# CONCURRENT ENGINEERING IN THE TENDERING PROCESS OF BUILDING & CONSTRUCTION

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***CONCUR*** *(Concurrent Design and Engineering in Building and Civil Engineering) is a four year initiative in the European Union* ***Brite-EuRam*** *workprogramme involving industry partners* ***Skanska*** *(Se),* ***IVO Power Engineering*** *(Fi) and* ***Taylor Woodrow*** *(UK), the specification body* ***STABU*** *(Nl), R&D institutions* ***VTT*** *(Fi) and* ***TNO*** *(Nl), and universities* ***DUT*** *(Nl) and* ***KTH*** *(Se). The project will develop, implement and industrially deploy an integrated CAx environment for concurrent construction tendering.*

*CONCUR is addressing the integration of information in the stages which lead to submission of tenders. The goal is to reduce tendering cost by 30 - 50% using integrated information systems and applications. The tendering process is a complex process involving many disciplines each of which uses different types of information. . In essence it is an information refinement process, in each refinement cycle addressing the high risk aspects of the moment.*

*In CONCUR we are addressing the integrated use of information and applications, using Project (Product and Process) Data Technology Using the major informational items the refinement process will come to information specifications. The specifications being derived are not re-invented but use is made of existing and emerging standards such as STEP and IAI. Results of the CONCUR efforts can be fed back to STEP and IAI.*

*This paper will present the methods and findings of the first year's work of the project – the combined description of process and information flows.*

## INTRODUCTION

The main aim of CONCUR is to develop an information exchange platform that will allow contractors, individually and in consortiums, to handle project information needed in the first phases of a construction project meaning information covering the aspects and detail level used from inception to tender. The work is divided into four years (1997-2001) focussing on respectively: 1) defining information and integration requirements, 2) defining an information and software integration procedure, 3) developing and testing information exchange and 4) developing and testing integration of information. (Storer et. al. 1998). The project involves not only industrial partners (constructors) and researchers developers but also software houses willing to participate in this development.

At the moment the first year’s work has been finished. This paper will mainly discuss the process and methods of modelling the information requirements leaving out the project’s implementation strategies.

## CONCUR MODELLING METHOD

The CONCUR approach to project integrated information is not to develop still another candidate for a standard model but adapt and use existing and emerging standards to the industrial partners’ business needs. Thus the first step has been to define those business needs, i.e. the scope of the process, both for each partner individually and in case of a possible co-operation in construction projects. The second step has been to define the processed by which information is created and refined. The third step has been to define the information aspects and objects handled in the various steps.

In several meetings with practitioners information was to capture work practice (process analysis). We looked for the main activities they were responsible for, which were then used to develop a first level process model. The process model was used to expand the analysis to refine work practice into two or three levels of detail. Questions, as listed below, were used to establish broad principles for work practice. On the left hand are the asked questions and on the right hand the information being sought.

| Question | to identify |
|---|---|
| what do you do? | activities |
| why do you do it? | decisions |
| how do you do it? | procedures |
| what do you need to know to do it? | information needs |
| what help do you use? | tools |
| what bottlenecks do you usually meet? | improvement |
| how might you solve the bottlenecks? | way to improve |

*Table 1.: Topics discussed during information elicitation*

## Integrated modelling

Integrated modelling addresses the various models not independently but includes the individual relations. It also looks at existing models and tries to position them in the CONCUR environment. Integrated models including processes, information semantics and information content are necessary to enable an integrated work practice sharing and using the same data. The most challenging issue has been to devise a way to capture, define, develop and maintain a consistent view of the business scope, business processes, information aspects, information objects and information flows.

CONCUR needs two-way semantic information exchange about building projects. To do so CONCUR will use and implement existing models and concepts, based on a common terminology, common semantics and definitions. In CONCUR modelling has been done to identify activities, which are carried out during tendering by the industrial partners to capture work practice and information. We identify the (physical) objects of interest (ooi) which practitioners use in tendering. Objects of interest denote the way practitioners look at a facility during the tendering process. Different views can be introduced when a proper product tree is available.

