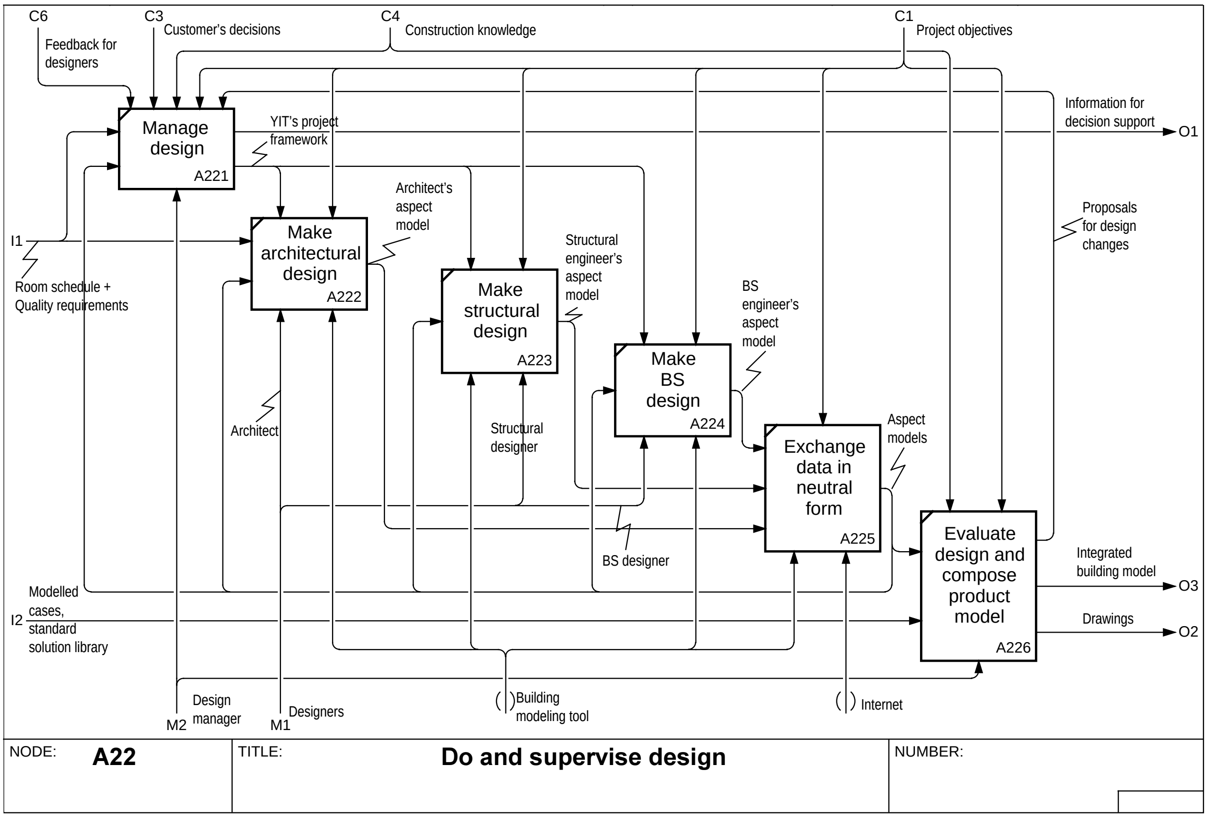


Figure 4.8. A22, Do and supervise design, to-be.

The design phase activity chart describes the continuity of the design process and is implemented the same way irrespective of how complete the design is. An essential factor in the process is the contractor's design management activities, which result in proposals for changes going back to the building's product model in the form of design control. The chain of activities can be described as a closed circle until it is frozen for decision-making in the design phase or for production, at which time the material requirements are listed as output from the building's product model or it is transferred to the next phase of the project as basic data.

The integrated design is independent of the phase of the project or how complete the design is (there are not "different design phases"). The only alteration is that the data content of the product model increases and grows as the project moves ahead. The main change in the phases of present-day practice in collaboration between designers is that it is possible to make structural and installation models in considerable detail even on the basis of the early versions of the architect's aspect model, even if its data content is not final. In this way, it is possible to examine the characteristics of the solutions in greater detail even in the initial phases of the project. Data communication between all the partners takes place using a neutral format according to a core model approach.

The model based approach is the main difference with the as-is model. The design is carried out using building modelling tools and the output is aspect models. The data exchange is executed in model form using Internet facilities.

4.2.2 Manage cost and value engineering

The design solution data is analysed and evaluated during *Manage C&V engineering* (A23), figure 4.9. This phase covers the composition of the production model using the contractor's knowledge-based application. Proposals for changes to guide design work are produced as a result of the process, e.g. changes due to analysis of alternative solutions like production methods etc. The practical implementation of the process procedures (mechanism) necessitate the use of knowledge based engineering techniques (KBE). Data on production engineering are transferred to other partners in the form of partial models from the production model as necessary, especially when alternatives are being investigated.

The *Analyse the design* (A231) activity involves analysing the scope, efficiency, form and functionality of the design solution. Of these, the analysis of the scope, efficiency and form of the project is based on statistical methods and comparative data from other, similar projects. Co-operation with the user would be highly advisable for the assessment of the building's functionality.

In the *Compose production model* (A232), the contractor's know-how is added to the building product model. This covers all production knowledge; methods, recipes, resources, materials and equipment needed to accomplish the building.

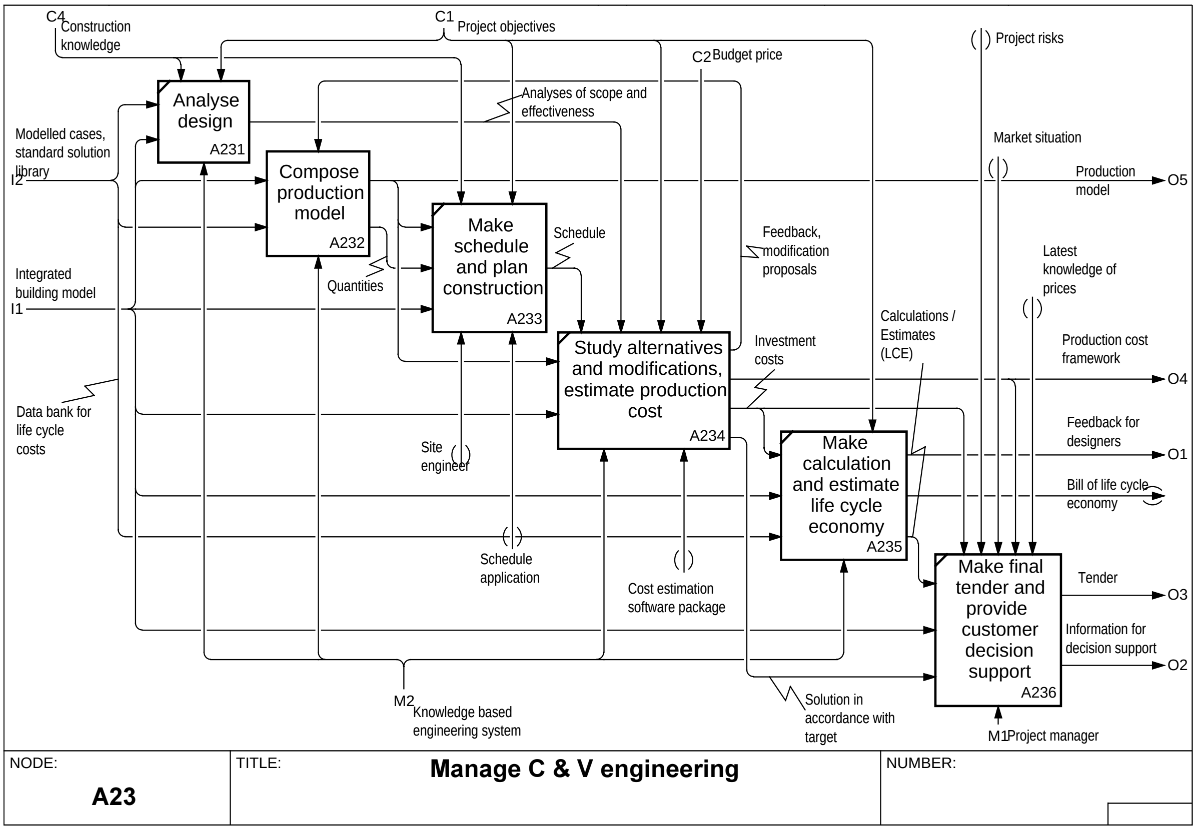


Figure 4.9. A23, Manage cost and value engineering, to-be.

Basic data for the time scheduling application is generated using the production model, which is used to produce a provisional schedule for the project. The activity *Make schedule and plan construction* (A233), includes both the making of a schedule for the project and the analysis of the construction plan and especially its constructibility. The schedule guides and to some extent restricts alternative forms of product planning, which helps to control costs. This activity seeks alternative solutions for production.

In *Study alternatives and make proposals for modification* (A234), the economy of the project is determined. *The Make alternative calculations* (A235), covers examining the cost impact of the alternative solutions put forward to designers. The comparative calculations may, for example, help to determine:

- the most economical space solution
- the most economical alternative structure in production terms
- the cost impact of the client’s requests for changes.

It is of paramount importance in design management to be aware of the cost impact of the choices to be made on the overall economy of the project. For this reason, to avoid partial optimisation, it is important to examine the effects of the alternatives being studied on the overall costs and yields.

The determination of comparative calculations, like those of the overall costs, should be based on the contractor's own cost database, methods and recipes as well as the associated real-time input prices, so that costs can be assessed with precision even at an early phase.

The assessment of life-cycle economy generates a calculation of the costs of using, maintaining and repairing the building throughout its service life. The assessment of these costs is based on estimated repair and maintenance at calculated intervals according to the usage of the spaces.

Alternatives are then researched and possible modifications made and the contractor's targets will be checked in accordance with the alternatives and the latest knowledge of the market situation. The final tender and documentation will be produced in *Make final tender for the customer and create decision support* (A236). This information forms the decision base of the analysed alternatives, their impacts and reliable calculations.

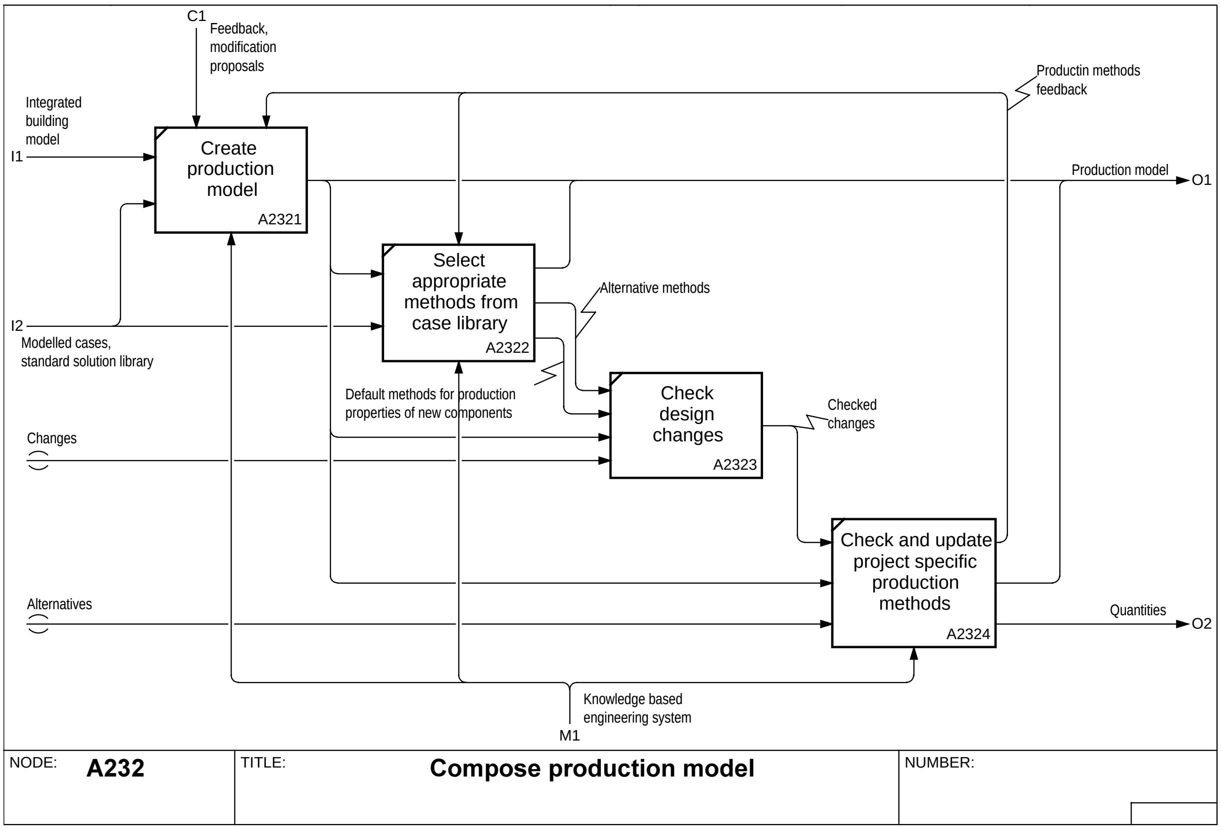


Figure 4.10. A232, Compose production model.

The *Compose production model* (A232), diagram 4.10 describes the combination of a product model and a contractor's production data into a production model, i.e., the integration of the designers' and the contractor's know-how. Aspect product models transferred by the neutral model are put together into the building's product model and then composed into the contractor's production model. Default production methods for the production qualities of the product model's components are accessed from the 'case' library according to the project type. This is illustrated in figure 4.10.

The difference compared with the as-is process is on the activity level: analyse design, analyse design, compose production model, study alternatives and modifications and estimate production cost, and make calculation and estimate life cycle economy. The manual quantity survey is not needed anymore.

Due to the utilisation of production model it is easy and quick to make alternative calculations in order to evaluate their impact on the costs and production. The life-cycle economy evaluations in terms of energy and cost are possible to do using the same production model and data bank of life-cycle costs.

Summary

In summary the main differences between the As-is and To-Be processes on the activity level are in the activities *define brief* (A21) and *manage cost and value engineering* (A23). The process reengineering can be seen in these differences. In the definition of the brief there are two new activities in the model based approach: creation of the architect's preliminary aspect model and preliminary production model. In the management of cost and value engineering there are several reengineered changes: analyse design, compose production model, study alternatives and modifications and estimate production cost, and make calculation and estimate life cycle economy. The manual quantity survey is not needed anymore. These changes are possible due to the model based approach.

The main change in the management of information are in the inputs of activities, such as designers' product models and YIT's knowledge libraries: modelled cases, standard solutions, standard production plans and data bank of life cycle cost. Another key issue is the utilisation of YIT's knowledge libraries in the briefing phase for the decision support. Important is also the possibility to produce alternatives for production (calculations) or use different methods or materials in order to evaluate their impact on the costs and production.

The main differences in the mechanisms are the utilisation of knowledge based engineering systems and building modelling tools. Another major change is the creation of the architect's preliminary aspect model and preliminary production model by YIT.

5 TECHNICAL SOLUTION

5.1 Requirements for the system

In order to achieve the target process as described in chapter 4 the following features were required for the prototype system:

- The architecture and accuracy of the product model should comply with YIT's needs for tendering, cost estimation and production planning activities.
- It should be possible to apply production knowledge, in the form of methods and recipes stored in data bases, to the building elements obtained from the building product model.
- The system should allow the use of designers' current documentation, which mainly comes as 2-D CAD-files, as input that can be transformed by the contractor to the format required for the product model.
- Alternatively it should be possible for the designers to directly create the parts of the product model for which they are responsible.
- The system should be able to generate bills of quantities including the knowledge of the hierarchical locations of building elements, i.e. section, staircase, apartment or room, and to extract material lists structured for different purposes, e.g. quotation tendering.
- The basic analysis of the design solution in terms of scope, efficiency, form and functionality (basics of cost and value engineering), should be as automated as possible.
- The system should allow to use predefined and accepted building systems (e.g. frame, heating system) or structural details from knowledge libraries, so called YIT best practice.
- The system should enable the exploitation of information from reference projects, especially in the early phases of the process, using previously modelled projects to support case based reasoning.

One additional requirement was added, which doesn't follow directly from the target process description in chapter 4, but which was deemed important in view of the anticipated developments in the near future towards international standards:

- The system should be able to read input formatted according to the STEP physical data exchange format and should be structured in a such way that it could easily be adapted to receive data according to the emerging STEP/IFC core model schemas.

5.2 Choice of basic tool

For the prototype work the Design++ system was chosen as a basic software platform. There were several reasons for this choice:

- Firstly it is a tool which integrates a number of technologies needed for the prototype; a knowledge based tool, a CAD-system (AutoCad) and a data base system. The integration of these tools is illustrated in figure 5.1.

- Secondly it is a commercial tool which already has been tested in real engineering work [Katajamäki 1991], not a research prototype.

- Thirdly it was originally developed in Finland and consequently it was easy to get a high level of support from the developers.

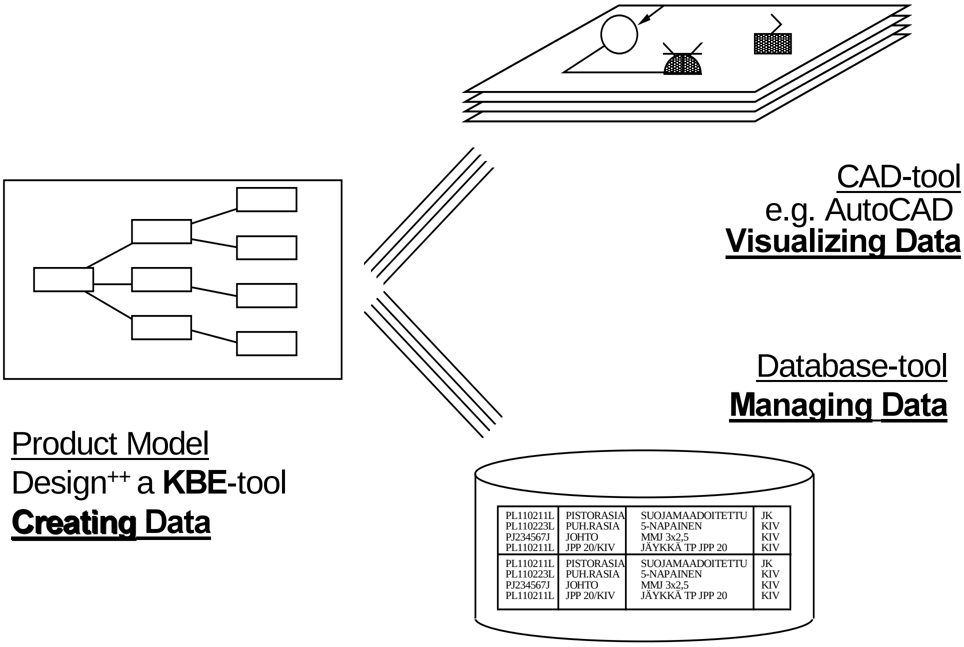


Figure 5.1. In the prototype environment different generic types of software applications (knowledge-based system, CAD-system, data base system) are used for achieving the different sorts of functionality required.

