

## 13. Design and Building Informatics Research

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### Keywords

Design and building informatics, product modelling, concept modellers.

### 13.1 Introduction

This paper gives an overview of current education, research and development activities of the design and building informatics group at Civil Engineering section of the Faculty of Civil Engineering and Geosciences, Delft University of Technology. The group also benefits from other informatics and IT research and development activities within the section such as application of artificial neural networks and decision support systems.

The Building Informatics group aims at contributing to the generation and dissemination of knowledge in the field of computational intelligence for design, building and construction systems. The group wants to bridge and integrate the disciplines building and civil engineering with informatics by means of research on complex design, building and construction systems. The theme of education and research of the group concerns the modelling of complex design and construction projects, that is the description of the end-result and intermediate stages of resulting facilities, the construction processes with the resources and controls and the supporting information and knowledge. Perhaps rightly we keep the subtitle of the theme as Building Design and Construction IT.

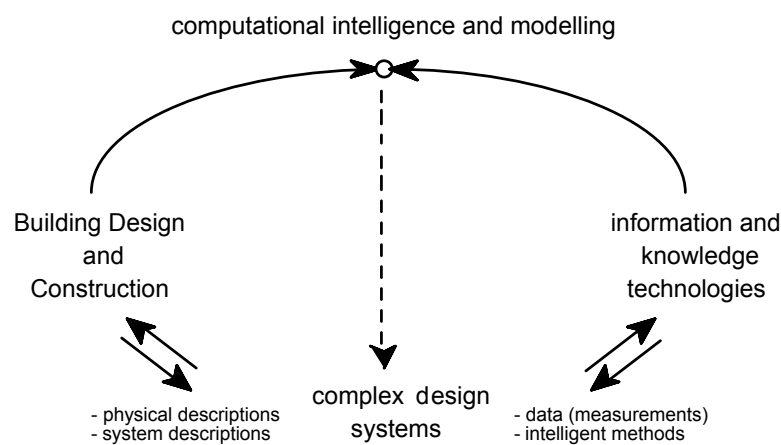


Figure 13.1: The scope of research of the Building Informatics group.

## 13.2 Nature of research

The group aims at performing:

- Fundamental research on design, building and construction modelling methods.
- Fundamental and applied research on method integration in modelling of complex design, building and construction systems.

The group encourages curiosity driven research with academic freedom within project aims.

### 13.2.1 Research aims

The aim is to contribute in three ways to building and civil engineering science:

- Contribute to new modelling methods.
- Contribute to integrated method modelling.
- Contribute to knowledge of physical phenomena by application of integrated method modelling.

The research is at such a level that it meets the international standards including:

- EU standards for large research projects.
- STW Technology Foundation.

The fundamental research orientation should meet the interest of science and academic community as well as professional parties in such a way that results are promising for further practical applications.

### 13.2.2 Object of research

The research of Building Informatics Group consists of modelling methods for complex building and civil engineering systems. The main research theme of the group is Building and Construction IT that concerns the modelling of complex construction projects, i.e. descriptions of the end-result and intermediate stages of resulting facilities, the construction processes with the resources and controls and the supporting information and knowledge.

Building and Construction is a sector of industry that has extreme difficulty in improving or even maintaining its competitiveness. Information, Communication and Knowledge Technology (ICKT) support is very relevant here. Improvements are sought for inter and intra project communication, reduction of cost of failure, multi-discipline design, engineering and construction, process quality and speed, robotics, integration issues and re-use of existing information and knowledge. The main questions under research are:

- Meaningful sharing and communication of electronic project data, information and knowledge. Communication standards like STEP, IFC, and XML. Concurrent and co-operative design, engineering and construction. Internet applications.
- Neutral modelling of artefacts and construction processes in different life cycle stages. Geometry and topology modelling. Simulation. Virtual Reality.
- Integration of multiple discipline views, information and knowledge. Object Trees.
- Knowledge modelling, sharing and exchanging. Multiple knowledge paradigm support. Re-use of knowledge and earlier designs and plans.

### 13.2.3 Methodology

In Building & Construction IT, integration also plays a major role. Here the emphasis is on integration of different partner roles, models and methods like product modelling, communication technology and knowledge engineering in order to cope with complex

systems. The research in this field is strongly driven by present and long term needs of the Building and Construction industry.

In both research themes some other methods are also used such as expert system technology, database technology, genetic algorithms, genetic programming and intelligent agent technology.

#### ***13.2.4 Co-operation***

In accordance with the bridging role of the research the group co-operates with other research groups in civil engineering and informatics. The orientation on method integration approaches is appreciated by both civil engineering groups and informatics groups. The co-operative initiatives from the informatics discipline within civil engineering lead to results that would not have been achieved otherwise.

The concentration of both hydro-informatics and Building & Construction IT in one group on the faculty has the advantage that researchers in the same methodological field stimulate and encourage each other and there is a better occasion for cross-disciplinary idea exchange. External co-operations have a national as well as an international nature.

#### ***13.2.5 Products***

Ph.D. theses, papers in scientific journals, papers in proceedings of conferences and reports about contract research results. The contract research products other than computer programs have been also been published in a scientific environment since the emphasis is on new modelling methods. The group organises and chairs among others the 8th EuropIA International Conferences on Advances in Design Sciences and Technology (April 2001).

#### ***13.2.6 Funding***

There has been a gradual shift in funding sources during the last five years. After a start with mainly contract research, the faculty recognised our results and provided some project funding. Later, because some 'past performance' had been achieved, national and European funds became available. By the end of the period a proposal for fundamental research, based on a ideas and results of the group, was written among others for the following:

- European Commission (EC: ATLAS, CONCUR, E-Construct).
- STW Technology Foundation.
- Delft Cluster.
- Directorate General for Public Works and Water Management.
- TNO Building and Construction Research.