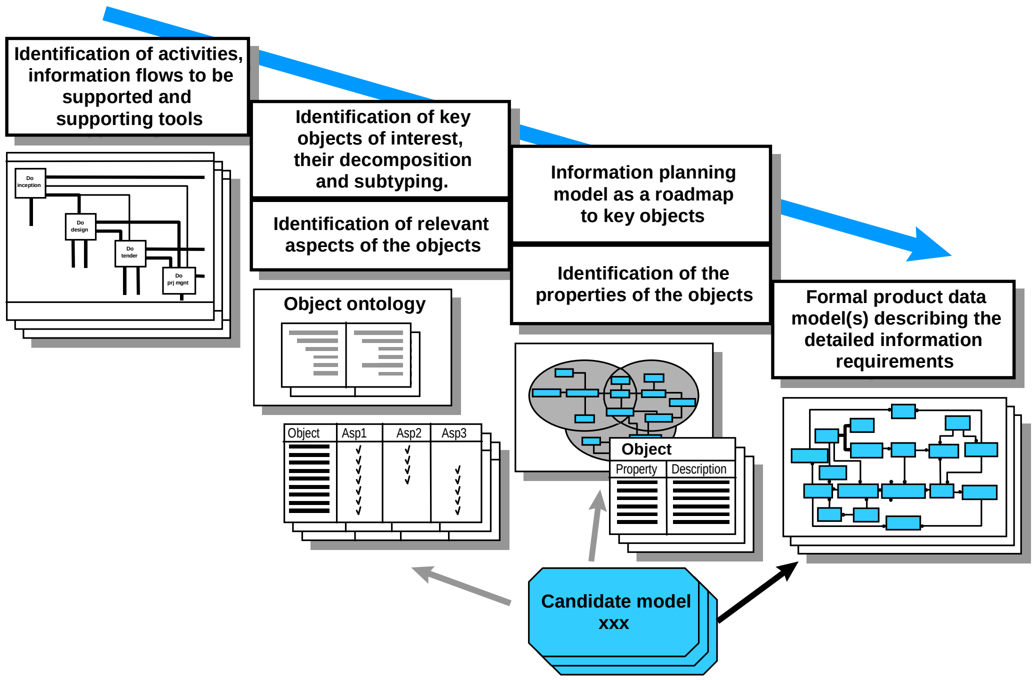


*Figure 1: Overall scoping and capturing steps of information requirements into a formal* product data model

## BUSINESS PERSPECTIVE

The first step in the requirement modelling process was to define the process scope and process the generic activities. This was done basically using the IDEF0 terminology. The first important effect was the opportunity to formulate and discuss the business process within each team and between the partners, a discussion of which the outcome is summarised below.

### Business change

In today's business environment clients and facility operators demand better quality, faster and cheaper built facilities incorporating more complex technology. At the same time, governments have increased the regulatory constraints on safety, waste and energy consumption. A changing world also induces changing ways of co-operation.

During the past decade a change in work practice has been identified. Two business directions can be distinguished: (1) with a low risk factor to the contractor and (2) with a high risk factor to the contractor. In the low contractor risk area a client more and more appoints a management consultant, who is knowledgable about the building process and acts on behalf of the client. Risk is largely commuted to the suppliers.

In the high risk area a change can be seen from traditional build only contracts, based on extensive specifications through design & build contracts to opportunity development processes.