The Elements of Design^{++}

Design++ is a knowledge-based engineering (KBE) tool for engineering and design automation, which supports both engineering decision making and drafting tasks. (For a general discussion of knowledge-based design systems cf. Dym and

Levitt [1991]). The system was originally developed by Nokia Information system in the latter half of the 1980's for use in the design of air ducts for process plants. After successful pilot use by the Tampella company, which indicated the reduction of design time by 75 % [Riitahuhta 1993 et al. 1993], the basic software was commercialised and moved to a spin-off company which has its headquarters in the United States. Examples of recent uses of Design++ include the following [Lippus 1995], [Vos and Buvelot 1995]:

- Robertson Ceco Corporation, building design process reengineering.
- Flour Daniel, Inc., reengineering of the work process.
- HBG Construction, customer driven design of modular housing units.

Design ++ applications can be used to capture design intent and engineering expertise into parts and assemblies stored in libraries. In a design session, models are constructed from library classes. "Assembly" components configure the models while "parts" components size and select themselves to meet end user requirements. Data can be handled also through interfaces to relational databases and through two-way integration with CAD systems.

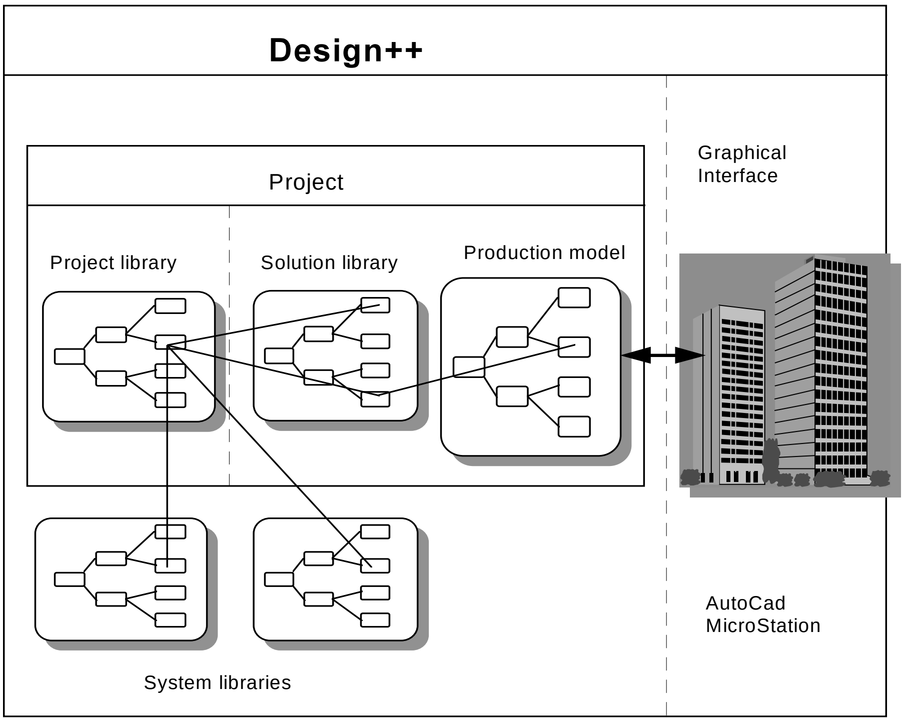


Figure 5.2. Parts of the Design++ application system.

The parts and assemblies used in a model are defined as classes in libraries. A class must exist in a library before creating an object (instance) of it. Once a component (object, instance) is created in a model it may have local individual attribute values that can be modified.

The attributes of classes are defined interactively using tools provided with the user interface. Rules that are attached to class attributes can be used to capture the expertise used in the design process. Examples of engineering rules that can be attached to attributes, and which assist in the automatic creation of new information, are:

- *Configuration rules* that are used to determine what components are needed based on the requirements e.g. load bearing capacity.
- *Selection rules* are used, for example, to determine the type of a wall.
- *Sizing rules* are used, for example, to determine the thickness of the facade element.

This knowledge, once captured into the system, forms the core of an application.

The library classes are defined in a hierarchy, which is represented graphically by a tree. A class can be defined broadly and then refined into successively finer subclasses. Each subclass incorporates, or inherits, all of the properties of its superclasses and adds its own unique properties. A subclass may inherit properties from more than one superclass (multiple inheritance). The underlying data model of Design ++ is a framebased representation, which has been quite a popular representation mechanism used in knowledge-based system [Lucardie 1994]. In the earlier versions the core of Design++ was based on the KEE environment, which has originally been programmed in the LISP language, but later versions are programmed in C and C++.

In addition to the knowledge-based core Design++ also incorporates a commercial CAD-system and a relational data base system. This is because the CAD-system has a good user interface and good facilities for manipulating the geometrical aspects of a model, and because a data base system is good for storing and searching in large repositories of homogeneous data, for instance about components.

Model and Product Structure

A model in Design++ is a collection of objects that are arranged into assemblies, subassemblies, and components. The number and types of objects and their arrangement depends on the initial values (requirements) given to the application. The product structure, that is, the division of objects into assemblies and subassemblies, etc. is often standardised. The product structure can be created by product structure files. An example of a product structure file is given in figure 5.3. This file defines, that a building has a spatial_system and several floor_plans, where the number of the latter is defined by the user.

```
(project
 (:N 1 building))

(building
 (spatial_system
  (:N floor_plan))
 (structural_system
  (foundation
   (foundation_floor))
  (frame
   (:N structural_floor)
   (roof))
  )
 (blocks)
 (technical_system)
 )
```

Figure 5.3. An example of a product structure file in Design ++, which is used as a sort of template to create a first version of a model.

Product structure files are generally used just to create the initial skeleton of the model. More assemblies and components to this model are created by design rules or functions that are activated by the user from the end user interface.

Components and Attributes

Any attribute value defined in a library class is inherited to the component in the model. Locally defined values, either assigned by the user or obtained from a rule attached to that component attribute override the inherited values.

The attribute values are determined in the model in the following order:

- inherited information (value)
- data imported from external files
- calculated using engineering rules or
- defined by a user during a design session.

5.3 Architecture of the product model

The data exchange paradigm of the prototype system [Serén et al. 1996] complies in general well with the principle of a core model supported by aspect models, which was presented in chapter 3. The aspect models, core model and the contractor’s production model are described in a highly abstracted way in the following figures 5.4 and 5.5. Set-theoretic Venn diagrams have been used to try to illustrate the overlaps between the data contained in the different models.

The following models and views are illustrated in figure 5.4:

- The apartment building product model
- The architect’s aspect model
- The structural engineer’s aspect model
- The building services engineer’s aspect model
- The contractor’s aspect model
- The apartment building core model (ABCM)

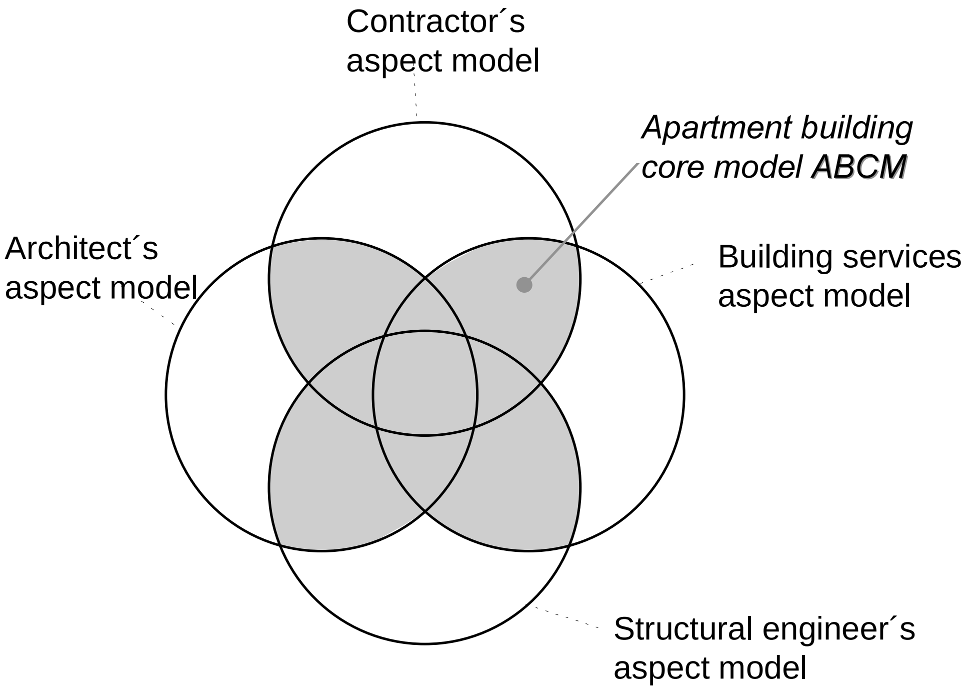


Figure 5.4. The relationships between the different models illustrated by a Venn diagram.

The ***apartment building product model*** is the union of all the model data created by any of the project participants and which describes the apartment building as a product.

The ***apartment building core model (ABCM)*** is that subset of the apartment building product model in which more than one participant has an interest and may need to access. It is shown with a grey raster in figure 5.4 [Serén et al. 1996]. An example of data structures included in the ABCM are shown in fig. 5.5.

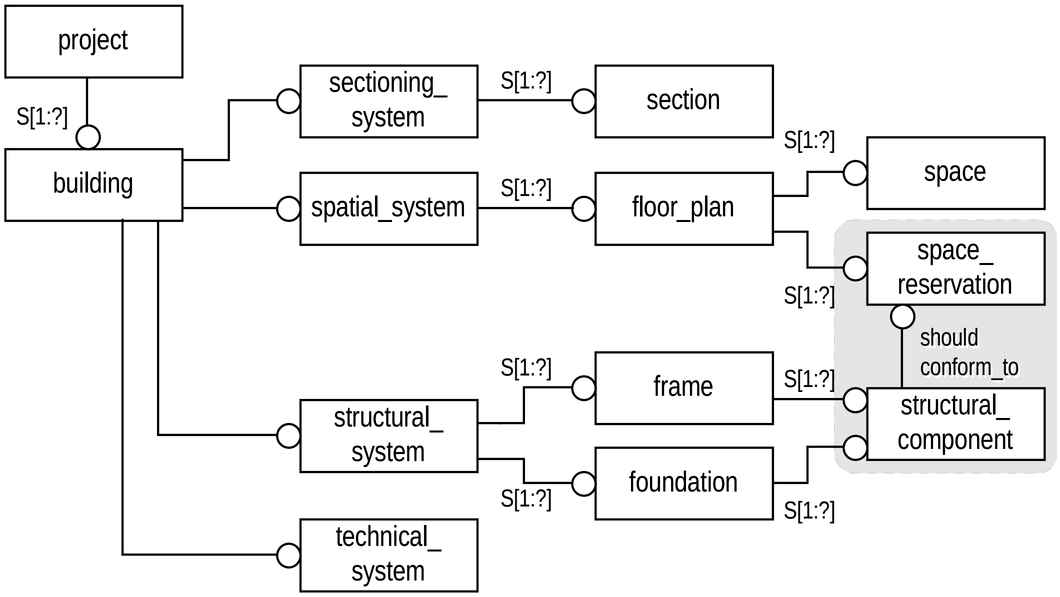


Figure 5.5. The main part of the ABCM model: decomposition hierarchy view.

The ***architect's aspect model*** contains all the information in which the architect is interested in. Part of this data is also important for the other participants (for instance the placement of walls) and belongs consequently to the ABCM . This part can also be information created by other parties which has a relevance for the architect. Other data, such as the colour of walls, is not relevant for any of the other participants and belongs to that part of the architect's aspect model which doesn't intersect with the ABCM.

The ***structural engineer's aspect model***, the ***building services engineer's aspect model*** and the ***contractor's aspect model*** are defined in a similar way.

The ***contractor's production model*** is the union of the contractor's aspect model, which is a subset of the overall building product model, and the relevant information on recipes and methods (here been called the production knowledge) needed to produce the building components. The contractor's production model is illustrated in figure 5.6.

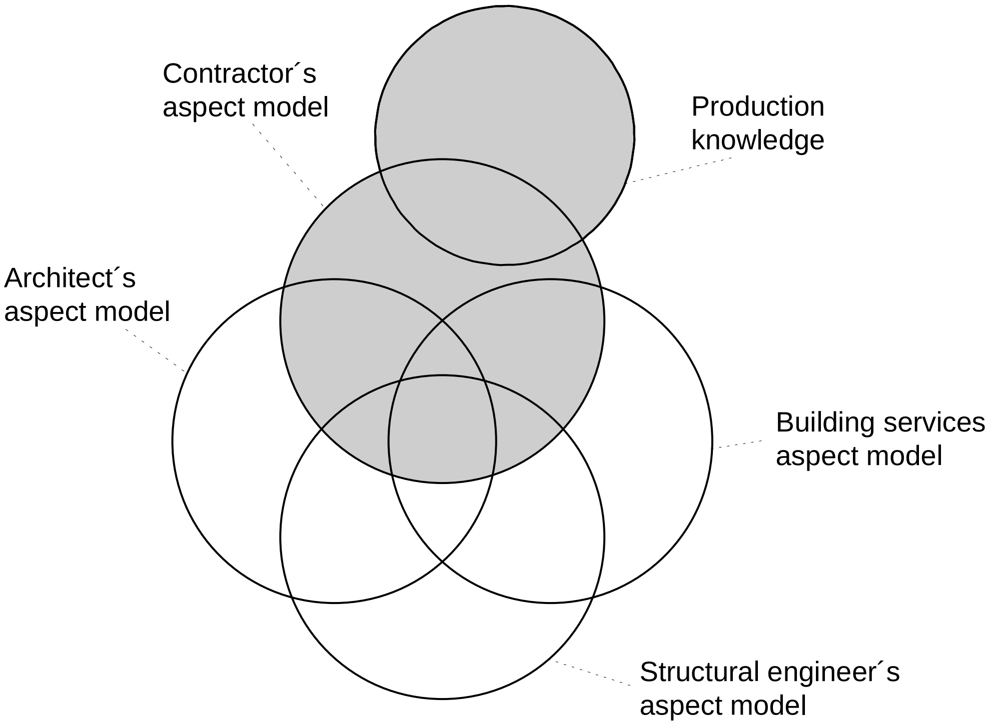


Figure 5.6. Contractor's production model where the production knowledge (methods and recipes) is integrated with the contractor's aspect model.

The management of the logical contents of the shared information relies on the knowledge-based tool used by all the partners, and some solutions are based on the specific features of this tool. The product models of each partner are structured according to the common model (ABCM) implemented as standardised class libraries shared by all partners.

The partners are able to specialise these classes according to their own needs in their applications which deal with the information belonging to their aspect models. In addition, a basic reference product composition structure file is used. The partner-specific specialisations are implemented by incorporating additional super-class links to the common entities (a kind of multiple inheritance, figure 5.7). The additional super-class links may either be connected from common classes to the application-specific classes or even dynamically bound to instances of the common classes. These links are disconnected when exporting data and re-connected when importing data. The main part of the common classes instantiated in a model is presented in figure 5.7. To make the data management easier the classes are implemented as a set of separate class libraries.

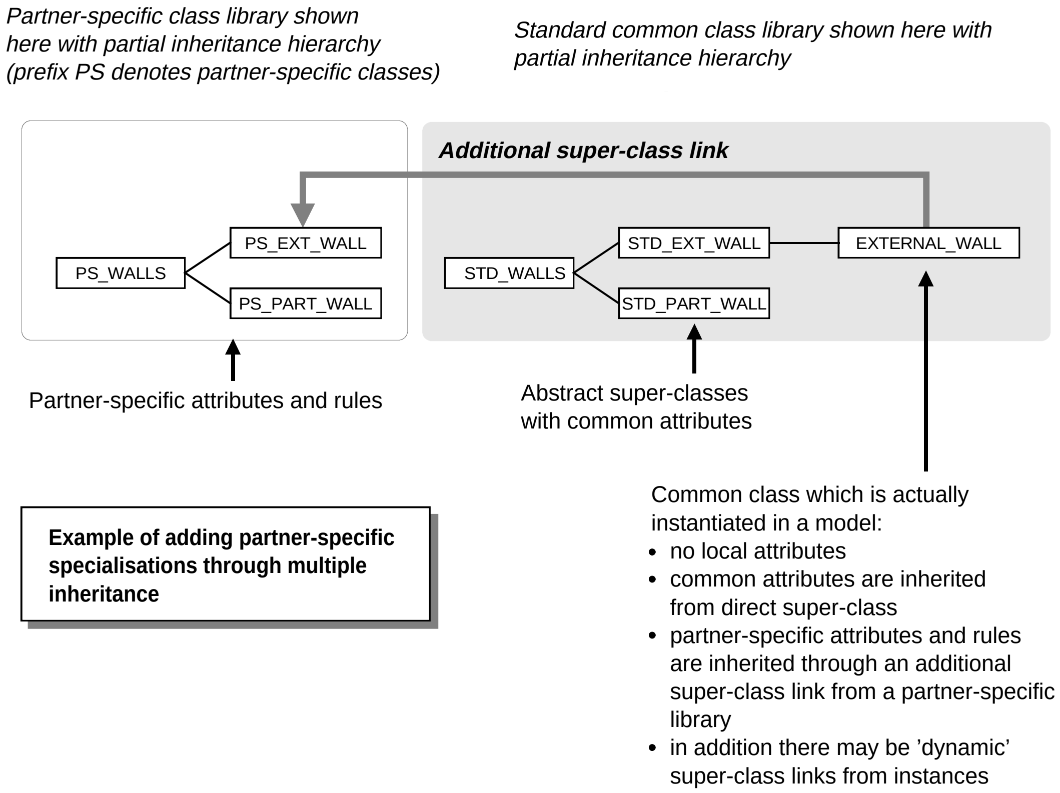


Figure 5.7. Multiple inheritance used in the PILOT environment: PS_EXT_WALL inherits both from PS_WALLS and from EXTERNAL_WALL.

One key feature of the common classes is that each class and its instances have a specific partner as owner, who generally is responsible for the maintenance of these objects. This ownership concept is also implemented on the attribute level. This feature is essential as the project typically is performed concurrently by several designers from different disciplines. Consequently it is important to control who is in charge of creating or deleting spatial or structural components of the model. Likewise it is crucial to agree who is in charge of attribute values e.g. an architect defines the location of a partition wall (space reservation) and structural engineer creates the actual wall component and defines how thick it must be. The system monitors that only the user in charge is able to alter attribute values he "owns". This is illustrated in the figure 5.5, presented earlier, as a shaded area.

The maintenance of the class libraries and the product model decomposition branches are divided according to partners. This means, for example, that the architect does not model any structural components as such. Instead, the architect models *space reservations*, which the structural engineer uses to locate the structural components. The product model of an architect has different components than the model the structural engineer has. This is natural as the model incrementally expands during the design life cycle and the participants in the whole building process all have different viewpoints to the model. This means that there are several aspect models that communicate through the core model.