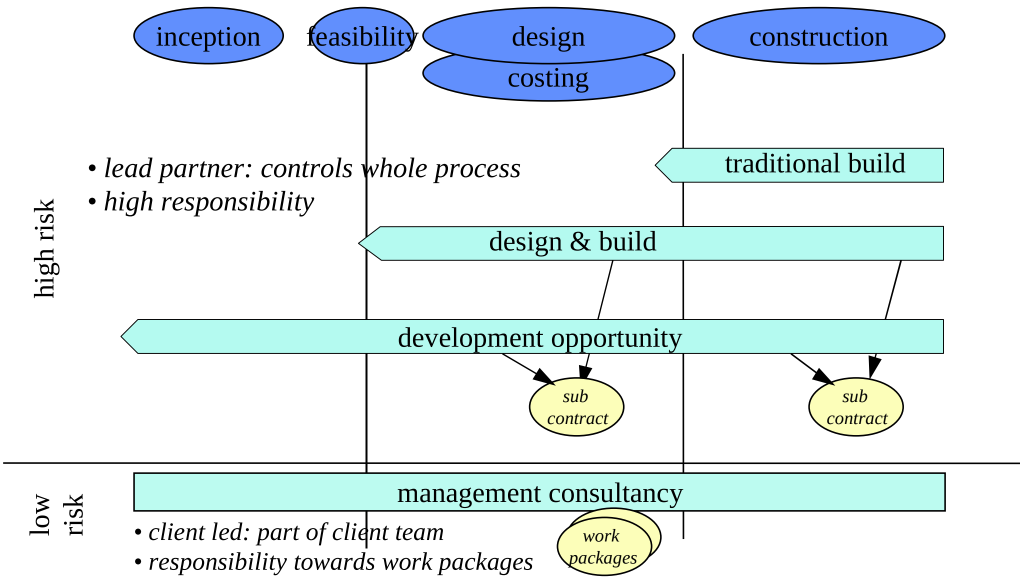


*Figure 2: Evolving from contractual labour provider to service provider*

In a development opportunityprocess, the contractor (more accurately: a contractor consortium) controls and manages the complete process. He accepts a higher than normal risk, which will be spread out between the consortium partners. The package may include providing finance for erecting and operating a facility. In this process the consortium is also responsible for sub-contracting the work to be done, ranging from preparing a specialist design part to the operation of a completed facility. The new approach has been motivated by a competitive market and by changing client views. Implications have been mainly contractual, but a number of implications of the use of IT can be seen. Ownership of information, responsibility and liability for information, are just examples of issues which will be raised and which need to be resolved before different ways of co-operation and collaboration will become common practice. This is the process the Concur industrial partners are aiming to support.

## Enablers for change

When change becomes imperative a number of ways to enable change and support the process are already available. Enablers can be separated into approach, where people are really working in a different way from a different perspective, and enabling technologies, which can be taken from other industries. Introducing and using enabling technologies is the purpose of CONCUR.

The challenge for CONCUR is in the area of integrating business processes with the latest views and insights in European research. Effectively this means that CONCUR will use existing and emerging results for implementation of its integration strategy.

## What is tendering

The result of CONCUR for the industrial partners is the implementation and use of integrated systems, spanning the early stages of the project life cycle: from inception to tender. This period of a project discusses business needs, try different solutions and design a selected one. Using integrated systems provides a consistent means of handling data and information, accelerates the process and acts as a basis for further work in construction, operation and decommissioning.

Our analysis in CONCUR revealed that the tendering process also changes. In conventional tendering for building projects an organisation received a detailed set of requirements and specifications for a facility, sometimes even containing detailed drawings. In CONCUR we leave the conventional notion of tendering based on a detailed description of the facility but we focus on the process ignoring a number of issues, like information ownership and authorship, differing or additional contractual obligations and changing responsibilities and liabilities.

A definite end of the tendering process cannot be given, it is all up to the client, and depends on the succeeding process. For the purpose of CONCUR we let the tendering process end with the formal approval or dismissal of the client based on an accurate costing and detailed planning. A typical tendering process therefor ideally involves all disciplines that have any relationship to the facility and also elaborates on the complete life cycle of the facility. The consortium talking to the client is much more than a construction preparations group. It will act as a trusted partner to the client.

## Objectives in tendering stage

The main objective of the tendering stage is the specification of a facility in such a way that the client has a reasonable accurate price and has a sufficiently accurate description of the facility to be constructed and the delivery time of the facility, in accordance to set requirements.

There are a number of bases to which people arrange the tendering process. As long as there is no contract to carry out work, a balance will exist between depth and detail, and effort. Despite the fact that decisions made early on might lead to large consequences in the remainder of the project.

A tender team needs to take care that a minimal amount of waste is produced. As waste we might think of the effort made and results produced in case a project does not lead to an order. On the other hand the team needs to assure that effort and results produced are sufficient to win the order. That this leads to tension may come as no surprise. A hit rate of 25% means that 75% of the time and effort spend on tendering is waste and must be recovered in some other way. Reducing the effort in the 75% which is lost will directly result in better margins. The first test of the team will be to assess the viability of the project and judge it on its merits for client and other participants. It may well come out that a proposal for a facility might look promising, but lacks viability because of huge ground prices. During the assessment of viability and feasibility work is done in close co-operation with the client and other (potential) partners in the consortium to enable sound value engineering.

The priority of the information gathering process is driven by the need to acquire more certainty and confidence. The first items to be refined, i.e. detailed, will be items that constitute risk or have high uncertainty. Building houses one would very much like to know whether the ground is heavily polluted which results in expensive cleansing operations, building a process plant one might care less. The team and the client together need to obtain confidence that a particular facility fulfils the business requirements of both parties and solves a problem to the client. Confidence will also be obtained or strengthened by producing a realistic construction programme with possible issues and bottlenecks clearly defined.

The tendering process is one of many decisions: shall we build a high rise or shall we remain shallow, shall we use glass cladding or wood planes, ... . What happens is that each action is aimed at providing information for the next decision. The tendering process therefore is in essence an information production process. An information production process that takes some bits of information and refine and refine until enough is gathered for a sound decision. In fact each decision is aimed at determining the viability, assessing and reducing risk, and eventually in calculating the cost. As tendering is a refinement process this also holds for the requirements. In each refinement cycle more will be known and more detail will be presented about the performance requirements of the building or product under design.

Today an electronic model of the product that is collaboratively arrived at will facilitate the communication between disciplines and with the client. It also enables keeping consistent information about the facility.

## PROCESS CHARACTERISTICS

### Common process model

One of the modelling activities in CONCUR was the synthesis of a more generic process model incorporating the joined efforts of the process analysis carried out. Producing the CONCUR Common Process Model was restricted by the observations earlier made resulting in a number of requirements for modeling and a modeling tool.

The selected approach focuses on systematic views on the project life cycle in stead of the more conventional phased approach. Phasing is the way a project is carried out usually also denoting contractual steps and obligations. The same type of information comes back in each phase but with a higher level of detail. More knowledge of what to build and how to build it is obtained in each phase. Depending on the type of project detailing various aspects takes place at different points in the project. This mainly depends on the amount of risk involved: trying to minimise risk and coping with uncertainty.

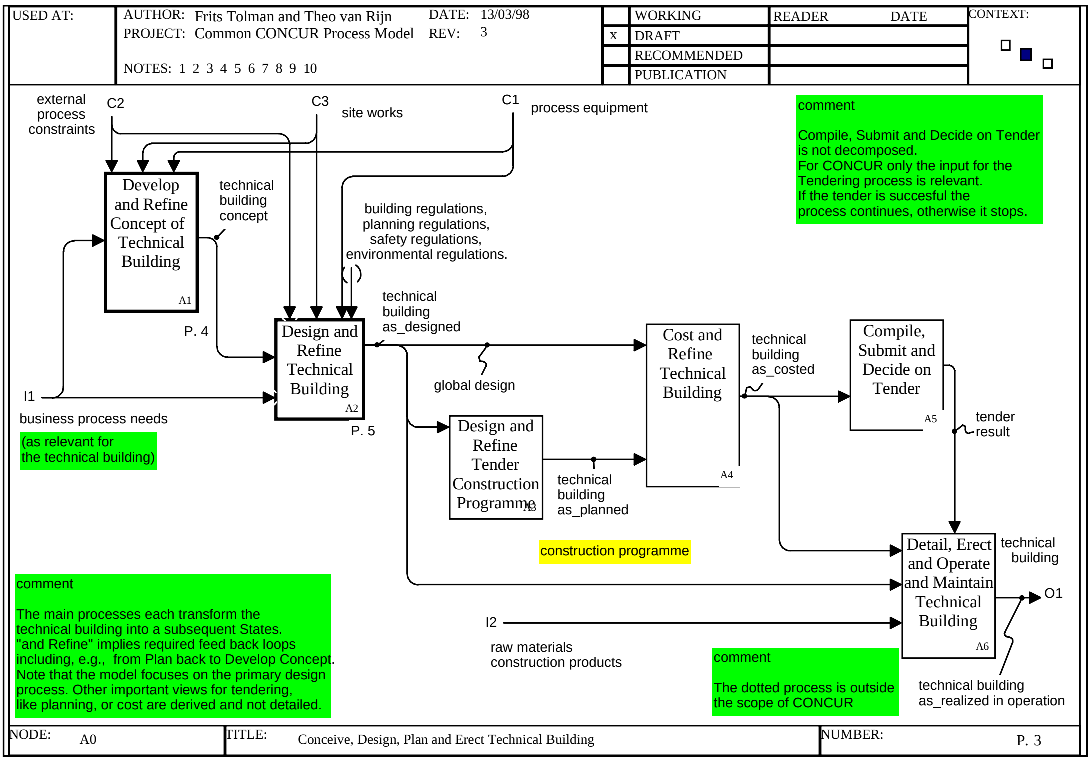


*Figure 3: Refine and detail example process diagram showing relation between design, time and cost.*

## Model viewpoint

Before one can judge about a model there are some restrictions to be known. Each representation of reality might be different, dependent on scope, purpose and viewpoint. Because many viewpoints exist in construction and in CONCUR, many different models might be constructed. Therefore the scope of modelling for CONCUR has been set to technical buildings with reference to interfacing the site surroundings and associated civil works, constraints imposed by heavy primary process equipment, and general building equipment (HVAC, installation, ...). The synthesised model supports the selection of software tools and enables collaboration amongst the partners. Furthermore the synthesised model assists identifying the major entities which are exploded into more and more detail during the project life cycle. So the purpose of the CCPM is to identify the common objects_of_interest (ooi) and common workflow used until a formal offer can be produced. Attention will be given to the various conventional information refinement stages: Inception, Global design and Scheme design.