5.4 Data exchange format

If all the partners would use Design ++ applications based on the ABCM , only adding partner specific specialisations (those parts of the aspect models outside the ABCM), it would be straightforward to exchange data using the internal data formats of Design ++. It would, however, be unrealistic to assume that all partners that YIT co-operates with in future commercial projects are able to use Design ++, and thus it was considered strategically important to build a data exchange facility which as far as possible relies on international or national standards. This data exchange facility is based on the use of the OOCAD generic product data model and the corresponding OXF file formats, described earlier in chapter 3. The main reasons for choosing this were the availability of some software tools and local expertise who could help in sorting out possible problems. In the pilot project a simplified version of the OOCAD model was used (figure 5.8). It should be mentioned that at the time of the building of the prototype tool the STEP Building Construction work hadn't produced any usable results and the IAI work had not yet started.

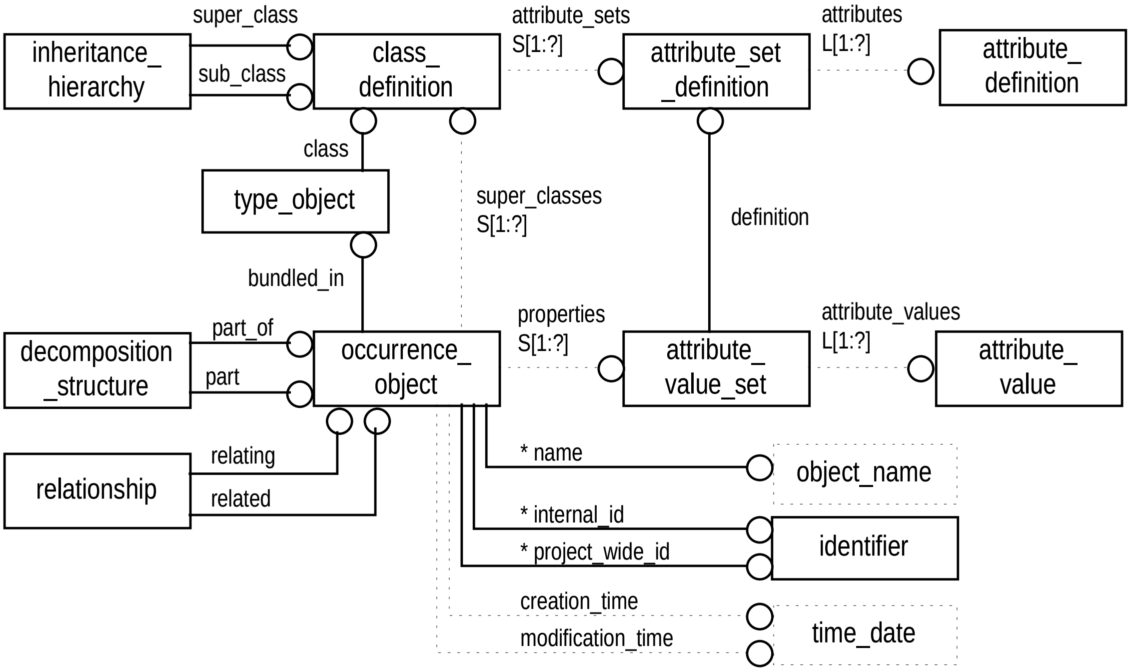


Figure 5.8. Data exchange meta-model used in the prototype.

The exchange meta-model and, consequently also the syntax, includes basic data structures for representing definition classes and attribute sets and object declaration attributes with values, composition relationships, other relationships, object identification, owner information, etc. The file format is alphanumeric with a Lisp-like syntax, where entities and their attributes are bundled as parenthesis-separated lists with nested sub-lists as described in chapter 3.

Using this meta-model meant that mapping software had to be developed from the ABCM model to the OOCAD meta model, and vice versa. Most of the information contained in the ABCM can be transferred, design rules and knowledge can not be transferred as such.

In figure 5.9 is an overview of the mappings, which are included in the data exchange:

- From a participant's aspect model to the core model ABCM.
- From the core model to the data exchange model.

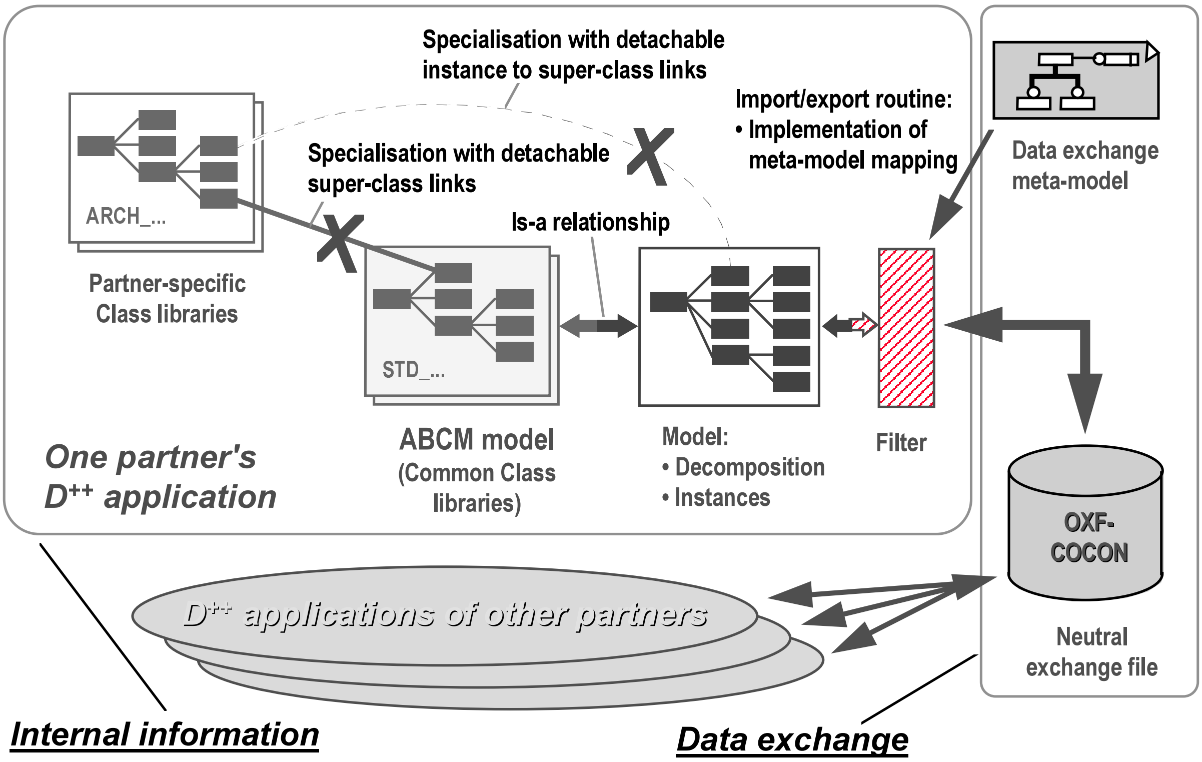


Figure 5.9. Overview of the different mappings.

The rules are defined in Class (Knowledge) Libraries. Rules are proprietary per participant i.e. knowledge will not be shared by others. Adding rules to shared ABCM classes was considered but not implemented in the prototype environment.

5.5 Network solution for the data exchange

An Internet-based network solution was chosen as the basic infrastructure for the pilot integration environment. The main reasons for choosing Internet were that the basic software and network technology were readily available and that connection services to the Internet were accessible to all partners at the different geographical locations (in the cities Helsinki, Espoo, Vantaa and Tampere). Due to its openness the Internet has some limitations concerning data security, mainly during transfer time. However, these were not considered a major concern. Internet services, especially the World Wide Web (WWW), have in recent years been investigated as a basic distribution medium for public and general building information [Hannus et al. 1996], and more specifically for design standards and building codes [Vanier and Turk 1994]. The pilot project is one of the first attempts in Finland to use the Internet for data exchange in real-life building projects.

The physical network connections and system administration are based on a centralised project server, to which the partners have access via Internet connection services (figure 5.10). The individual aspect models of each partner are used locally and only the common class libraries belong to the ABCM and the data exchange files are distributed via the server. Typically the partners use modem-based dial-up connections. The project server is set up with home directories for each partner. Each partner has full read/write access rights to his own directory and read-only access to the other directories. The directory system is password-protected.

Standard Internet services are used for information sharing:

- *FTP* is used for up- and downloading data exchange files to and from the server. Basic FTP client software is usually not very user-friendly, but FTP has proven to be the most simple and reliable system in transferring large files.

- *Internet e-mail* is used for the message traffic, such as change notifications. Data exchange files could also be transferred by e-mail as attached files; however this was found impractical due to the large file sizes.

- *WWW* is used for distributing common information, both public and restricted to project partners (news, event logs, minutes of meetings, etc.), as HTML homepages. Data exchange files may also be downloaded with a suitable WWW-browser.

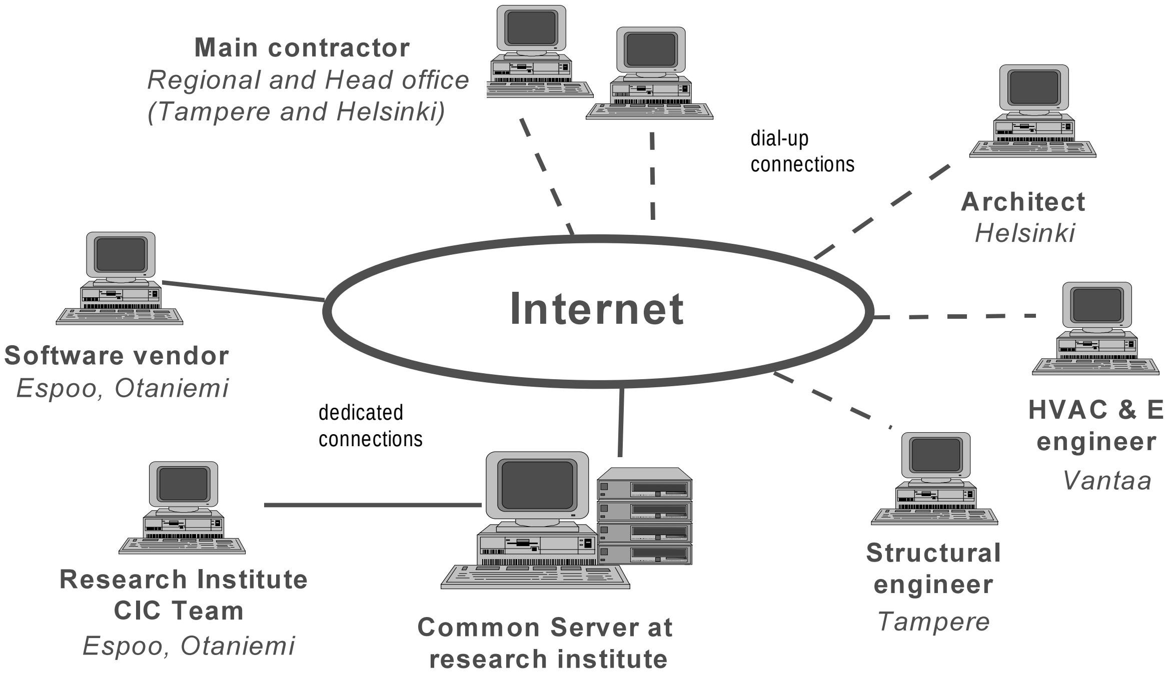


Figure 5.10. The network architecture of the prototype environment.

5.6 Production model

5.6.1 Contractor's production model

YIT's production model is created by the so-called "COst and Value Engineering" system, for which the abbreviation COVE will be used in the following. This application is based on the corporation's knowledge of its own production: structural solutions, production methods and recipes and input price lists of resources and equipment.

COVE's own application-specific libraries include the attributes required to analyse costs and scope data. Eventually life-cycle economy and environment will be added when that kind of knowledge of building materials and products becomes available. The COVE libraries are linked with superclass link to the standard ABCM libraries shared by all participants.

The structure of COVE is such that the creation of the production model is also possible without the imported product model data. In this case the model is built interactively by the cost analyst through interpretation of paper, or CAD-drawings.

The overall structure of the COVE model complies with the product structure of the ABCM core-model. In the class specification, an apartment building and the structures and spaces used in it have for the time being been taken as the reference point.

In COVE a building is decomposed into a spatial system, a structural system and an installation system (building services) corresponding to the architect's aspect model, the structural engineer's aspect model and the building services designer's aspect model respectively. An example of the COVE model's product structure is shown in figure 5.11.

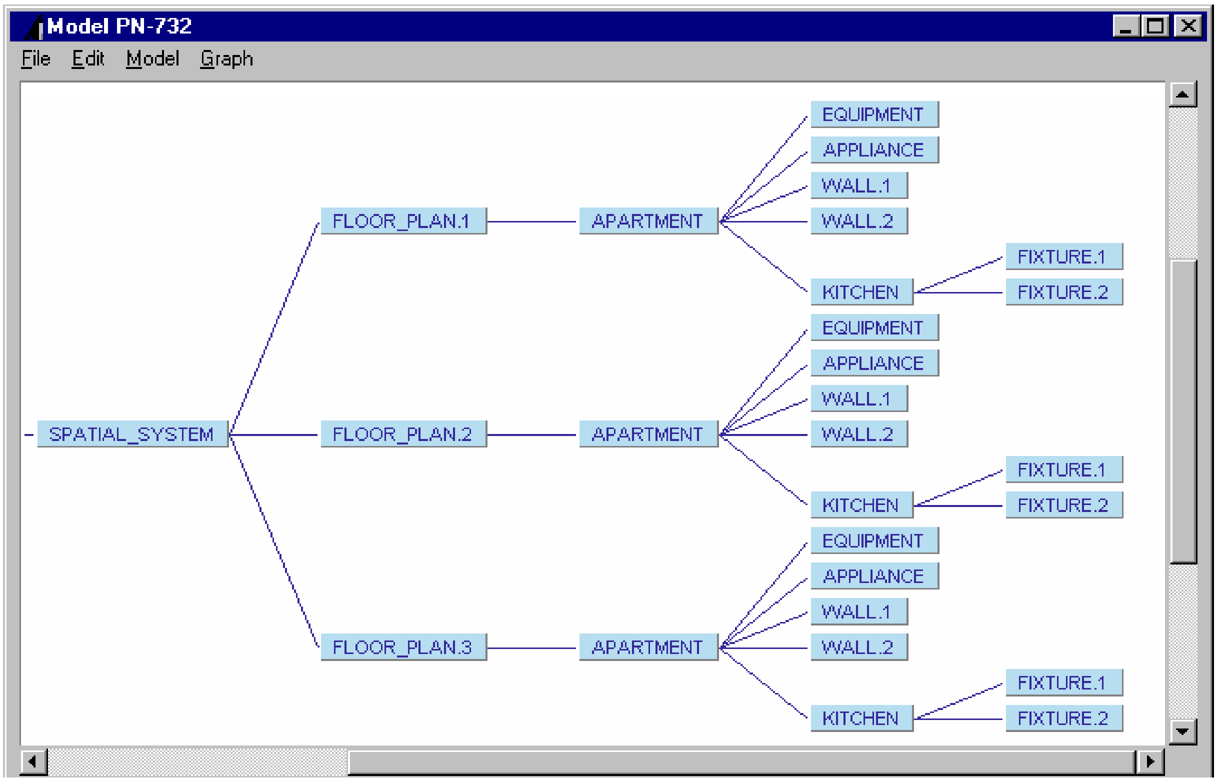


Figure 5.11. Example of the COVE model's product structure.

Figure 5.12 shows the main window of the COVE interface, which was constructed on top of AutoCad. In the main window, the Structures (rakenteet) and Spaces (tilat) menus are the key interfaces for model creation. The other menus contain the functions required for modelling and model processing. In the figure the Structures menu is open and part of the corresponding product structure is shown.

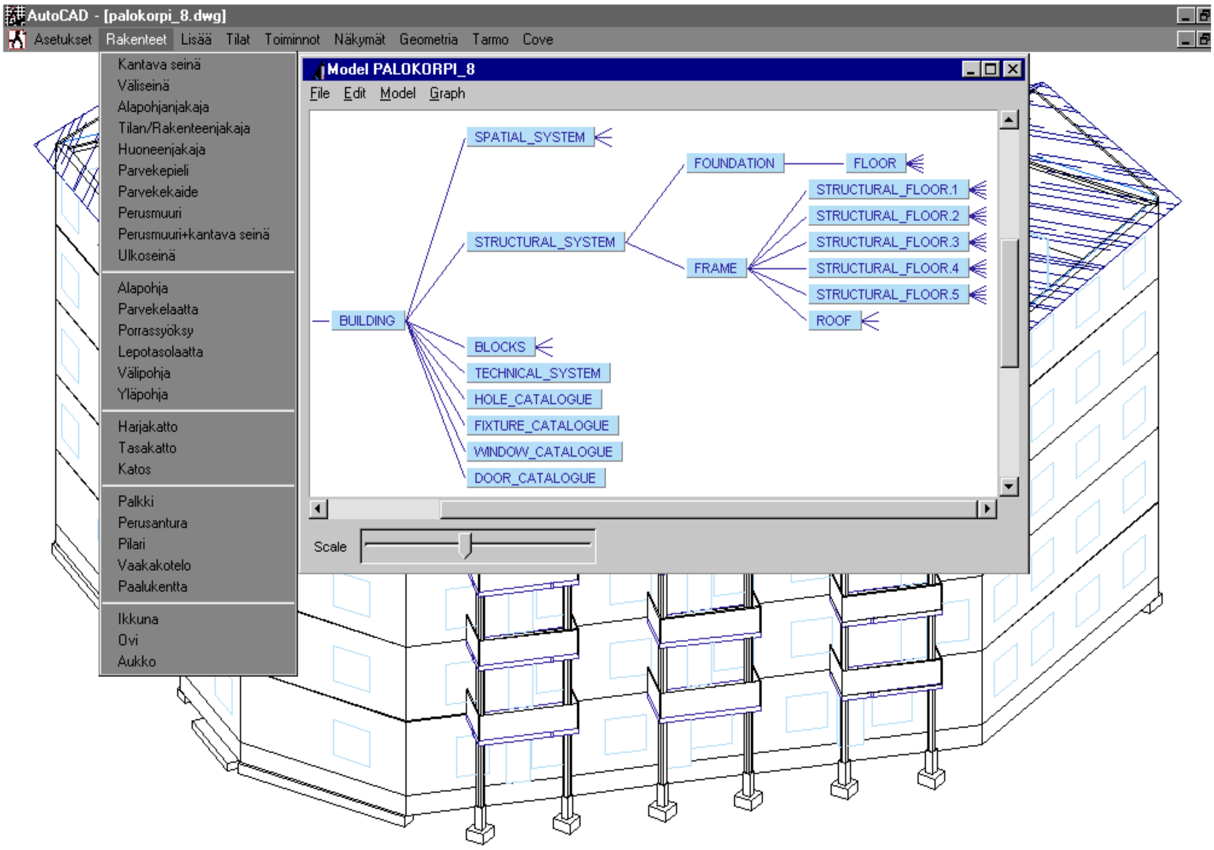
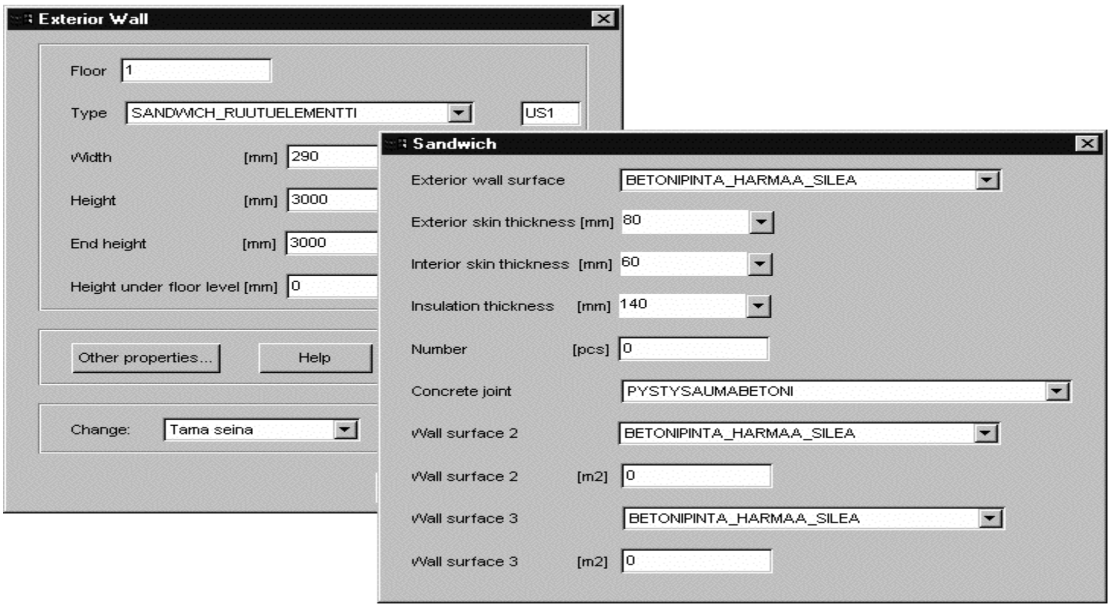


Figure 5.12. COVE main window with Structures menu and part of product structure.

For each product structure class, interface functions have been developed for the creation of components and for specifying and checking the attributes through the interface windows. The options in the interface windows are the values of the production model components' production attributes, i.e. production knowledge. The production model components generated in the case of integrated design are in a similar way given their attribute values.

In figure 5.13 the user interface during the modelling is shown: on top the interface of the sandwich elements, the default values for this type are shown. In the figure above the user has selected all the alternative types that are possible. This way all building elements are modelled and methods and structures are checked.



Floor 1
Type SANDWICH_RUUTUELEMENTTI US1
Width [mm] 290
Height [mm] 3000
End height [mm] 3000
Height under floor level [mm] 0
Change: Tama seina

Exterior wall surface BETONIPINTA_HARMAA_SILEA
Exterior skin thickness [mm] 80
Interior skin thickness [mm] 60
Insulation thickness [mm] 140
Number [pcs] 0
Concrete joint PYSTYSAUMABETONI
Wall surface 2 BETONIPINTA_HARMAA_SILEA
Wall surface 2 [m2] 0
Wall surface 3 BETONIPINTA_HARMAA_SILEA
Wall surface 3 [m2] 0

Figure 5.13. User interface for modelling sandwich elements and the selected type.

5.6.2 The creation of the production model from paper drawings or CAD-files

The COVE application can be used to create a production model on the basis of the plans from the architects. At present there are two distinct methods of performing the modelling, using either drawings on paper or AutoCad dwg files.

The modelling of the building may be performed with the help of tools built into the interface application, to facilitate fast and simple routines for drawing components and attribute specification. The production model is created solely through the interface functions, i.e. the model and its components are built up as the user ‘draws’ the building and its structural elements.

The order in which the production model is constructed cannot be entirely free; instead it must follow the product structure hierarchy (Figure 5.12). In the product structure hierarchy, the components which are higher must be modelled before the lower-level components.

The dependencies between components are clearly defined when they derive from the product structure hierarchy. This is a ‘part-of’ relationship between components. Some ‘connected-to’ relationships are also used in the COVE model, the expression of which is less distinct. Such a dependency may occur, for example, between spaces and the walls (or similar structures) surrounding it when space components are created.

The object-oriented nature of the COVE model makes it easier to create and process a model. When constructing the model, it is possible to use the components’ copying attribute in such a way that, for example, the load bearing structures of a high-rise apartment building are modelled in the lowest storey and copied ‘upwards’ on other, similar storeys. Similarly, the apartments are modelled on the bottom storey and copied upwards. Also, when making changes to the attributes of the production model’s components, they propagate to all similar cases in the model in question.

Determining the geometry of a component takes most time when it is derived from an architect’s drawings on paper. In this case it is necessary to measure the geometrical information of the building elements with a ruler and enter them in numerical form while creating the components.

Modelling is simplified if the architectural plans are available as CAD-files. In this instance an architecture layer is formulated from each storey, and this is used as the base image in AutoCad. In the modelling of the building the architectural layer is used to ‘draw’ the geometry of the components, a process that resembles digitising.

5.6.3 The creation of the production model from the designers’ product model

The import of the product model

In the case where the designers are already using product-modelling tools, which is not the current practice, the COVE system can use designer’s output data as input data directly. As described earlier in section 5.6.1, the ABCM core-model sections modelled by the various designers are transferred into the COVE application by OXF data communications using mapping software.

The creation of the production model

After the product model has been created or imported it is processed by adding to it production know-how (to the building elements), either in the form of default values or by the interactive (through the user interface) selection of methods individually or for the various types of building elements. After the inspection of the product model and the addition of production know-how, the result is a production model that will serve as input data for production requirements. The production model is created quickly using the information in the ABCM core-model and with little extra work for the contractor.

The COVE model can also be created using only a part of the ABCM core-model. For example, a structural model made by a structural engineer may be used, augmented with COVE for the spaces.

5.7 Conclusions

The prototype application COVE meets the requirements stated in section 5.1 as follows:

- The starting point for the model based cost and value engineering approach was to exploit the tendering and costing system which was already in use in the company. COVE’s architecture and accuracy is defined according to the requirements of this system.

- Production knowledge, in the form of methods and recipes are included in the COVE system. The user defines them from interface windows while creating the production model.

- Designers’ current documentation, either as paper drawings or as 2-D CAD-files, can be used as input information for COVE.

- Designers can create partial aspect models of the building product model for which they are responsible and that can be used as input for COVE.

- From COVE it is possible to generate bills of quantities including the knowledge of the hierarchical locations of building elements. Material lists can be extracted and stored in the way the end users require.

- The basic design solution analysis in terms of scope, efficiency, form and functionality, as used in YIT are included in the system.

- The usage of predefined and accepted building systems or structural details is still on a prototype level, though the main structural systems are tested with COVE.

- The usage of reference projects as modelled cases is defined, but was not tested in a real project. This is mainly due to the lack of modelled projects.

- The definitions for the STEP physical data exchange format was made, but not on the level which could be used in real projects. A decision was made to wait for the emerging IFC-development.

6 TESTING THE MODEL

6.1 Scope of the testing

There are two major aspects to the testing of the prototype system and the target process that it supports. The first aspect is that the prototype tools work in a technical sense, that is that the needed data can be produced, stored in the model and transferred. This aspect also includes such issues as how fast the system works, what type of computer platforms are needed etc. It is relatively straightforward to test the technical functioning even in a single pilot project.

The second aspect is that the information management process as such, regardless of the technical implementation of the prototype, is feasible. This includes questions such as if the personnel involved in cost estimation and planning perceive the target process as better than the old one. A lot of issues of human interaction, power structures within company hierarchies, ease or difficulty of maintaining experience databases etc. might be raised. This is much more difficult to measure. Often personnel involved in pilot projects have themselves been involved in developing the prototype tools and defining the target process and are thus positively biased. Setting up reliable experiments for these aspects is consequently quite difficult.

The testing presented below concentrated on the technical functioning of the COVE prototype tool.

In 1995-96 the first pilot project using the COVE-application was carried out. Smaller-scale test projects had been carried out in the context of research work by the various partners during the definition of the logical contents of the information to be shared amongst participants. These were helpful in improving the reliability of the applications and the correctness of the information content. This was the case particularly in the development of YIT’s COVE application.

This chapter refers to two test projects in which the COVE system was tested. The development and testing of the COVE system was done separately from the normal design and construction planning process in order to avoid disturbances, but using the same case buildings and personnel. A COVE model can be constructed either on the basis of **document-based design** by producing the product model directly using the COVE application on the basis of design information which is interpreted by human operators, or it may be based on **model-based design**, in which case the production model is assembled from aspect product models imported digitally from the designers. The test projects were selected in such a way that both ways of constructing the model were tested.

6.2 Modelling based on drawings

6.2.1 Project description

The test job chosen was an apartment building built for the real estate holding company As Oy Tampereen Tikka, which represents a residential construction project typical for YIT. The frame type of this seven-storey building consists of one loadbearing stairwell, precast concrete panel walls and hollow-core slab floor panels.

Figure 6.1. Tampereen Tikka, southern facade.

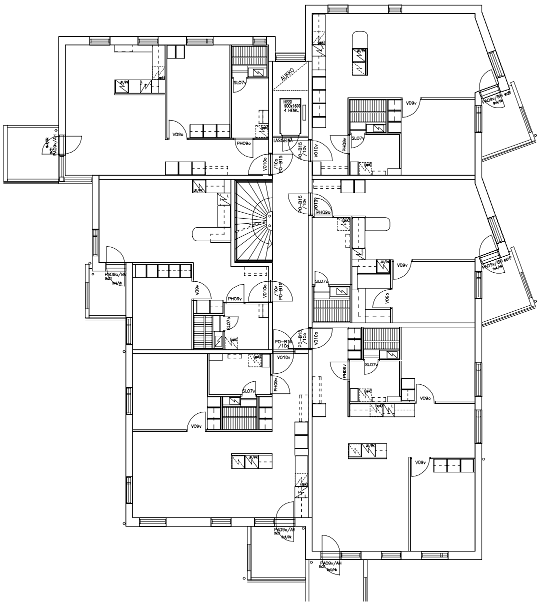


Figure 6.2. As Oy Tampereen Tikka, floor plan, 1st-6th floor.

6.2.2 COVE modelling

The modelling of the building was carried out using the AutoCad dwg files produced by the architect as input. The architect delivered dwg files for the different storeys in such a way that each storey was a separate file and that objects normally visible in 1:100 pictures were shown on one plan. The base points of each picture were placed in the same corner point on each storey.

Modelling was carried out on consecutive days, keeping a detailed account of the hours used and of activities performed. The computer used for modelling the test construction was a Sun SPARCstation 5 64 MB. In addition to AutoCad drawings, the specification of works, and the door and window schedules were used as input information for the modelling.

Using COVE the actual effective modelling time for the building was 12 working hours (one person), which may be broken down in greater detail as follows:

There were some 3,000 components (objects) in the final production model of the construction. The modelling of the building's frame structures, balcony and roof structures took a total of 4.5 hours. As the structural system also includes windows and doors, the structural system accounts for 7 hours of the effective modelling time.

The spatial system accounted for 5 hours of the actual modelling time. There were in all 10 different types of apartments to be modelled in the building. On the average, it took about 20 minutes to model one apartment. The times varied from 15 to 40 minutes among individual apartments, depending on their size and on how successful the modelling work was.

The time used on modelling depends not only on the complexity of the building but also on how precise a model is desired. For example, the precise location of the windows is not important if a cost estimate is required purely for tendering calculation purposes. The modelling of As Oy Tampereen Tikka was, however, performed with the maximum possible precision, which is apparent particularly from the times spent on modelling the apartments and the doors and windows. There is therefore good reason to compromise on the precision of modelling on a case-by-case basis, which will reduce the time spent on modelling work.

The automatic analysis of the building's scope and characteristic figures (described in chapter 4) was performed with the applications interface. The exploitation and appropriate usage of these key figures will only become possible when there are enough buildings modelled to put together a comprehensive body of comparative data as cases in reference library. The impact of the key figures on costs can be determined by studying their dependency on measured costs after the completion of the building.

6.3 Integration with the tendering activity

6.3.1 Current tendering system of YIT

An important requirement for the prototype system was to exploit the cost estimation system already used by the company as well as its built-in databases. As described in chapter 2., the quantity survey is the most time consuming part of tendering. The TARMO cost-estimating system used by YIT Building Construction is based on the calculation of building elements using the nomenclature of either Construction-80 or Construction-90. The Construction-90 item headings are used in connection with the COVE application. TARMO is programmed using the W-language and MDBS-database. W-language is a case tool programmed in the C language and MDBS is a database management system which uses an extended network data model.

TARMO uses three standard databases. These databases are for elements, methods and resources. The element database links element types with method structures which can be used for constructing these types of elements. The method database associates resource structures (work sections, recipes) with the methods. The resource database consist of resources and their prices. These standard databases are continuously updated with the current input price list. Updates of labour prices are based on actual site costs, which are collected from the sites in the form of final reports and audited information. Today the resource database consists of about 6 000 items.

TARMO allows to make the bill of quantities on two levels; on the level of elements and on the level of methods. Every element has also a structure composed of methods. These structures can be chosen from the element database or it can be composed of separate chosen methods.

The construction elements, equipment components, system components and spaces in a project are compiled into construction element structures by specifying their contents with an item heading. According to the context, the item headings included in the structure describe a performance, a structure layer, an accessory or an event. The contents of the item heading consist of inputs comprising the factor of production required to create the product.

Today the user first needs to have the bill of quantities, and then manually keys in this information to TARMO using a textbased interface. The user defines the chosen method and location of the building elements. The average time for this operation is about 10-15 working days for an apartment building of 5 000 m2.

6.3.2 Integration of COVE with the TARMO tendering system

The solution chosen for integrating COVE and TARMO was a transfer file which could be used for reading in the structural information from the production model into the cost estimating system. This transfer file is produced fully automatically from COVE. It is as well possible to transfer only parts of the model. The transfer file was designed in such a way that it is equal in content to the input information to TARMO in a project processed by conventional methods.

The structure of the transfer file complies with the standard of the Construction 90 system. The principal parts of the transfer file are as follows:

- the project
- project locations
- component (construction component, equipment component, project component, space)
- location of component (after the construction component or item heading)
- item heading (after the construction component)
- work section
- comments concerning the basis for decisions made and risk handling

The production model, in this case COVE-model, produces detailed information about components and their attributes. A component can be a space, surface, a structural component or a HVAC-element and has location and work sections (method and recipes) e.g. form work. The location attribute depends on the component. For some components, it can for instance be Building A, but for some other component it can be as specific as a single room. There is a hierarchical relationship between different locations which enables the use of this information in later stages. A rough cost estimation can be given by pricing the components' work sections. The integration of the COVE production model and the tendering database is illustrated in figure 6.3.

In order to determine a cost estimate, a transfer file was made from the production model for the TARMO cost estimate system. The stages of making the transfer file and the computer time used on them were as follows:

Examining the building using TARMO is similar to examining a building calculated with traditional methods. The cost estimate made with the COVE model is based on the pricing carried out in connection with the transfer run, in which standard item headings and standard input prices are used. Figure 6.4 illustrates a data transfer from the COVE production model to the TARMO tendering/cost-estimation system.

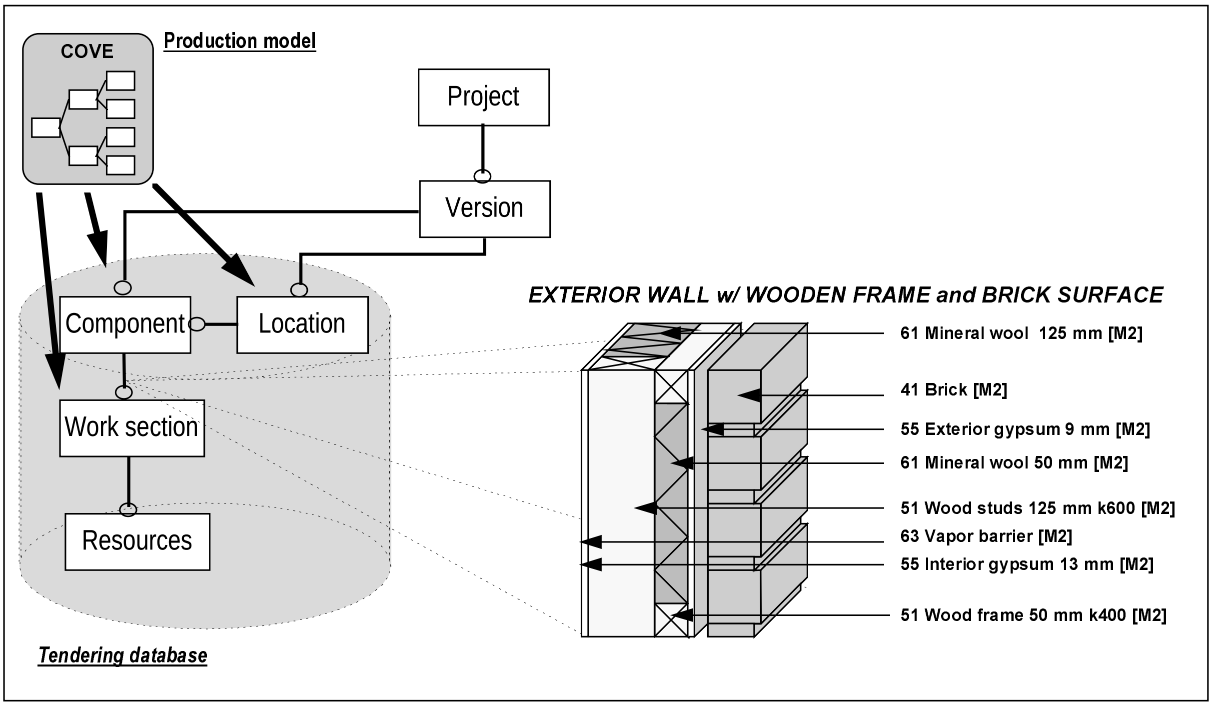
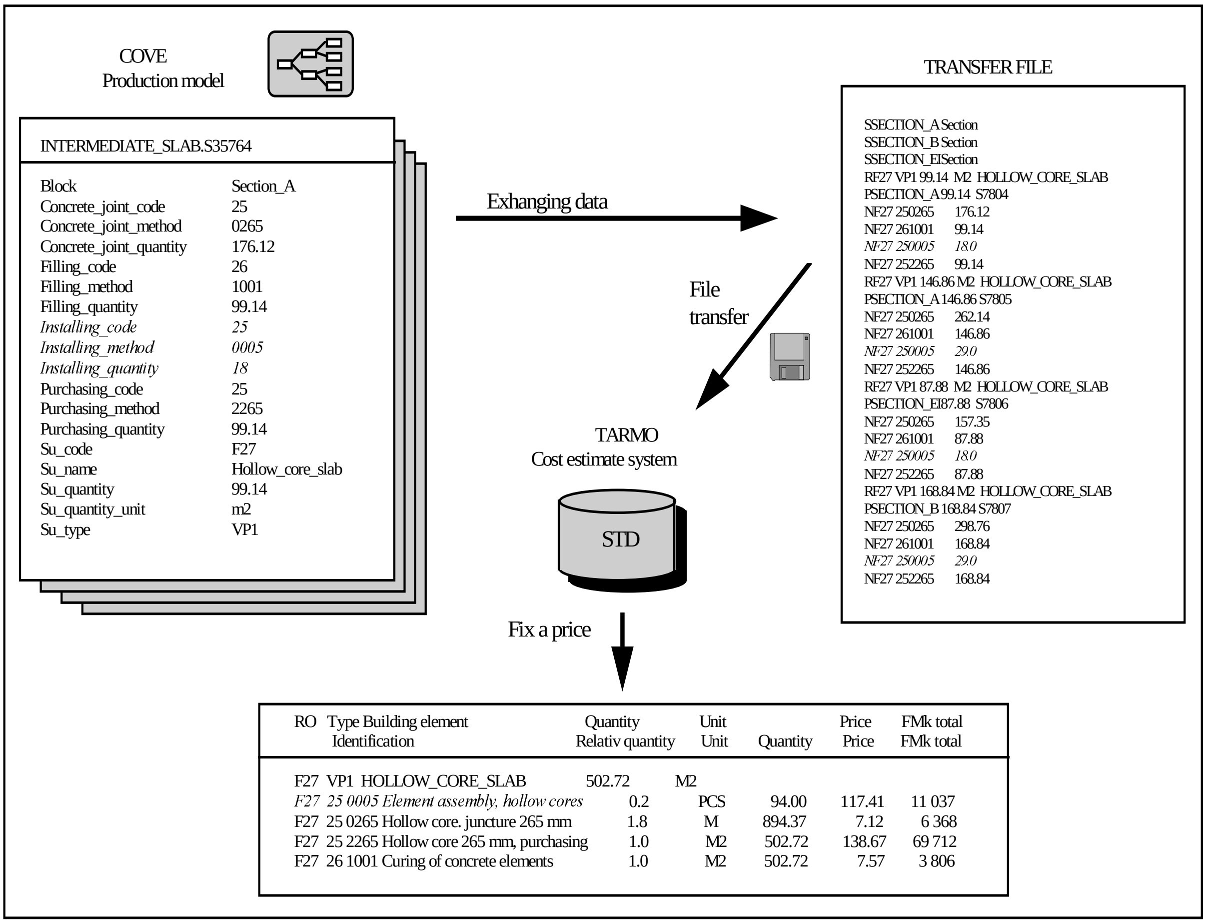