## Sequential & fragmented

The tendering process in its origin is very sequential and fragmented. The different parties involved only look at their own discipline and are not really interested in the interface with other disciplines. This often leads to unfitting systems and much rework. In the event that feedback is provided it usually only goes back one step. The amount of work already done is too much to redirect focus to earlier steps. Rather than to start all over again (which in some cases might be the best solution) people learn to live with imperfection.

## Cost driven

One major driver in the tendering process, cost, is monitored and calculated almost continuously throughout the tendering process. Another major driver is performance specification. All activities are really aimed at trying to assess the actual price for a facility as accurate as possible subject to realising performances specified. The process therefore looks at breakdown of major cost items. Equipment for power plants, civil works for tunnels, … are identifying major cost components of a product.

People may not explicitly recognise how they work, but in most costing projects the cost will be eventually derived from a set of hierarchies or trees, which are used to derive associated cost.

A perception of a product model can be described in a product tree. Practitioners in CONCUR have described the product tree from the early costing point of view. Major elements of a product can be expressed in a way which helps them to carry out the tendering process, which is effectively detailing information in such a way that uncertainties can be reduced and risks can be dealt with. To enable detailed planning and estimation of effort and skills a production tree can be built. A production tree is similar, if not identical, to a work-breakdown structure, specifying activities and breaking them down into sub-activities.

In a similar way requirements and specifications may be broken down into their constituent parts. Architects design roughly top-down. Complex products, such as buildings and complex systems, are developed by first specifying the functional or performance requirements as a whole. Then a global solution will be created which in turn is composed of a set of smaller functional requirement problems. When no acceptable solution exists for a problem, the problem will be decomposed into a set of smaller problems. The functional unit (FU) states the requirements of a specific part of the building onto which several technical solutions (TS) can be matched. Stating the functional or performance requirement as “Transportation across a river” several TS-s might be considered, e.g., bridge, ferry and tunnel. Selecting a bridge one has to think of the functional requirements that a bridge constitutes: needs anchoring with the ground, needs roadworks, etc..

## Levels of the costing detailing process

The approach for the 1$^{st}$ level breakdown is to take 5 - 7 main elements and assess the cost. The next step is to detail each element in terms of breakdown and assess time, resource and cost which leads to a more accurate state. The particular way a parameter will be detailed or whether a next step breakdown is needed depends on the risk and uncertainty associated with the specific element.

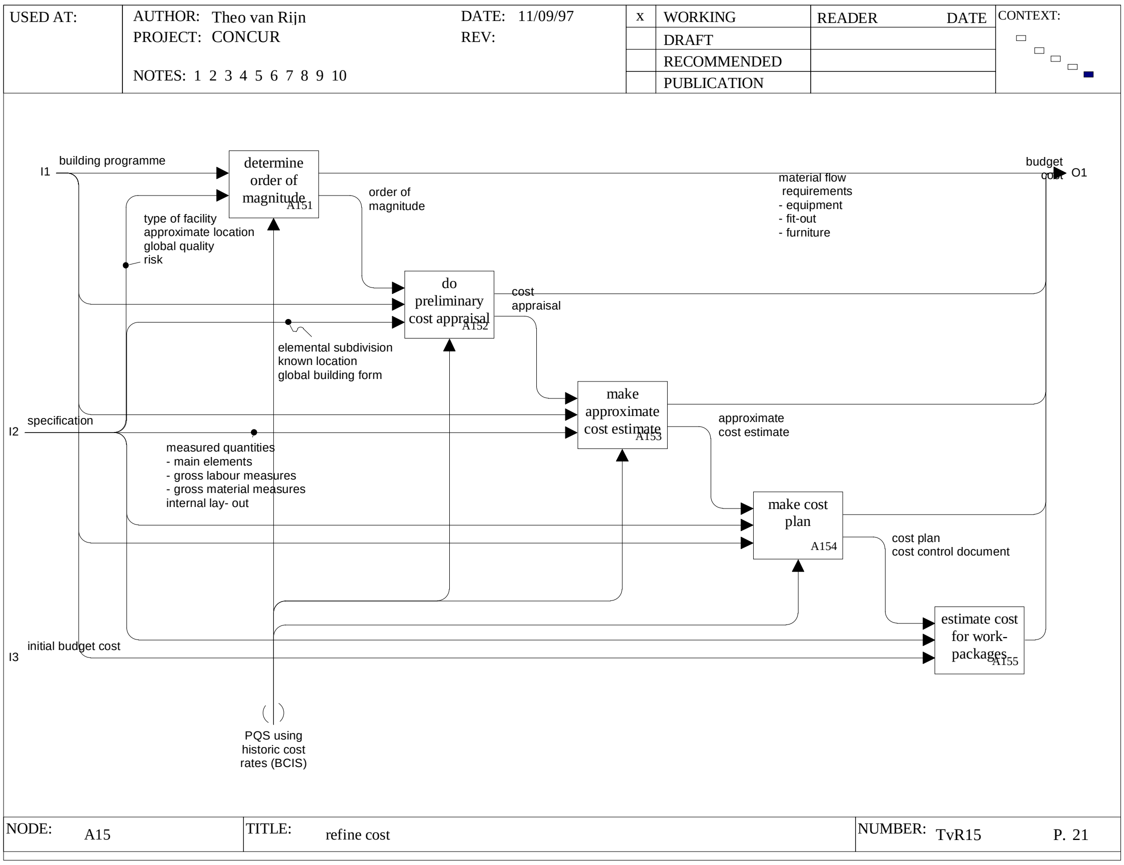


*Figure 4: Refining and detailing along cost axis.*

The cost detailing process closely resembles the staged approach. The difference with the staged approach however is the basis for the process, which is aimed at reducing uncertainty in stead of contractual obligations.

What was evident from early discussion was the cyclic nature of work in projects. Basically, the same tasks are undertaken at every stage in project evolution, but the degree of detail, the accuracy, the methods and the tools change. All design disciplines (including cost and planning) start by making broad assessments based on previous experience, progress to a slightly more refined assessment as more information and viewpoints are contributed, next into formal analysis and sizing (dimensions, capacities, costs as appropriate) based on the analysis results, then into detailing (precision) and finally specification (exactly what is to be done and how).

## Process modelling observations

Process modelling usually is the first step in the analysis phase before implementation of new IT. Regardless of the type of system to be introduced, it is important to obtain the work practice people use doing their job. The analysis of activities and work practice also involves looking at information, information flow and information content used to carry out activities and which are produced and detailed by activities. Careful examination of the processes and activities usually reveals signals for change. Where information is handed over many times without any addition of value might suggest useless activities. When many departments need the same information or information is moved back and forth between organisational units might suggest change.

A number of observations were made during process modeling:

- Conventional project stage definitions are too rigid. They are based on contractual obligations and aim at preparing contractual documents for hand-over between contract partners. Contractual models only have implications on the timing of the information availability, not the content itself. The content of each “stage” differs from project to project based on project specific critical aspects. As each next step is aimed at reducing risk and reducing uncertainty, items which bear high risk or have a high uncertainty are detailed first, thereby improving confidence in the proposed (designed) solution. As a consequence activities are cyclic - done in a circular fashion. Each next step in the tendering process is similar to the previous one. Primarily only the level of information detail changes in each cycle.
- Because of different types of projects carried out in construction industry (e.g. Build, ‘Design & Build’, ‘Private Finance Initiative’) imply the need to be able to enter a process model at different levels of detail. Irrespective of the entry point into a project, one needs to handle all existing information including how it was derived, i.e. what decisions were made.
- The very early project stages have the greatest impact on cost, time and quality (including functional performance), but occupy the shortest period of time with the smallest amount of resources.
- The process models were presented using the IDEF0 diagramming technique but the IDEF0 process modelling requires a simplistic view on work practice. Several scoping parameters need to be introduced to provide a specific context onto which modelling could be projected. Using IDEF0 in a generic manner we were unable to provide a meaningful set of diagrams in which the multi-axis (design, time, cost, status) relationship could be expressed in conjunction with multiple views, associated with the various disciplines and still capturing the cyclic, refining and detailing nature of the process. The possibility of using alternative aspect IDEF0-s would greatly benefit the understanding of work practice and information sharing and exchange.

## INFORMATION OBJECTS AND FLOWS

Information is used to communicate. To enable electronic communication one needs to identify the information used and needs to be communicated. During the process modelling activities some information modelling has already been done: globally identifying what information is needed and what is produced by activities.

Views associated with the disciplines involved in building and construction lead to different information entities. Information is associated with a functional system or unit, e.g., structural system, electrical system, spatial system. Each system has certain requirements to be derived from the use of the total product and the client perception. The functional units noted can be matched and implemented by technical solutions.