Figure 6.3. Integration of the production model with the tendering and cost estimation database.



INTERMEDIATE_SLAB.S35764	
Block	Section_A
Concrete_joint_code	25
Concrete_joint_method	0265
Concrete_joint_quantity	176.12
Filling_code	26
Filling_method	1001
Filling_quantity	99.14
Installing_code	*25*
Installing_method	*0005*
Installing_quantity	*18*
Purchasing_code	25
Purchasing_method	2265
Purchasing_quantity	99.14
Su_code	F27
Su_name	Hollow_core_slab
Su_quantity	99.14
Su_quantity_unit	m2
Su_type	VP1

```
SSECTION_A Section
SSECTION_B Section
SSECTION_EISection
RF27 VP1 99.14  M2  HOLLOW_CORE_SLAB
PSECTION_A 99.14  S7804
NF27 250265      176.12
NF27 261001      99.14
NF27 250005      18.0
NF27 252265      99.14
RF27 VP1 146.86 M2  HOLLOW_CORE_SLAB
PSECTION_A 146.86 S7805
NF27 250265      262.14
NF27 261001      146.86
NF27 250005      29.0
NF27 252265      146.86
RF27 VP1 87.88  M2  HOLLOW_CORE_SLAB
PSECTION_EI87.88  S7806
NF27 250265      157.35
NF27 261001      87.88
NF27 250005      18.0
NF27 252265      87.88
RF27 VP1 168.84 M2  HOLLOW_CORE_SLAB
PSECTION_B 168.84 S7807
NF27 250265      298.76
NF27 261001      168.84
NF27 250005      29.0
NF27 252265      168.84
```

RO	Type Building element Identification	Quantity Relativ quantity	Unit Unit	Quantity	Price Price	FMk total FMk total
F27	VP1 HOLLOW_CORE_SLAB	502.72	M2			
F27	*25 0005 Element assembly, hollow cores*	0.2	PCS	94.00	117.41	11 037
F27	25 0265 Hollow core. juncture 265 mm	1.8	M	894.37	7.12	6 368
F27	25 2265 Hollow core 265 mm, purchasing	1.0	M2	502.72	138.67	69 712
F27	26 1001 Curing of concrete elements	1.0	M2	502.72	7.57	3 806

Figure 6.4. Example data transfer from COVE to TARMO (concerning hollow core slabs).

6.4 Modelling based on the neutral model

6.4.1 Project description

The building for the real estate holding company As Oy Lapinniemen Isopurje is an eight-storey apartment building with two stairwells. The building is of precast panels throughout, with precast panel walls and hollow-core slabs as the load-bearing structures. The 1,700 cubic metre underground car park beneath the building was excluded from the pilot project.

The design team for the project consisted of the same partners as the members of the pilot study committee, so it was possible to combine actual design work and development-related modelling. However, the traditional design work progressed on the schedule required for the construction project irrespective of the schedule for pilot project. The COVE model of the building is illustrated in figure 6.5.

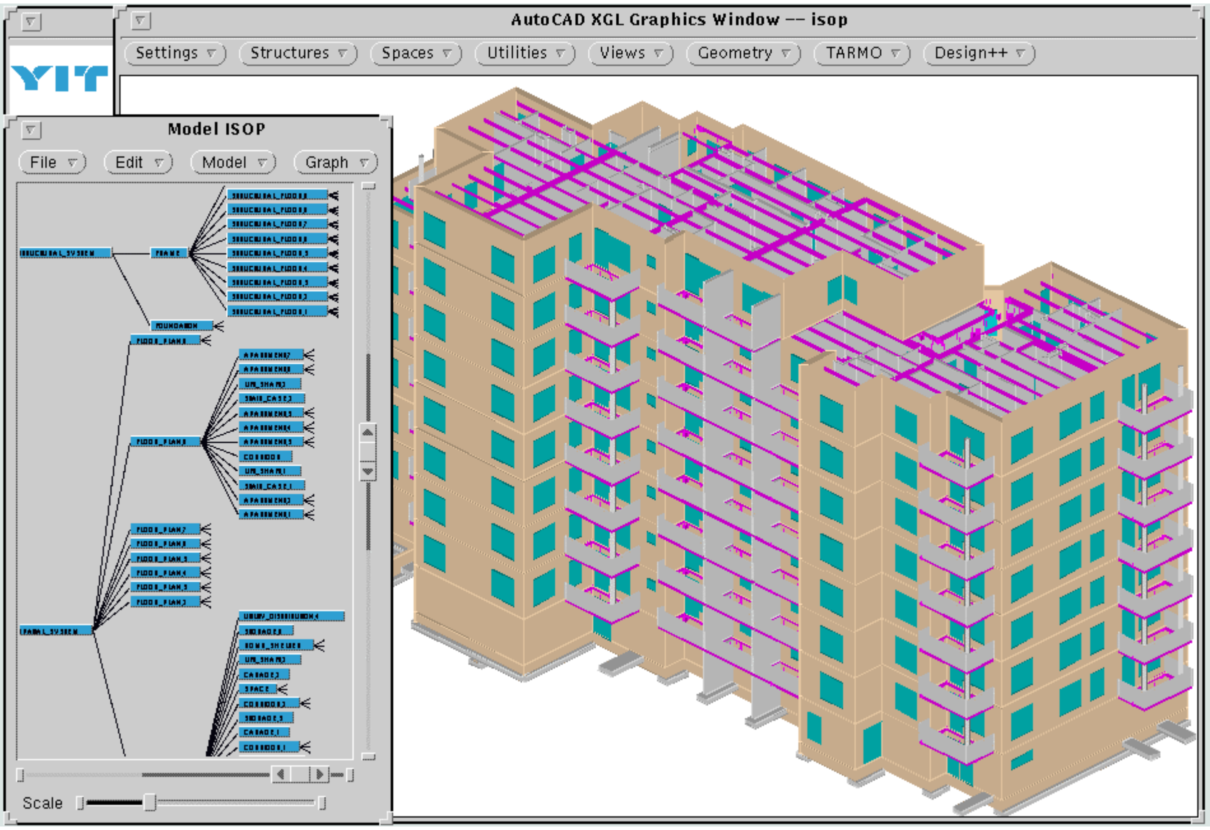


Figure 6.5. The As Oy Isopurje model in COVE application.

During the pilot project the development of the model based cost and value engineering system was still in progress, as was the exact definition of the common attributes to be exchanged. The data entry of the architect's and structural designer's aspect models was done successfully in a way which transferred the model's product structure with all its attributes and dependencies.

One of the main aims of this Isopurje pilot study was to provide feedback information through the testing in order to help in the definition of the ABCM core model. Partial data transfers from COVE to TARMO were carried out for such components as external walls, floors and foundations. These partial estimates facilitated testing the coverage of the attribute content, the correctness of rules, and the smooth running of transfer runs.

For the designers the usage of Design++ was a first attempt to utilise the product model approach (Isopurje pilot only). Compared to their daily work with AutoCad this was quite different, even if the graphical interface was AutoCad.

6.4.2 Data exchange

The data exchange concept (described in chapter 5) proved to be quite reliable. For instance, the data of the whole structural engineer's model, including the relevant parts from the architectural model, were successfully transferred to the contractor's application through the common server with no losses in the data: all the attribute, decomposition and relationship data were maintained intact through the conversions [Serén et al. 1996].

The normal data exchange procedure worked as follows:

1. The sender exports the data exchange file from his product model and uploads the file from his workstation to his directory on the server using FTP client software.

2. The sender notifies the intended receivers about the available exchange file and its location by e-mail. At the same time he also notifies the server administrator.

3. The receiver reads the e-mail message and downloads the exchange file to his workstation using FTP client software or a WWW-browser.

The receiver imports the exchange file into his product model and notifies the sender and administrator by e-mail if problems occur. The server directory structure is described in fig 6.6.

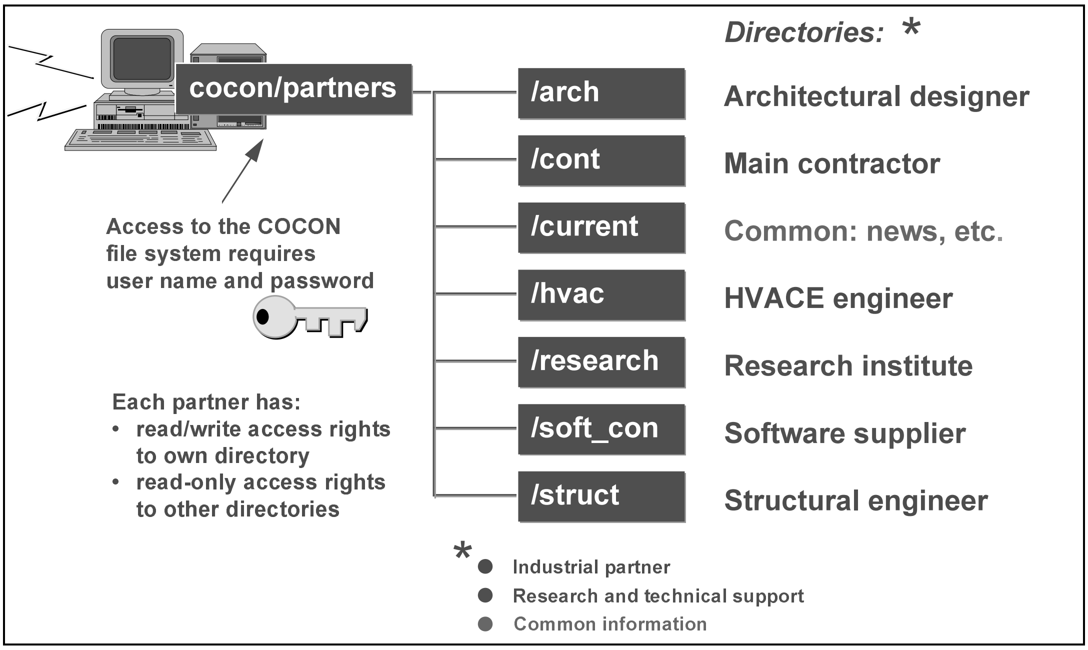


Figure 6.6. Server directory structure.

One problem in the pilot testing was the speed performance of data transfer: because a product model of an apartment building is large (5-10 MB), transfer times can pose a problem. For example, with relatively slow modem dial-up connections (transfer rates in the order of 9600 - 14400 bps) the data transfer time was in the worst case up to one hour, depending on the line loads. Faster dedicated or ISDN connections are recommended when larger data transfer volumes are handled. The transfer may of course be set up to be executed during night-time, which also accentuates the importance of an independent server for intermediate file storage. The use of a centralized server does not restrict the receiver's activities in any way; he may download the files at any convenient time.

One of the advantages of using the OXF format for the transfer files was that it lead to relatively compact files. For instance the size of the neutral exchange file (OXF) containing the structural engineer's model data was only 110 kB in the pilot. Even though some compression scheme could have been used, the advantage of using the neutral file format was obvious at the time of the pilot project.

6.5 Conclusions

The following discussion is based on interviews made with YIT staff after the pilot projects and after some other test projects, and with staff from design offices during and after the pilot projects.

A cost estimation produced with the COVE model currently covers about 60% of a full cost estimation. At present, the information generated by the production model can be used to determine the costs of spaces and structures, but the costs of technical systems, foundation works and site engineering must for the moment be determined separately for each project by traditional methods. Enhancements to the system are essential so that an all-inclusive cost estimation can be obtained.

6.5.1 YIT staff viewpoint

The examination of the extent of the building and of the various characteristic figures are based on the user's conclusions drawn from the COVE calculations. The way these characteristic figures are used has so far depended entirely on the user's skills and experience. In addition to the traditional characteristic figures, COVE enables the calculation of many characteristic figures which can be derived from the shape and the quantities of various construction elements described in the model; so far there is no experiential basis for the comparison of these. As the number of models rises, and as systematically compiled statistical materials accumulate, the possibility arises of analysing the data e.g. scope, efficiency of the design solution, on the basis of comparative statistics, which will yield information on the importance of these characteristic figures to design management.

The examination of the scope and especially of the functionality of a design solution is still performed through a graphical user interface. In other words, the user examines the designs with AutoCad images and draws conclusions on the basis of his own knowledge. It was found that these requirements are difficult to describe as design rules for the system (Design ++). The same difficulty was encountered in defining QFD requirements.

It is possible to carry out comparative estimates by generating a transfer file from a limited set of components, e.g. facade elements or the building frame. In the initial phase of modelling it is possible to estimate the design by determining a cost estimation for the loadbearing structure alone. The quantity of the loadbearing frame and its cost are appropriate points of comparison also for assessing the scope of design. This feature was found very useful by the staff involved.

The required design data can be taken from the production model by inspecting the model from various perspectives, viewing only the needed components and attributes in isolation. This open product structure was found very useful in particular to procurement operations, in which the modules required by the building component trade can be freely demarcated and assembled together. Precise data on quantities and designs can be appended to tenders, so the supplier's quantity estimation is left out and the risks inherent in the supplier's tender are reduced as the appended material becomes more accurate.

As a conclusion of the experiences so far the interviews indicated that the achieved accuracy is acceptable and the savings in time are about 80 %. Also most mechanical and human errors are avoided and in addition it is always possible to check the model using visual Auto-Cad images. Alternative design and production solutions are relatively easy and quick to cross-check.

The most probable way in which the COVE application will be used in the near future is for modelling production models by the contractor's design management and estimation staff. This has also been a basic assumption of the development work. Using AutoCad files as a basis for modelling is, for the time being, a convenient modelling method. Modelling on the basis of AutoCad image files was in the pilots found to be considerably faster than working with drawings on the paper. The time taken to precise modelling from paper drawings can be estimated as two to three times the time taken to model with AutoCad files (comparisons made in typical housing projects). However, the most important achievement according to the production planners is that now the information is in usable form for other activities (production planning, scheduling etc.) in later phases.

6.5.2 Designers' viewpoint

From the designers' viewpoint a crucial feature of the approach is that the latest, non-conflicting design data is stored only once, in a single location. This makes it quicker to keep up to date and to note changes.

In the opinion of the interviewed designers the overall design time will be shortened when the specialist designers are able to start designing simultaneously with the architectural drafts. Work done on early drafts will not be wasted as the data content can be augmented as the design progresses. If model-based design is carried out on an integrated basis, the overall time used on design is shortened. The different designers can work together simultaneously even at the draft stage.

A feature which the designers welcome particularly is that the contractor's model-based design management will give the designers immediate feedback on, for example, the cost impact of alternative solutions. The exploration of the overall cost impact of non-routine, new solution methods will promote development work and innovation by designers.

The main difficulty in implementing this new model based approach in practice is the lack of product model based design tools. The emerging IFC development will hopefully help in solving this problem.

6.5.3 Comparisons with the requirements

The results of the testing can be compared with the requirements defined in section 5.1:

- The architecture and accuracy of the product model should comply with YIT's needs for tendering, cost estimation and production planning activities. *This was demonstrated for the case of cost estimation and tendering through the interface to the TARMO application*.

- It should be possible to apply YIT's production knowledge, in the form of methods and recipes stored in data bases, to the building elements obtained from the building product model. *This was demonstrated in both pilot test cases.*

- The system should allow the use of the designers' current documentation, which mainly comes as 2-D CAD-files, as input that can be transformed by the contractor to the format required for the product model. *This was demonstrated in the Tikka pilot*.

- Alternatively it should be possible for the designers to directly create the parts of the product model for which they are responsible. *This was demonstrated in the Isopurje pilot*.

- The system should be able to generate bills of quantities including the knowledge of the hierarchical locations of building elements, i.e. section, staircase or room and to extract material lists structured for different purposes, e.g. quotation tendering. *This was demonstrated in connection with the data transfer to the TARMO system.*

- The basic analysis of the design solution in terms of scope, efficiency, form and functionality (basics of cost and value engineering), should be as automated as possible. *The basic analysis was defined and tested in both pilots on the level that YIT uses the characteristic figures*.