## CONCUR information ontology

CONCUR set the top level of a product tree, based on discussions with practitioners. A few levels of detail are added. The product tree will need to evolve into a complete product model. Modelling however is not the focus of CONCUR. But with insufficient existing material and standards for the tendering process, additional modelling work is done. CONCUR should use as many existing information models as possible. Therefore the information modelling activities are aimed at identifying the entities involved, i.e. what determines the product tree, and selecting from what existing model they might be taken. In a way that CONCUR will be able to compose its information model and use tools available for and associated with the models, e.g. AP221, IAA IFC 1.5, AP225.

Figure 5 shows the top level of the objects of interest which have been specified by the practitioners. The complete EXPRESS-G diagram also shows relations to IAI IFC 1.5 elements.

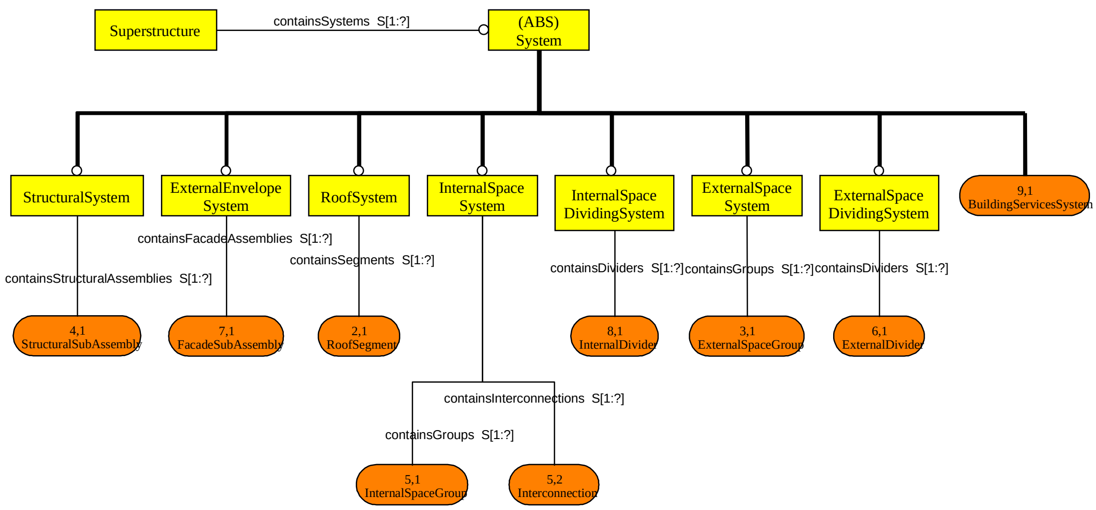


*Figure 5: CONCUR High level object of interest model*

## Information aspects

We use aspects to identify information needs in our discussions with practitioners. An **aspect** of an object describes (a collection of) distinct properties of an object. An aspect of an object may be represented in various ways by a collection of attributes. In other words, an aspect of an object is a grouping of object's attributes belonging somehow together and which are interesting enough to record information about. The role of aspects is to enable the capturing of relevant information grouped together which addresses a specific topic in relation to the object of interest.

Definition of the relevant aspects of interest of the objects is one step in the overall modelling process, and it serves the scoping of the modelling by providing some hints on what type of properties of the objects should be included in the product data model. The following addresses several aspects we may be interested in. The definitive list is under construction and will be reviewed shortly.

The main aspects of information are derived from the business process which specifies that the product cost and value to the client are the main outputs of the process. These are critical aspects for a project developer.

The value is derived from the product's specification and availability e.g. delivery time. The costs are derived from the size and terms of investment involved and the maintenance and operating costs. Both value and cost are thus dependent on the product specifications, on the production costs and the production time. Thus, the product description, the production cost and production time, are the basic information outputs needed.

Looking at cost one is only interested in quantities and unit cost to be able to calculate a price for the facility. This is true at any point in time in a project, irrespective of the level of detail of available information. The level of detail leads to a change in type of quantities and unit cost. Finishes are not priced individually at first but are part of the square meter price for office space. The actual cost estimates associated with the product and its realisation will be determined during the process. Deriving more accurate cost figures does not follow from increased knowledge. The set cost boundaries work as a balance. They imply that an increase in e.g. design complexity, which in turn will lead to a change in price, is followed by a balancing act: choosing a lesser price of material or supplier to decrease the total cost.

Several aspects, besides time and cost, can be derived from looking at a building from the associated viewpoints and in accordance to set requirements, e.g.: legislation, aesthetics, strength, safety, comfort, buildability, environmental impact. In the end the attributes contain the actual information values. Combining and grouping attributes provides the reader with the actual information he or she seeks.