- The system should allow to use predefined and accepted building systems (e.g. frame, heating system) or structural details from knowledge libraries, so called YIT best practice. *For the case of structural details this feature was included in the Isopurje pilot.*

- The system should enable the exploitation of information from reference projects, especially in the early phases of the process, using previously modelled projects to support case based reasoning. *This was not demonstrated during the pilots. This feature needs more projects to be modelled in order to make the definition for the case based reasoning*.

- The system should be able to read input formatted according to the STEP physical data exchange format and should be structured in such a way that it could easily be adapted to receive data according to the emerging STEP/IFC core model schemas. *The first attempts were carried out on suitable level for the Design++ system, but not in connection with the pilots pilots. This requirement was postponed to later phases and towards the emerging IFC definition.*

7 RESULTS AND DISCUSSION

7.1 Overview of the results of the study

In chapter 2 the results of an analysis of the information management process used currently in the chosen case company, YIT, are presented. The process is described in a formalised way using the IDEF0 modelling methodology. Six major shortcomings were identified in the current client service and design and construct processes. In particular the following problems were high-lighted:

- The contractor lacks the ability to provide adequate decision support for the customer, especially in the very early stages of a project, such as briefing.
- There is a lot of duplication of work involved in the transfer and reuse of data. The contractor cannot use the information coming from designers as input information for his own cost and value engineering information applications, and the internal integration of the contractor's own applications for cost estimation, scheduling etc. is also poor, causing a lot of repetitive work, and increasing the risk of errors.

Although the results are based on an analysis carried out inside one case company, they are very much in line with similar results reported by other researchers. For instance, Tarandi discusses in his thesis [Tarandi 1998] the problem of how to transfer product related information from design to construction. The individual building objects and their properties can be found only implicitly, i.e. through human interpretation of paper drawings and other documents. He focuses on the same kind of problems of quantity take-off and design change management as this study.

Construction process reengineering is the main focus for Fischer et al. [1995]. He discusses problems in current scheduling and cost estimation practice [Aalami and Fischer 1998]. In particular he points out that accurate and detailed feedback on the cost and schedule implications of design decisions are usually too late in the project delivery process. He discusses the possibilities to move construction management tasks into earlier phases of the process.

Froese [1992] believes, as in this study, that integrated computer systems offer the capability of improving the effectiveness and efficiency of construction management processes. His interest has been in developing and standardising high-level, generic core information models of construction processes.

Luiten concentrates in his thesis [Luiten 1994] on the DfC (design for construction) approach and analyses six interactions problems between design and construction in terms of the exchange of information, knowledge and tasks between designers and contractors:

- Forward exchange of the building design

- Feedback on the building design from construction
- Backward exchange of contractors’ information
- Backward exchange of general constructability knowledge
- Upstream shift of construction management tasks
- Downstream shift of design tasks

A research group at the University of Salford (UK) has taken quite another view to describing the problems within construction process information management; the co-maturation between the construction process and supporting IT [Aouad et al. 1998]. It is based on classifying the process maturity and IT-maturity of different stages of the construction process using a five-level model (the Capability Maturity Model, CMM). The process maturity levels include, from the lowest to the highest: emerging, ad-hoc, repeatable, defined, managed and optimised. The corresponding levels for IT technology maturity are: emerging, initial, applied, integrated, managed and matured. The result of the analysis is that the problem with the construction process and its IT support is that they reach only the three lowest levels. In particular the authors point out that: construction is on the level defined (3), design on the level repeatable (2), facilities management and feasibility on the level ad-hoc (1) and environmental management on the level emerging (0). The analysis of different types of IT-tools indicated that CAD, project planning, estimating, management of bills of quantity and purchasing are on level (2) applied, 3D and VR on level (1) ad-hoc and standards, communications, STEP, IAI and case based reasoning on level (0) emerging. These results are not in conflict with the results of this study, although the viewpoint and type of analysis is quite different.

The *process model* , described in chapter 2, of current practice in one construction company, can also be compared with some other formalised construction process models presented in the literature. The process model of current Finnish construction practice which was defined by VTT [Karhu et al. 1997] aims at being a systematic and generic reference description of the overall construction process, covering the building project from the need survey to the hand over to the customer. The basic scope is the prevailing practice within the construction industry. Although the study used the IDEF0 methodology, it used an earlier analysis of the process done by the Building Information Institute, in the form of client's and designer's task lists, as important input material. In contrast to the process model of this study, VTT's model contained several different viewpoints, since it included distinctly separated submodels for the client's activities, the activities of the different designers and for the production phase. The decomposition of the overall process model is shown in figure 7.1. The model is geared to the prevailing general contracting practice and has little provision for feedback.

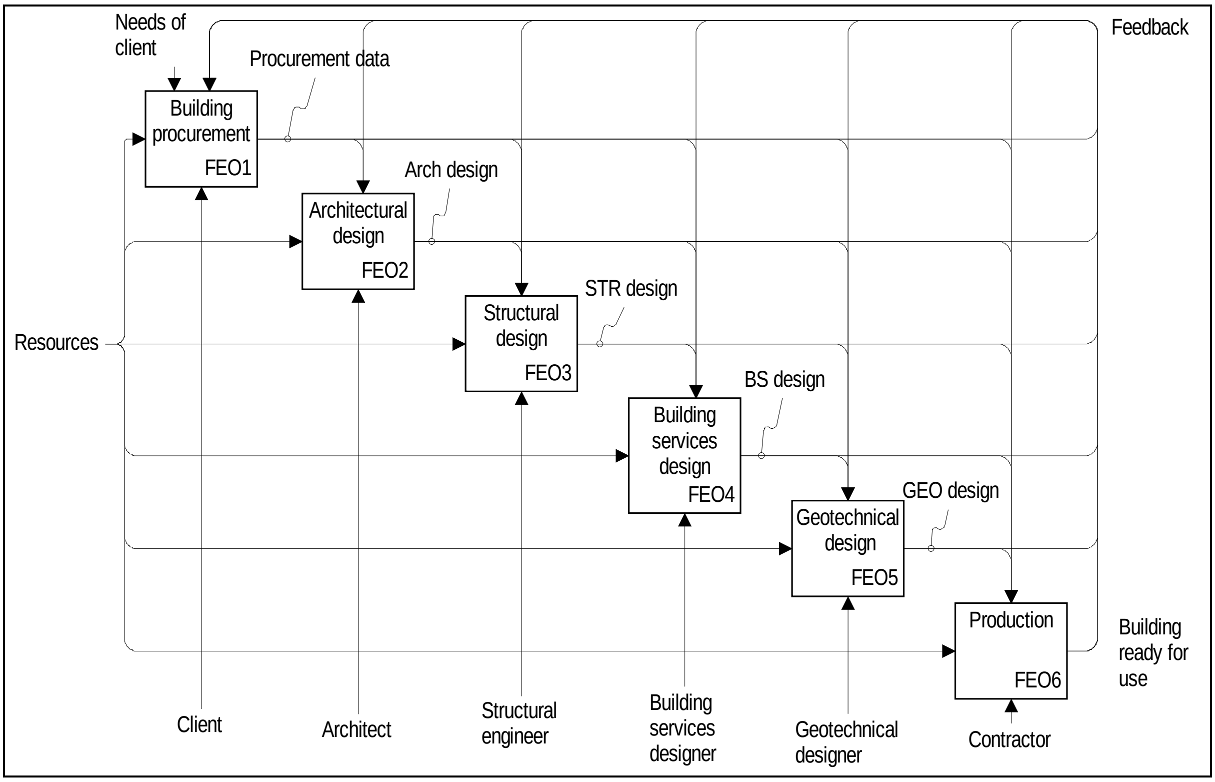


Figure 7.1. The overall decomposition of VTT's process model of current Finnish construction practice [Karhu et al. 1997].

In the Process Protocol Map of Salford University [Aouad et al. 1998] the construction process is broken down into four main phases and ten sub phases:

- Pre-project phase
- Pre-Construction phase
- Construction phase
- Post Completion phase.

These phases were analysed in terms of process maturity (CMM as described above). This map was used in identifying the supporting IT technologies.

Sanvido concentrated in his Integrated Building Process Model (IBPM) on the essential functions required to provide a facility to the end user [Sanvido 1990], [Sanvido 1995]. The main activities in his process model are manage, plan, design, construct, operate and maintain a facility.

Chapter 3 contains a review of relevant methods and research in the construction information classification and product modelling domain. The key conclusions of this review was that it was important to ensure future compatibility of the company’s systems with the standards emerging from the STEP and IAI work. The review also indicated that the core model - aspect model approach, which has been the focus of quite a lot of research recently, and which underpins the STEP/IAI efforts, could provide a good basis for the product model definitions needed in the prototypes.

Chapter 4 contains a description of the target process for information management, which takes into account the possibilities for process reengineering offered by product data technology. On the highest level the process model defines the relationships between the client’s building procurement activity, the information management of the contractor in a particular design and construction project, the continuous maintenance of the construction company's knowledge bases, and the use of the constructed buildings. It is in the interrelationships between these, through better feedback for decision support, that the most significant benefits of the reengineered process occur.

There are hardly any examples of reenginered company process model which have been reported in the literature, although there are a number of on-going R&D projects which include such modelling in their scope (i.e. the European CONCUR project [Storer and Los 1997]). There are two reasons for this, firstly that formalised techniques like IDEF0 are seldom used by companies in the construction industry, secondly that companies are unlikely to publish the results of such modelling efforts.

Based on the results from the state-of-the art review and on the target process description a framework architecture for a model based cost and value engineering process was defined. This framework, which is presented in *chapter 5*, uses the notions of a core model and aspects models, and adds the concept of a production model to these, where the production model is obtained through the integration of the construction company's aspect product model and the company's production knowledge, in the form of knowledge bases containing construction methods and recipes. Based on this framework architecture a prototype application, which uses a knowledge based tool called Design++ and which also uses some of the results of earlier Finnish research at VTT for its physical data exchange schema, was developed.

This architecture can be compared to models defined by other researchers. In the PreFacto system [Jägbeck 1996] the generic product data model holds a core of information needed for managing a construction project. Also in Prefacto the product description is based on a neutral core model solution influenced by STEP. The information is imported from design documents and is used as input for creating PreFacto's own aspect model (a Production Management Model), which is quite similar in scope to the contractor's production model of this study.

The minimal NICC (Neutral Intelligent CAD Communication) conceptual schema [Tarandi 1998] specifies the use of concepts for the exchange of computer interpretable information relating to all parts of buildings. NICC contains building object shape and type, connectivites, assemblies and graphical representation. The NICC model consists of three meta classes: building object, building space and building system. The production aspect is not as pronounced in NICC as in the COVE-application, which includes production knowledge in terms of methods and recipes.

The architecture in Luiten's PMshell [Luiten 1994] is based on main user requirements. The most important was the integration, also the modularity and support of the STEP formats, which is similar to the approach in this study. The architecture of PMshell consists of layers with domains. A layer can be interpreted as a group of conceptual models with the same scope. A domain represents a field of interest, a so-called universe of discourse.

Luiten and Fisher have tested the usefulness of a conceptual project model and system architecture as information models for integrated construction management in the prototype system called SPACECAKE [Luiten and Fischer 1995]. The conceptual project model was built up of project classes and their attributes and relationships. The main finding was the need for the development of computer interpretable representations of construction knowledge, which complies well with the direction of this study.

In chapter 6 the results of some pilot tests with this prototype were presented. In the Tikka pilot the method where the contractor's own personnel modelled the production model directly from CAD drawings was tested. In the Isopurje pilot the different designers used product model based (prototype) tools and the product model was first assembled from these, after which the production knowledge was added by the contractor's own personnel.

7.2 Results discussed in the framework of the target process

In the following, the results of the prototype development and testing are discussed in slightly more detail, using the target process description from chapter 4 as a framework for structuring the discussion. The requirements described in chapter 5 are also taken into account.

The order of the discussion does not follow the hierarchical structure of the IDEF0 model directly. Rather the discussion starts with the submodel *Manage design and construction* (A2), to which most of the demonstrated results are related, and then returns to the more comprehensive model, *Design and construct building* (A-0), including the activities outside the contractor's activities.

The submodel *Manage design and construct* (A2) figure 4.6, contains six activities ranging from *Define brief* to *Manage hand over*. In the submodel *Define brief* (A21) figure 4.7, there are two additional activities due to the reengineering of the process*: Create preliminary architect's aspect model* (A213) and *Create preliminary production model* (A214). The activity *Create preliminary architect's aspect model* has as input the architect's sketches and as output the preliminary architect's aspect model. This is related to the requirement*: alternatively it should be possible for the designers to directly create the parts of the product model for which they are responsible*. This feature of the model was tested in the Isopurje pilot. The creation of a preliminary production model is made possible by the use of the knowledge based engineering system (as mechanism) and indirectly provides better decision support for the customer through the usage of this intermediary output as input in the *make budget price for the customer* activity.

YIT's design management is described in the submodel *Do and supervise design* (A22) figure 4.8. The activities are quite the same as in the traditional process, but the design is carried out using model based applications and the form of information to be exchanged is totally new, model based. The media for data exchange is Internet (shown as mechanism). The lack of suitable model-based applications today is the key problem which hampers this new approach.

The subactivity *Exchange data in neutral form* (A225) has both as input (sender's view) and as output (receiver's view) the designers' aspect models which are in OXF-form. This partly fulfils the requirement: *the system should be able to read input formatted according to the STEP physical data exchange format and should be structured in a such way that it could easily be adapted to receive data according to the emerging STEP/IFC core model schemas*. This feature was tested in the Isopurje pilot and later with the architect's and structural engineer's aspect models separately. The final output from this submodel is an integrated building model.

In this activity the central input is the integrated building model emanating from the designers. Another input consists of libraries, in the form of detailed methods, recipes and resource information. This fulfils the requirement: *it should be possible to apply production knowledge, in the form of methods and recipes stored in data bases, to the building elements obtained from the building product model*. This is the basic function for tendering and cost estimating, and it was tested during the pilots. One part of the library input is in the target model in the form of standard solutions. This was stated in the requirement: *the system should allow to use predefined and accepted building systems (e.g. frame, heating system) or structural details from knowledge libraries, so called YIT best practice*. The definition and development of this feature is still going on and some basic tests have been done concerning structural engineering.

The main submodel from YIT's point of view is *Manage cost and value engineering* (A23), figure 4.9. In this submodel the process reengineering is rather extensive. The new activities are: *analyse design, compose production model, study alternatives and estimate life-cycle economy*. Since the information is now in manageable form (product model) it is possible to make quick analysis of alternative solutions of methods and materials to accomplish the building. The main input is an integrated building model which is based either on integrated model based design or modelling by COVE from drawings (figure 4.3), or using aspect models. This fulfils the following requirements: *the system should allow the use of designers' current documentation, which mainly comes as 2-D CAD-files, as input that can be transformed by the contractor to the format required for the product model*, and *alternatively it should be possible for the designers to directly create the parts of the product model for which they are responsible*. This has been tested and demonstrated in the pilots. There is a totally new input, data bank for life-cycle costs, which is still under development and has not been tested. The main output from the *Manage C & V engineering* activity is the production model, the key issue of this research. This fulfils the following requirements: *the architecture and accuracy of the product model should comply with YIT's needs for tendering, cost estimation and production planning activities* and *it should be possible to apply production knowledge, in the form of methods and recipes stored in data bases, to the building elements obtained from the building product model*. This feature was tested carefully.

The production model is on a more detailed level an output from the activity *Compose production model* (A232). Another output from this activity are the quantities, which is in accordance with the requirement: *the system should be able to generate bills of quantities including the knowledge of the hierarchical locations of building elements, i.e. section, staircase, apartment or room*, and *to extract material lists structured for different purposes, e.g. quotation tendering*. Due to its paramount importance for YIT this output has been tested thoroughly. The utilisation of the production model information in production planing is in the activity *Make schedule and plan construction* (A233). This is now on a prototype level as reported by Oinas [1998].

The highest level of the *Design and construct building model* (A0) figure 4.5, describes the interfaces between YIT’s activities in a particular project with the customer’s activities, the activities of the building’s end users and YIT’s long-term maintenance of its knowledge bases. From the customer’s point of view the main differences compared to the current process are:

- Better decision support and decision support in earlier phases
- Building documentation in model form (so called as built model)

These features have not yet been tested in real projects.

Overall most of the requirements defined in chapter 5 and most of the new activities in the to-be process model are achieved. The central features, in which the target process model differs from the as-is model, were demonstrated in the pilot projects. Due to the lack of modelled cases there is still quite lot of research to be done concerning better decision support in the briefing phase.

7.3 Generalisation of the results

This study has been conducted as a case study in a single company and has thus been limited in several respects. Nevertheless it ought to be possible to reuse some of the ideas and technical solutions also in other contexts than the original one. The main directions for generalisation are shown in table 7.1 below.

Table 7.1. The main directions for the generalisation.

Original context	Generalisation aspect
Design and construct contract	General contracting
Residential building	Any building construction
Main contractor's viewpoint	Other construction process parties' viewpoint.
Prefabrication	In-situ construction
Finnish practice	Practice in other countries

In this study the design and construct process approach was chosen due to its strategic importance for YIT. The model based tendering and estimating approach can be used in Bid and construct as well. If general contractors define their information process according to their business needs, the chosen model based approach can be utilised. The data exchange paradigm is suited to both construction processes almost unaltered.

The focus on residential buildings was based on the market situation at that time. The model based approach can, however, be used in any kind of building construction. Obviously the product data models need to be redefined for different types of buildings. The basic knowledge of the production is the key issue and must be defined first. In later stages the modelled buildings should be sorted in the library according to the building type (e.g. residential, office, industrial) in order to be able to utilise them as cases.

The process analysis described in this thesis is based on the main contractor's viewpoint, but there has been active involvement of other parties, especially designers as in the Isopurje pilot. Saarnivaara [1997] describes the system unit supply approach which can be obtained in this information process analysis. As described in chapter 1 the supply process is one of the main processes. Using the same methodology and tools the supply process can be integrated into the main contractor's process. This kind of research is going on in Europe, for instance in the IMS/Globeman project [Globeman 1998].

A big effort has been made in the industrialisation of the construction process in Finland [Saarnivaara 1990]. The prefabricated concrete industry is the market leader in building frames and facade elements [Karhu 1997]. Even though the tendency is towards industrialisation (prefabrication), in some cases in-situ construction is desirable. The contents of in-situ constructed ”modules” must be defined and modelled in terms of methods and recipes (as described in chapter 3). This requires some changes in the model builder (COVE), but basically the same functions can be utilised.

This study is based on Finnish construction practice. In comparison with international practice the main differences lie in the roles and responsibilities of diffrerent partners. The key issue is the definition of the information flows within the process and its context. On a European level the on-going CONCUR project [Storer and Los 1997] has already adopted a similar model based approach. In Japan and USA [Lahdenperä 1995] there are several R&D projects which basically have similar targets.

8 CONCLUSIONS

In chapter 1 the overall aim of this research was defined as:

- To study how the data management of a general contractor, who mainly aims at working in design and construction projects, can be improved, in order to provide better client value and more cost-efficient production.

The underlying belief was that significant improvements can be achieved by using product modelling as enabling technology.

On a more detailed level the objectives of the study were:

- Identify the ways in which design information can be made amenable to computer interpretation.
- Define the structure and content for a cost and value engineering management system.
- Demonstrate the working parameters of a cost and value engineering management system.

The objectives of the research have been achieved through a number of interrelated activities as outlined and discussed in Chapter 7. In this respect, it has been decided not to repeat those arguments here, but to concentrate instead on the further application and benefits of the results of the research.

8.1 Future research and development topics

8.1.1 The positive effects of standardisation

From the contractor’s viewpoint, all standardisation for data exchange is beneficial. In the opinion of the author, the definition of the IFC schemas will speed up the standardisation needed for a large scale proliferation of product data technology in the construction industry. Another very significant consequence of the work of the Industry Alliance for Interoperability is promoting the introduction of product model technology as such.

The specifications for an architect’s space model are already fairly advanced in the IFC work. The other fields of design have also made a good start, particularly in the area which in this study was neglected - building services. When the IFC/IAI definitions eventually will become embedded in commercially usable software, the use of the product model approach in the construction industry will take a great step forward. For the case company, this will only improve the prospects of expanding the utilisation of IT. The compatibility of the company’s systems with emerging IFC-based applications has been attended to in advance as far as this was possible.

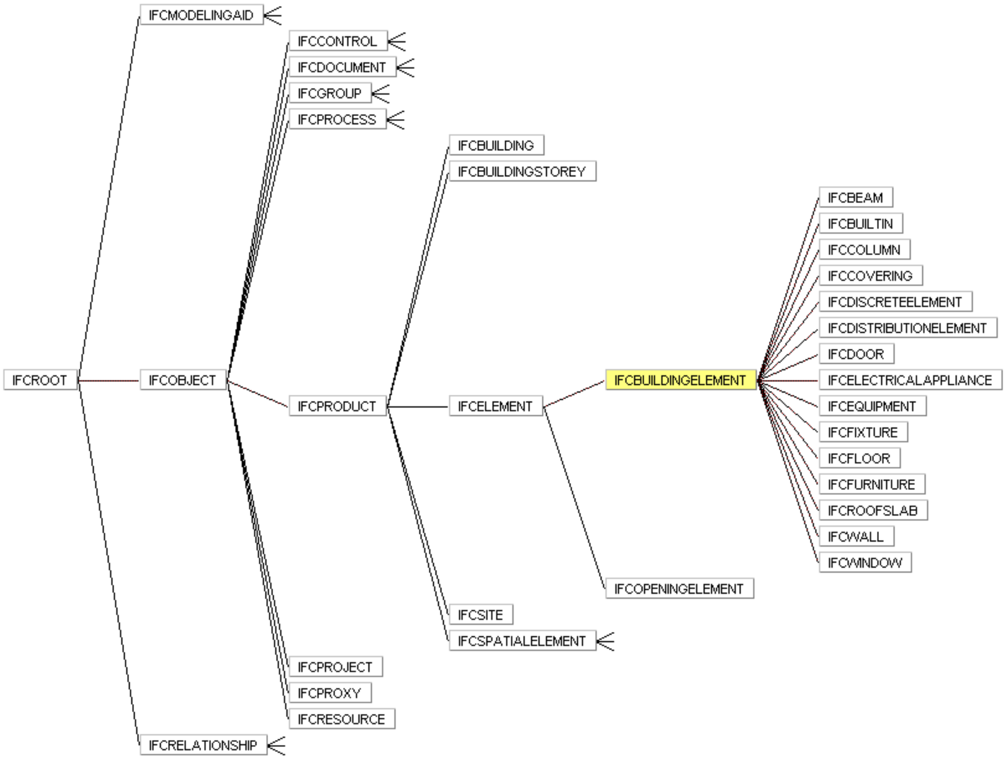


Figure 8.1. A part of class library in Design++ which is structured according to the IFC version 1.5 schema. This illustrates the upwards compatibility of COVE with developments in international product model standardisation.

8.1.2 Research and development needs from the viewpoint of the case company

Chapter 2 described the main problems of the construction process life cycle, from the viewpoint of the case company. This study provided a contribution to solving one of these: the integration of design and production planning as well as tendering and cost and value engineering activities. From the viewpoint of the case company research topics and development aims in the future should include:

- The creation of a ”space” model in the briefing phase as a link with the production model. This will achieve the integration of the first part of the process with design and production and will provide a basis for producing information supporting decision-making for the client and the other partners in the process: designers, contractors and suppliers. Another goal is to develop tools for visualising the differences between alternatives.
- Utilising and integrating the product/production model in production planning, where it will serve as basic data. The main areas lie in time scheduling, logistical planning, purchasing planning, and production activity planning. The viewpoints should be: the main contractor’s, the building services contractor’s and the suppliers’.

- The definition and implementation of the ”as built”-model as a logical continuation for the production model. In this model there should be the information of designers (why and based on what the technical solution was chosen) and of the contractor (materials, systems and maintenance information). The target situation [Oinas et al. 1997] is described in figure 8.2.

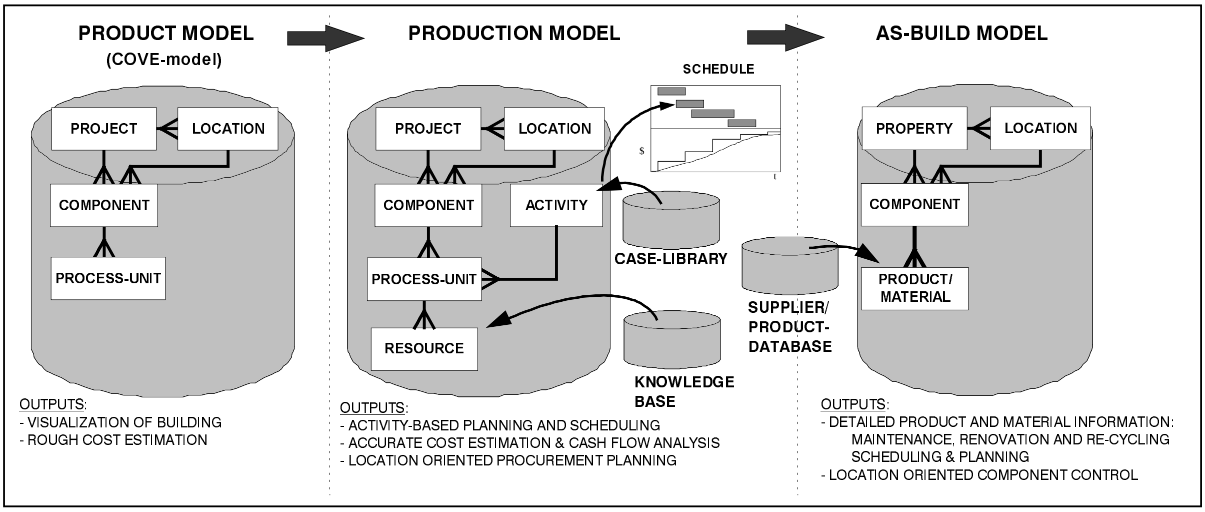


Figure 8.2. Target situation for the use of model support throughout the construction process life-cycle.

8.1.3 Research needs from society’s perspective

The long-term research needs for the construction industry have been discussed in numerous publications and conferences world-wide. Of particular relevance to the Finnish industry (and thus also to the case company) are the visions which have been discussed by the Finnish Technology Development Centre [Saarnivaara 1997]. This is not only due to the fact that these visions and R&D strategies are based on an analysis from the Finnish national viewpoint, but also, quite pragmatically, because the centre can back up its strategy formulation with substantial R&D funding. Figure 8.3 illustrates some of the key concepts included in these strategies.

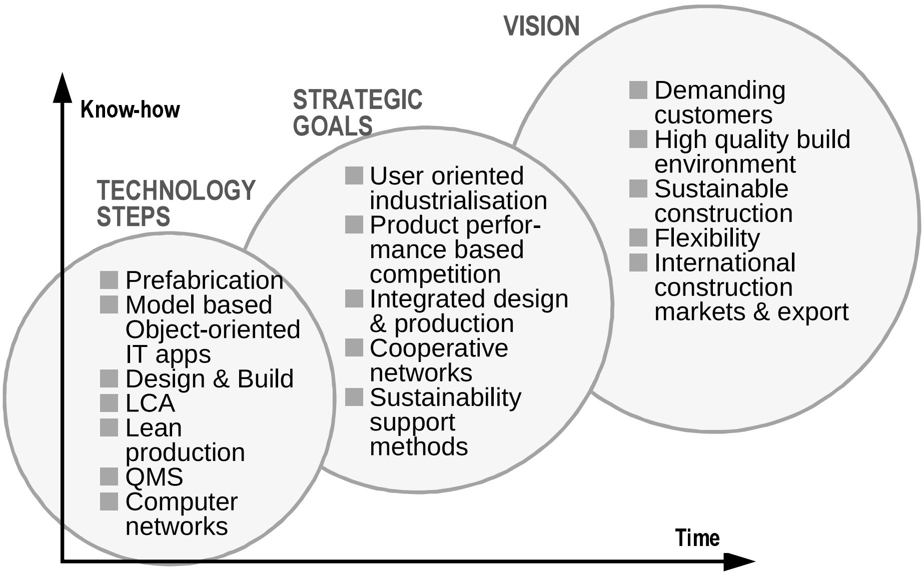


Figure 8.3. Strategic goals and visions for the construction industry [Saarnivaara 1997].

Central topics in long term research will be the management and assessment of the life-cycle economy of the buildings. From the viewpoint of sustainable growth, which respects the environment, construction is in a very central position. The present construction practice concentrates on achieving the lowest construction cost instead of optimising the life cycle costs and environmental impacts of the use of a building. This prevents to accomplish the principles of sustainable development in the building sector. The results of future research ought to give better opportunities for sustainable construction technology. (Less energy contents, less use of scarce building materials, less waste by optimising logistics and simulating the buildings before they are built.)

Improvements in the customer service process is also a primary R&D topic. The customer ought to be offered more tangible information on the project’s investment costs and its life cycle costs as well as on the time schedule. This will help the customer make better decisions.

Concerning the impact of information technology on the construction industry Tekes has recently launched a major development programme called VERA [VERA 1998], which by international comparisons is quite substantial, considering the size of Finland (150 Mill FIM over 6 years). The main purpose of VERA is to promote the utilisation of product data technology and information networks within construction processes. The author of this thesis is heavily involved in VERA, in the capacity of chairman of the board. The studies reported in this thesis have de facto acted as a forerunner to the projects now being carried out by a large number of companies with VERA funding.

One key feature of VERA is the strong emphasis on "forcing" companies to use existing and developing IT standards. For this reason there has been a policy decision to support the IFC work both by Finnish active participation in the definition of the IFC's and by implementing the ensuing standards in VERA development projects.

8.2 Final conclusions

In parallel with this research some other researchers have taken similar approaches to the problem of integrating design and construction information (see discussion in chapter 3). Compared to these the research reported in this thesis has taken a rather more comprehensive approach to integrate the whole construction process throughout its life-cycle. The briefing phase has been less in focus for the other researchers mentioned above.

The proposed main contribution of the research reported in this thesis is that the product model approach can be used as the technical means for a substantially reengineered information management process of a main contractor. Although the testing is not complete, it goes a longer way into full-scale testing in an industrial setting than most of the reported building product model research. This type of applied research is very much needed to provide the "proof-of-concept" of the utilisation of product models within the construction industry, which is needed to convince company managers to go ahead and invest in reengineering the way their companies work.

References

Aalami F., Fischer M., 1998
Joint product and process model elaboration based on construction method models
In: Björk B-C and Jägbeck A. (eds.) *The life-cycle of IT innovations in construction – Technology transfer from research to practice*, Proc. CIB W78 conference, June 3-5 1998 Stockholm, Royal Institute of Technology, Dept. of Construction Management, Stockholm

Allweuer, T, Babin-Ebell, T., Leinenbach, S., Scheerer, A.-W., 1996
Model based reengineering in the European construction industry
In: Turk, Z, (ed) *Construction on the Information Highway,* Proc. CIB W78 and TG10 workshop in Bled, Slovenia, June 10-12, 1996, pp. 21-32

Aouad G., 1994
Integration of Construction Information, ICON (Final Report)
University of Salford, UK

Aouad, G., Cooper, R., Kagioglou, M., Hinks, J., Sexton, M., 1998
A synchronised process/IT model to support the co-maturation of processes and IT in the construction sector
In: Björk B-C and Jägbeck A. (eds.) *The life-cycle of IT innovations in construction – Technology transfer from research to practice,* Proc. CIB W78 conference, June 3-5 1998 Stockholm, Royal Institute of Technology, Dept. of Construction Management, Stockholm

Atkin, B., 1995
Information management of construction projects
In: Brandon, P. And Betts, M. (eds.) Integrated Construction Information, E&FN Spon, London, pp. 291-315

Augenbroe, G., 1992
Integrated Building Performance Evaluation in the Early Design Stages
Building and Environment, vol. 27, no. 2 pp. 149-161

Augenbroe, G., 1994
An Overview of the COMBINE Project
In: *First European Conference on Product and Process Modeling in the Building Industry*, Dresden, Germany, 5-7 October 1994

Bacon, M. 1997
Lean Construction: Process Change in BAA
In: Brandon, P., Betts, M. (eds) *The Armathwaite Initiative, The Formation of a Global Construction Network*
Construct IT Centre of Excellence, Salford, UK

Barrie, D. S., Paulson, B. C., 1992
Professional Construction Management
McGraw-Hill Book Company, New York

BEC 1991
Manual of Precast Concrete-CAD (Betonielementti-CAD)
Finnish Concrete Association, Helsinki

Betts, M., 1997
Lean production as a purpose for computer integrated construction
In: Alarcón, L. (ed.) *Lean Construction*, A.A.BALKEMA, Rotterdam, 1997, pp. 343-353

Betts, M., Walker, S. P., Clark, A. M., 1997
Re-engineering the construction process and its implications for construction management research
In: Mohamed S. (ed) *Construction Process Reengineering*, Proc. International Conference on Construction Process Reengineering, Gold Coast, Queensland, Australia, July 14-15, 1997, Griffith University, Queensland, Australia

Bindslev, B., 1995
Logical Structure of Classification Systems,
In: Brandon, P. And Betts, M. (eds.) Integrated Construction Information, E&FN Spon, London, pp. 117-136

Binford, T., Chen, T-L., Kunz, J. C., Law, K. H., 1997
Computer Interpretation of Process and Instrumentation Diagrams
Technical Report 112, Center for Integrated Facility Engineering, Stanford, CA, August, 1997

Björk B.-C., 1989
Basic Structure of a Proposed Building Product Model
Computer-Aided Design, vol. 21, no. 2, pp. 71-78

Björk, B.-C., 1994
The RATAS project-an example of cooperation between industry and research towards computer integrated construction
ASCE Journal of Computing in Civil Engineering, vol 8, no. 4, pp. 401-419

Björk B.-C., 1995
Requirements and information structures for building product data models
Doctoral dissertation, VTT publication 245, Technical Research centre of Finland, Espoo

Björk, B.-C., Löwnertz, K., Kiviniemi A., 1996
ISO 13567- the proposed international standard for structuring layers in computer aided building design
In: Turk, Z, (ed) *Construction on the Information Highway,* Proc. CIB W78 and TG10 workshop in Bled, Slovenia, June 10-12, 1996, pp. 77-88

Bröchner, J., 1995
Feedback from facilities management to design and construction-system issues
In: Langford, D. A. and Retik, A. (eds.) Managing Construction Information, E&FN Spon, London, pp. 238-246

CIMsteel, 1998
CIMsteel on the Internet
WWW-CIMsteel, http://www.leeds.ac.uk/civil/research/cae/cimsteel/Cimsteel.htm

Davenport, H. T., 1993
Process Innovation. Reengineering Work through Information Technology
Harvard Business School Press, Boston

Dell'Isola, A. J., 1973
Value engineering in the construction industry
Construction Publishing, Washington

Dym, C. L., Levitt, R. E., 1991
Knowledge-based Systems in Engineering
McGraw-Hill, Inc., 1991

Eastman, C., 1992
Modeling of Buildings: Evolution and Concepts,
Automation in Construction, vol. 1 no. 2, pp. 99-109

Eastman, C. M., Assal, H., Jeng, T., 1995
Structure of a product database supporting model evaluation
In: Fischer M., Kincho H. L., Luiten B. (eds.) *Computers and information in construction,* Proc. CIB/W78/TG10 workshop, CIB proc. 180, Stanford University, pp. 327-337

Eastman, C., Augenbroe F., 1998
Product modelling strategies for today and the future
In: Björk B-C and Jägbeck A. (eds.) *The life-cycle of IT innovations in construction – Technology transfer from research to practice,* Proc. CIB W78 conference, June 3-5 1998 Stockholm, Royal Institute of Technology, Dept. of Construction Management, Stockholm

Ekholm, A., 1996
A conceptual framework for classification of construction works
Electronic Journal of Information Technology in Construction (Itcon), vol. 1, htpp://itcon.org/1996/2/

ELSEWISE, 1997
Home page for the ELSEWISE project
http://www.lboro.ac.uk/elsewise/index.html

Enkovaara E. Salmi, M., Sarja A., 1988
RATAS project - computer aided design for construction
Building book Ltd, Helsinki

European Commission, 1994
Strategies for the European Construction Sector- A Programme for Change
W S Atkins International Ltd, Office for Official Publications of the European Communities, Luxemburg

Fergusson, K. J., Teicholz, P., 1993
Impact of Integration on Industrial Facility Quality
Technical Report 84, Center for Integrated Facility Engineering, Stanford, CA, June 1993

Fischer, M., Betts, M., Hannus, M., Yamazaki, Y. & Laitinen, J., 1993.
Goals, dimensions, and approaches for computer integrated construction.
In: Mathur, K., Betts, M. & Tham, K.W. (eds.) *Management of information technology for construction*, Singapore: World Scientific Publishing & Global Publications Services, pp. 421–433

Fischer M., Luiten B., Aalami F., 1995
Representing project information and construction method knowledge for computer aided construction management
In: Fischer M., Kincho H. L., Luiten B. (eds.) *Computers and information in construction,* Proc. CIB/W78/TG10 workshop, CIB proc. 180, Stanford University, pp. 404-414

Fischer, M., Aalami, F., 1995
Scheduling with Computer-Interpretable Construction Method Models
CIFE Working Paper, Center for Integrated Facility Engineering, Stanford, CA, June, 1995

Fischer, M., Froese, T., 1996
Examples and Characteristics of Shared Project Models
Journal of Computing in Civil Engineering, Vol. 10, No. 3, July 1996, pp. 174-181

Fowler, C. E. A., Palmer, S. J., 1997
Business process re-engineering timber engineered structures: a feasibility study
In: Mohamed S. (ed) *Construction Process Reengineering*, Proc. International Conference on Construction Process Reengineering, Gold Coast, Queensland, Australia, July 14-15, 1997, Griffith University, Queensland, Australia

Froese, T., 1992
Integrated Computer-Aided Project Management Through Standard Object-Oriented Models
Ph.D. thesis, Dept. of Civil Engineering, Stanford University, Stanford, Ca, USA

Froese T., 1996
Models of Construction Process Information
ASCE Journal of Computing in Civil Engineering, Vol. 10, No. 3, pp. 183-193

Froese T., 1998
Developing Data Standards for Construction--An IAI Perspective
In: Björk B-C and Jägbeck A. (eds.) *The life-cycle of IT innovations in construction – Technology transfer from research to practice,* Proc. CIB W78 conference, June 3-5 1998 Stockholm, Royal Institute of Technology, Dept. of Construction Management, Stockholm.