## Benefits of integrated use of information during refinement steps

The sequential and fragmented nature of design precludes effective communications. Communications is aimed at covering specific parts of the design, rarely looking at the effect of decisions on other disciplines and other parts of the design. In many cases design planning is done backwards, i.e. start at the delivery date and count back when to start designing ones piece. Consequently the necessary feed-back will usually be too late and people will not go back to the appropriate activity because "We've spent this much, so we don't restart, but step back a little & live with it". This will inevitably lead to mismatch between systems and consequently a substantial amount of rework in subsequent stages. . And drawings are redone twice or three times by different parties involved, which leads to incorrect and inconsistent information.

Integrated use of a product model will be implemented using IT tools, e.g. a project database based on a product (data) model. Using integrated information and data sharing might condone the following benefits:

- consistent versions, preventing many rework activities
- one-time information creation
- accessible as needed
- many "views" can be derived
- clear responsibilities for information can be laid out

- used throughout facility life-cycle
- comparison between versions
- comparison of e.g. cost estimates and their refinement

## Observation in the information modelling process

Modelling work practice and associated information explicitly lays out the work that people are doing. Explicitly identifying work practice is the first step to cope with increasing complexity. Coping with ever increasing complexity using explicit work practice also enables the usage of tools. Explicitly described work practice leads to lists of activities, which will get a need for structure: the work breakdown structure. Growing lists of objects of interest will eventually lead to more complexity and hence a need for structure: the product tree.

Although many different views exist the product tree should only denote the more or less physical elements, which are of interest and for which attributes, i.e., information needs to be captured. The product modelling has suffers to some extent from the same problem as the process modelling, i.e. a one-dimensional sub-typing paradigm. This means for example that one needs to make a choice between several well motivated sub-typing principles such as function versus material or procurement manner (structural/non-structural wall versus concrete/wood wall or pre-fabricated/in-situ structure versus steel/concrete structure).

Discussing work practice and identifying processes practitioners talk about objects of interest, which are physical objects they use to establish business solutions: products and determine the associated cost. The CONCUR ontology lists objects of interest and definitions used by practitioners to communicate and exchange information. Based on different backgrounds the focus of the communication differs. Especially the content of the information one communicates. Different backgrounds lead to a difference in importance of informational items. The views associated with various disciplines involved lead to different information entities too.

## CONCLUSIONS

The business needs of the CONCUR industrial partners point to an information system that allows an increasing level of detail of information to be viewed from different aspects. Pre-defined levels of detail are expected to be helpful for information retrieval and sharing but the detailing levels of each process cannot be pre-defined. The product hierarchy is the central information object tree but it has to be viewed from different aspects, the main ones being performance relative to requirements and cost relative to value.

Information needs to be formatted for use in related integrated systems. Specifying the information for usage in multiple systems will soon lead to information bases, which are able to communicate with a multitude of systems. This means that a multitude of users have access to the same information. The next evolutionary step is the sharing of information: access to all information simultaneously with other project partners.

In CONCUR we will not be involved in extensive development of new systems, but will depend on existing, emerging, model based systems in co-operation with the software industry.

## REFERENCES


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

Storer G., Klintmalm L., Välikangas P., Woesteneck K., 1998, **Implementing Concurrent Engineering in the Tendering Process of Building and Construction**, in *Proceedings of the European Conference Product data Technology Days 1998*, 25-26 March, QMS, Sandhurst, Berkshire, UK

Mitrovic M., Male, S., Brohn, C, 1997, The Current LSE Industry, ESPRIT 20876 - ELSEWISE - public report

eLSEwise consortium members, 1998, The LSE Vision and Recommendations, ESPRIT 20876 - ELSEWISE - draft public report

Bakens W., et. al., 1997, Future organisation of the building process, CIB W82

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

ISO/TC184/SC4 (1994), **Part 221: Functional data and their schematic representation for process plants,** ISO CDC 10303 - 221, TC184/SC4

ISO/TC184/SC4, 1996a, **Part 106: Building Construction Core Model,** ISO/TC184/SC4/WG3 N496 (Also available online: http://www.tno.nl/instit/bouw/project/Bccm/bccmhome.html)

ISO/TC184/SC4, 1993a, **The STEP Standard,** Draft International Standard ISO/DIS 10303 (To be published in several different parts) ISO Technical committee 184

ISO/TC184/SC4 (1996b), **Part 225: Building Elements Using Explicit Shape Representation,** ISO CD 10303 - 225, TC 184/SC4 N338