Gielingh, W. ,1988
General AEC reference model
ISO TC 184/SC4/WG1 doc. 3.2.2.1, TNO, BI-88-150 Delft

Giertz, L.-M., 1995
Integrated Construction Information Efforts Since 1945
In: Brandon, P. And Betts, M. (eds.), Integrated Construction Information, E&FN Spon, London, pp. 101-116

Globeman 98
IMS/Globeman project on the Internet
http://toyo-eng.co.jp/

Green, S. D., 1992
A SMART methodology for value management
The Chartered Institute of Building, Occasional paper no.53, Ascot, United Kingdom

Green, S. D., 1994
Beyond value engineering: Smart value management for building projects
International Journal of Project Management, vol 12 no 1, 1994, pp. 49-56

Grilo, A., Betts, M., Clark, A., Mateus, M., 1995
Effective managing the construction network: the enabling role of IT
In: Fischer M., Kincho H. L., Luiten B. (eds.) *Computers and information in construction,* Proc. CIB/W78/TG10 workshop, CIB proc. 180, Stanford University, pp. 66-75

Hannus, M., Heikkonen, A., Laitinen, J., 1996
Internet in construction projects and research
In: Turk, Z, (ed) *Construction on the Information Highway,* Proc. CIB W78 and TG10 workshop in Bled, Slovenia, June 10-12, 1996, pp. 265-272

Hannus, M., Karstila, K., Serén, K.-J., 1995
Generic product data model for product data exchange – Requirements, model and implementation
In: Pahl, P.J. & Werner, H. (eds*.) Sixth International Conference on Computing in Civil and Building Engineering VI-ICCCBE*, Berlin 12–15 July 1995. Vol. 1. Rotterdam: A.A. Balkema, pp. 283–290

Huovila, P., Lakka, A., Laurikka, P., Vainio, M., 1995
Involvement of Customer Requirements in Building Design
In: 3rd International Workshop on Lean Construction, Albuquerque, October 16-18, 1995

IAI 1997
IFC Object Model, Release 1.5
In: CD-ROM, Industry Foundation Classes Release 1.5 – IAI Members CD, International Alliance for Interoperability

IAI (International Alliance for Interoperability), 1998
Defining a Universal Language for Collaborative Work in the Building Industry
http://www.interoperability.com/ (1998 March 15th)

Institution of Civil Engineers, 1996
Creating Value in Engineering
Thomas Telford Publishing, London

ISO 1993a
Product Data Representation and Exchange - Part 1:
Overview and Fundamental Principles
ISO DIS 10303 TC 184/SC4, Geneva: International Organisation for Standardisation

ISO 1993b
Product Data Representation and Exchange - Part 11:
The EXPRESS Language Reference Manual
ISO DIS 10303 - 11, TC 184/SC44 N151, Geneva: International Organisation for Standardisation

ISO 1993c
Product Data Representation and Exchange - Part 21:
Clear Text Encoding of the Exchange Structure
ISO DIS 10303 - 21, TC 184/SC4, Geneva: International Organisation for Standardisation

ISO 1996a
Product Data Representation and Exchange - Part 225:
Application Protocol: Building Elements Using Explicit Shape Representation
ISO CD 10303 - 225, TC 184/SC4 Working Paper N338, Geneva: International Organisation for Standardisation

ISO 1996b
Product Data Representation and Exchange - Part 230:
Application Protocol: Building Structural Framework: Steelwork
ISO/TC184/SC4/WG3 Working Paper N486, Geneva: International Organisation for Standardisation

ISO 1996c
Product Data Representation and Exchange - Part 106:
Building Construction Core Model
ISO/TC184/SC4/WG3 Working Paper N496, Geneva: International Organisation for Standardisation

ISO 1997
Organisation of Information about Construction Works - Part 2:
Framework for Classification of Information
ISO/TC59

Jägbeck, A., 1996
PreFacto - A Construction Management Tool Using Product Model Data,
In: Kumar, B. and Retik, A. (eds.). Information representation and delivery in Civil and Structural Engineering Design, Proceedings of ITSCED '96 in Glasgow 14-18th August 1996. Civil-Comp Press, Edinburgh, pp. 199-207

Jägbeck, A., 1998
IT support for construction planning- A system design based on integrated information
Ph.D. thesis, Royal Institute of Technology, Stockholm

Karhu, V., 1997
Product Model Based Design of Precast Facades,
Licentiate thesis, Royal Institute of Technology, Department of Real Estate and Construction Management, Stockholm

Karhu, V., Keitilä, M., Lahdenperä, P., 1997
Construction process model- Generic present-state systematisation by IDEF0
Technical Research Centre of Finland, VTT Research notes 1845, VTT, Espoo, 1997

Karstila, K., 1997
The Use of STEP Product Data Technology in Two AEC Pilot Projects
In: *Computers in the Practice of Building and Civil Engineering,* Proc. Worldwide ECCE Symposium, Lahti, Finland, September 3-5, 1997, Association of Finnish Civil Engineers

Katajamäki, M., 1991
Knowledge Based CAD
In: Expert systems with applications, vol 3, Pergamon press Plc, USA, 1991, pp. 277-287

Kirk, S. J. , 1998
Value Management Integration in the Design-Build Process
In: Vogl, O. J. (ed) SAVE International Annual Conference
SAVE International, Washington, D.C., June 14-17, 1998, USA, pp. 218-223

Konchar, M. D., Sanvido, V. E., Moore, S. D., 1997
The benefits of design-build contracting in the United States
In: Mohamed S. (ed) *Construction Process Reengineering*, Proc. International Conference on Construction Process Reengineering, Gold Coast, Queensland, Australia, July 14-15, 1997, Griffith University, Queensland, Australia

Koskela, L., 1992
Application of New Production Philosophy to Construction
Technical Report 72, Center for Integrated Facility Engineering, Stanford, CA, September, 1992

Koskela, L., 1997
Lean production in construction
In: Alarcón, L. (ed.) *Lean Construction*, A.A.BALKEMA, Rotterdam, 1997, pp. 1-10

Kulusjärvi, H.,1996
Engineering towards knowledge based solutions
In: *Produktmodeller -96*, Linköping, November 12-13, 1996

Lahdenperä, P., 1995
Reorganizing the building process, The holistic approach
Ph.D. thesis, Technical Research Centre of Finland, VTT Publications, 258, Espoo 1995

Laitinen J., 1995
Model based cost engineering as a basis for the management of construction process
In: Fischer M., Kincho H. L., Luiten B. (eds) *Computers and information in construction*, CIB/W78/TG10 workshop, CIB proceedings 180, Stanford University, pp. 435-494

Latham, M. Sir, 1994
Constructing the Team
Joint Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry
DDP Services, July 1994

Lautanala, M., 1997
A process approach to design for construction
In: Alarcón, L. (ed.) *Lean Construction*, A.A.BALKEMA, Rotterdam, 1997, pp. 237-248

Law, K. H., 1992
Managing Design Information in a Shareable Relational Framework
CIFE Technical Report, 60, Center for Integrated Facility Engineering, Stanford, CA, January, 1992

Lippus, A. C., 1995
Enhancement of Sow Housing Design by the Use of Knowledge Based CAD
In: 2nd IFAC/IFIP/EurAgEng Workshop on “Artificial Intelligence in Agriculture”, May 29-31, 1995

Love, P. E. D., Mohamed, S., Tucker, S. N., 1997
A conceptual approach for re-engineering the construction process
In: Mohamed S. (ed) *Construction Process Reengineering*, Proc. International Conference on Construction Process Reengineering, Gold Coast, Queensland, Australia, July 14-15, 1997, Griffith University, Queensland, Australia

Lucardie, G. L., 1994
Functional object-types as a foundation of complex knowledge-based systems
Disertation TUE

Luiten G., Froese T., Björk B.-C., Cooper G., Junge R., Karstila K., Oxman R., 1993
An Information Reference Model for Architecture, Engineering, and Construction
In: Mathur K., Betts M., Tham K. (eds.) *Management of Information Technology for Construction*, World Scientific & Global Publication Services, Singapore, pp. 391-406

Luiten, G. T., 1994
Computer Aided Design for Construction in the Building Industry
Ph.D. thesis, Delft University of Technology

Luiten, G. T., Fischer, M., 1995
SPACE CAKE, System for Project Management in Civil Engineering using Computer-Aided Knowledge Engineering
CIFE Working Paper, Number 40, Center for Integrated Facility Engineering, Stanford, CA, May, 1995

Marca, D. A., McGowan, C. L., 1987
SADT-structured analysis and design technique
New York, McGraw-Hill

Miles, L. D., 1972
Technigues of Value Analysis and Engineering
McGraw-Hill, New York

Miyatake, Y., Yamazaki, Y., Kangari, R., 1992
Current Status of Computer Integrated Construction in Shimizu Corporation
In: Preproceedings Björk, B.C. and Hannus, M. (eds) *Frameworks for Computer Integrated Construction*
Technical Research Centre of Finland, Espoo

Mohamed, S., 1997
BPR Critic-CPR Advocate
In: Mohamed S. (ed) *Construction Process Reengineering*, Proc. International Conference on Construction Process Reengineering, Gold Coast, Queensland, Australia, July 14-15, 1997, Griffith University, Queensland, Australia

Oinas, M., 1998
The utilisation of product model data in production and procurement planning
In: Björk B-C and Jägbeck A. (eds.) *The life-cycle of IT innovations in construction – Technology transfer from research to practice*, Proc. CIB W78 conference, June 3-5 1998 Stockholm, Royal Institute of Technology, Dept. of Construction Management, Stockholm

Oinas, M., Myllymäki, R., Laitinen, J., 1997
A New Approach to Integration of Design and Production
In: *Computers in the Practice of Building and Civil Engineering,* Proc. Worlwide ECCE Symposium, Lahti, Finland, September 3-5, 1997, Association of Finnish Civil Engineers, RIL

Paulsson, B., Appelqvist, I.; Bengtsson, K. and Tarandi, V., 1990
Produktionsanpassad mängdavtagning MCAD
[Drawing up Bill of Quantities Using CAD], Byggforskningsrådet R14:1990, Council for Building Research, Stockholm

Penttilä, H., Tiainen, P. and Hult, S., 1991
RATAS - Building Product Model Prototype. Quantity Take Off from a Building Product Model Representation of Design Data
Conference proceedings from ARECDAO 1991, ITEC, Barcelona, Spain

PM Glossary 1996
Product modelling glossary on the Internet
http://www.vtt.fi/cic/service/glossary/glossary.html

Rezgui, Y., Cooper, G., Björk, B.-C., Bordeau, M., 1997
From Construction Product Information to Consistent Project Documentation: the CONDOR approach
In: Drogemuller, R., (ed) *IT Support for Construction Process Reengineering,* Proc. CIB W78 and TG10 workshop in Cairns, Queensland, Australia, July 9-11, 1997, pp. 337-346

Rezgui, Y., Debras, P., 1996
An Integrated Approach for a Model Based Document Production and Management
Electronic Journal of Information Technology in Construction, Vol. 1 (1996), http://itcon.org/1996/1/ pp. 1-21

Riitahuhta, A., Salminen, V., Aho K., 1993
PRODEAL, Technology Program for the Development of Process Plant Construction
In: Proceedings *of International Conference on Engineering Design ICED -93*, The Hague, August 17-19, 1993, pp. 405-414

RTS 97
Building Information Institute- Annual Report 1997
Building book Ltd, Helsinki

Rumbaugh, J., Blaha, M., Premerlani, W., Eddy. F. and Lorensen, W., 1991
Object-Oriented Modeling and Design
Prentice-Hall, Englewood Cliffs, New Jersey, USA

Saarnivaara, V-P., 1990
Information technology as a tool for industrialised construction systems and processes
In: *2nd Finnish-French collogium for information technology in construction*
VTT Symposium 118. Technical Research Centre of Finland, Espoo, Finland

Saarnivaara, V.-P., 1997
User-oriented industrialised construction as a stretegic target in Finland
In: Mohamed S. (ed) *Construction Process Reengineering*, Proc. International Conference on Construction Process Reengineering, Gold Coast, Queensland, Australia, July 14-15, 1997, Griffith University, Queensland, Australia

Salmi, M., 1995
Computer Integrated Building Information
In: UICB seminar October 30, Lyon, France

Sanvido, V. E., 1990
An Integrated Building Process Model
Technical Report No 1, The Pensylvania Sate University, Department of Architectural Engineering, January 1990

Sanvido, V., 1995
From modelling to applications
In: Brandon, P. And Betts, M. (eds.) Integrated Construction Information, E&FN Spon, London, pp. 278-288

SB-Rekommendationer 1997
BSAB 96. System och tillämpningar
[BSAB 96. System and Applications], Swedish Building Centre, Stockholm

Schenck, D. and Wilson, P., 1994
Information Modelling the EXPRESS Way
Oxford University Press, Oxford, UK

Schmitt, G., 1993
Case-Based Reasoning in an Integrated Design and Construction System
In: Mathur K., Betts M., Tham K. (eds.) *Management of Information Technology for Construction*, World Scientific & Global Publication Services, Singapore, pp. 453-465

Serén, K.-J., Hannus, M., Karstila, K., Kihlman, M. and Pellosniemi, J., 1993
Object-Oriented CAD Tool Implementations for the Construction Industry
VTT Research Notes 1460, Laboratory of Structural Engineering, Technical Research Centre of Finland, Helsinki, Finland

Serén, K.-J., Hannus, M., Laitinen J., 1996
Integrated Design and Planning in Building Projects-System architecture, Implementation and Experiences
In: Kumar, B. and Retik, A. (eds.). Information representation and delivery in Civil and Structural Engineering Design, Proceedings of ITSCED '96 in Glasgow 14-18th August 1996. Civil-Comp Press, Edinburgh

Serpell, A., Wagner, R., 1997
Application of Quality Function Deployment (QFD) to the determination of the design characteristics of building apartments
In: Alarcón, L. (ed.) *Lean Construction*, A.A.BALKEMA, Rotterdam, 1997, pp. 355-363

Seymour, D., Crook, D., Rooke, J., 1997
The role of theory in construction management: a call for debate
Construction Management and Economics (1997) 15, pp. 117-119

Smith, I., 1996
Augmenting design integration and communication using idiom
In: Turk, Z, (ed) *Construction on the Information Highway,* Proc. CIB W78 and TG10 workshop in Bled, Slovenia, June 10-12, 1996, pp. 467-478

Storer, G., Los, R., 1997
Taking Control of the Building Process
European Conference for Industrial use of Product Data Technology, CSTB, Sophia Antipolis, France, April 1997

Svensson, K., 1998
Integrating Facilities Management Information- A Process and Product Model Approach
Ph.D. thesis, Royal Institute of Technology, Stockholm

Tarandi V., 1998
Neutral, Intelligent CAD Communication – information exchange based upon a minimal schema
Ph.D. thesis, Royal Institute of Technology, Stockholm

Tiula, M., 1993
Construction 90, Element classification in the control process of the Finnish construction industry
Building Information Institute, ICSA meeting, Alexandria, March 1993

Tolman, F., 1991
Some Integration Requirements for Computer Integrated Building,
In: Pre-proceedings of the CIB W78 seminar *The Computer Integrated Future*, Eindhoven University of Technology, The Netherlands

Tolman, F., Böhms, H. M., Nederveen, G. A. van, Bakkeren, W. J. C., 1994
LSE Project type Model, version 1.0
ESPRIT 7280-ATLAS, final public, D-106-I, TNO, Delft

Tupamäki, O., 1997
Future Construct
RTD Strategies for European Construction, Villa Real Ltd/SA, Helsinki, March 1997

Turk, Z., Wasserfuhr, P., Katranuschkov, P., Amor, R., Hannus, M., Scheerer, R., 1997
Conceptual Modelling of a Concurrent Engineering Environment
In: *1st International Conference on Concurrent Engineering in Construction*, London , UK, 3-4- July, 1997

Vahala, P., 1997
Tiedonsiirto kiinteistönpidossa (data exchange in facilities management)
Rakennuksen tuotemallin siirtäminen kiinteistönpitomalliksi, pilottina ICL Data Oy:n toimitalo (in Finnish)
TALO 90 ryhmä, Rakennustieto Oy, 1997

Van Nederveen, S., 1993
View integration in building design
In: Mathur, K., Betts, M. & Tham, K.W. (eds.) *Management of information technology for construction.* Singapore: World Scientific Publishing & Global Publications Services, pp. 209–221

Vanier, D. & Turk, Z., 1994
WAN opportunities for distributed construction information
In: Karstila, K. (ed.) *CIB W78 Workshop on Computer Integrated Construction*, Pre-Proceedings, Helsinki 22–23 Aug. 1994. Espoo: Technical Research Centre of Finland & International Council for Building Research Studies CIB

VERA 1998
VERA programme on the Internet
http://www.tekes.fi/english/programm/prod/vera

Vos, C. J., Buvelot, R., 1995
Development of Knowledge-Based Systems Cofferdams
In: Knowledge Support Systems in Civil Engineering, IABSE Colloquium, Bergamo, 1995

Walker, D. H. T., 1997
Choosing an appropriate research methodology
Construction Management and Economics (1997) 15, pp. 149-159

Watson, A., 1995
To Product Models and beyond
In: *Integrated Construction Information* (eds. Brandon, P., and Betts, M.) London, E&F Spon

Wittenoom, R., 1995
Use of Draft ISO 13584 Parts Library Standard for Design Decision Support
In: Fischer M., Kincho H. L., Luiten B. (eds.) *Computers and information in construction,* Proc. CIB/W78/TG10 workshop, CIB proc. 180, Stanford University, pp. 339-347

Yamazaki, Y., 1990
Integrated design and construction planning system for computer integrated construction
Preproceedings of the *Computer Integrated Construction*, CIB Working Groups W78 and W74, Architectural Institute of Japan, Tokyo

YIT Corporation, 1998
YIT Corporation on the Internet
http://www.yit.fi

Yusuf, K., Smith, N. J., Tizani, W., Nethercot, D. A., 1997
Enabling Technologies in Integrating Design and Construction
In: Drogemuller, R., (ed) *IT Support for Construction Process Reengineering,* Proc. CIB W78 and TG10 workshop in Cairns, Queensland, Australia, July 9-11, 1997, pp. 337-346

LIST OF FIGURES