#### ***13.2.7 The role of the research programme in the educational programme***

The impact of the research on masters' education has three aspects:

- Knowledge that is generated in the research is introduced in courses at higher level. This is especially the case of a fifth year course of the curriculum where advanced modelling and information systems are integrated into the curriculum.
- Tools that have become available as spin-off during the research are used in the fifth year's course of advanced applied informatics exercise of the section Civil Engineering informatics. Also, most products of the course are being initiated and used as educational tools by various courses at the faculty of civil engineering. Some of these products are used by various research projects such as a recent computer program developed as a tool for designing mooring systems for offshore platforms.

- During the final curriculum year students may choose their engineers thesis project within the research program of the group. This provides graduate students with the latest knowledge on design, building and construction ICT developments, which is useful for the research activities of the group as well as being valuable experience for students graduating with specialization in Building Informatics.

As impact on international masters education in the research co-operations have led to common courses of five European partners on modelling in the field of river design. The following universities participated in this experiment: universities of Cottbus (Germany), Grenoble (France) and Budapest (Hungary), IHE (Delft), TUD (Delft). In this courses students from different group countries are co-operating in the same exercises. The international teams communication via Internet, email and ftp. They run models that are located at one of research groups. This experiment is part of a research project on web-based virtual campus initiated by the group to design and develop among others distant learning and design tools using the latest available technologies (Beheshti).

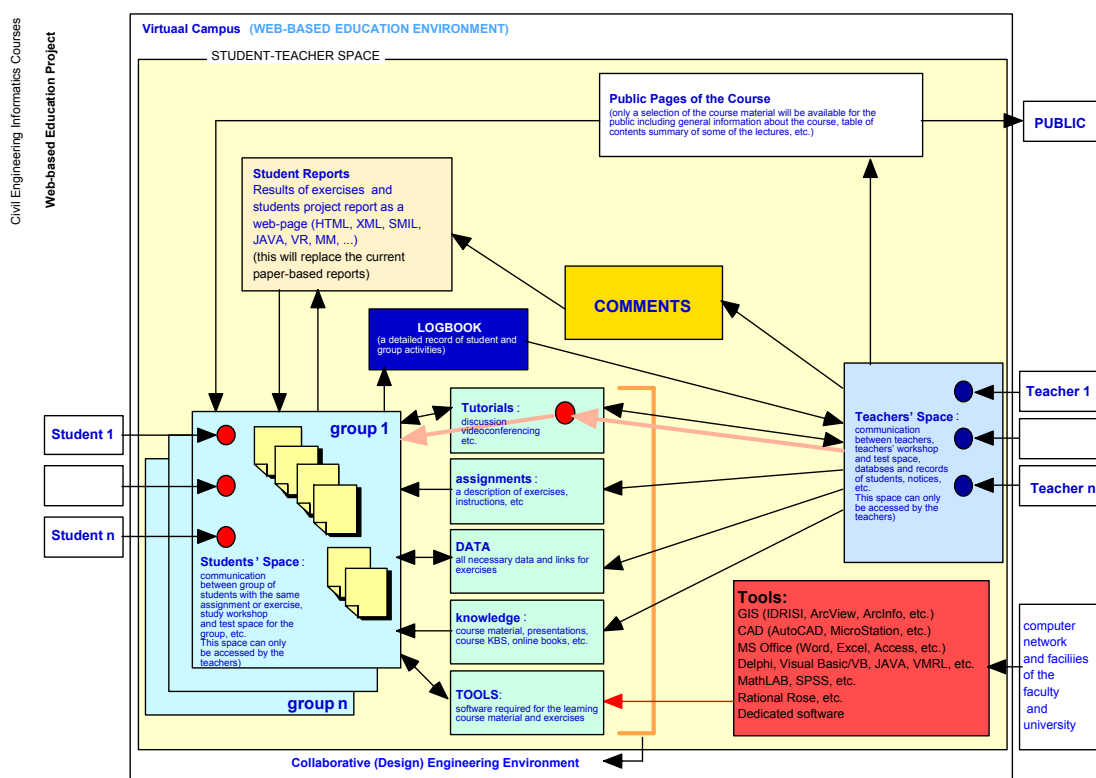


Figure 13.2: Web-based virtual campus.

An impact on PhD education in various groups is realised by our research seminars (ca. 10 times per year). Presentation and discussion between PhD students of different groups with a common interest in computational intelligence lead to exchange of knowledge between students.

The group contributes to PAO, an organisation for post-graduate education. In the lectures the state-of-the-art of research is presented, embedded in an overview of the fundamental and practical aspects of the methods that are covered.

### 13.3 Overview of academic results

The present research programme started five years ago. Collaboration with other research groups have been set up and intensified. Recognition has been gained in winning relevant European projects. Principal results obtained during the last five years are described below in order of the research aims.

The theme Building and Construction IT focuses on the modelling in complex building and construction projects. The current situation is that the knowledge of Communication Technologies for Building and Construction has deepened and that two PhD studies on Inception Support for large-scale Building & Construction projects could be started.

Research on costs aspects and the required multidiscipline knowledge structure dealt with conflicting knowledge from different sources. For that problem methods have been developed and a prototype tool was made that can handle multi-layer inception processes like (a) the inception of a power plant somewhere in a foreign country, (b) the inception of the power plant layout, (c) the inception of the turbine building.

Modelling methods for value aspects, both end-user values and general Building & Construction values have lead to a first prototype system for the inception of new or renovated Hospitals. Shortly a new PhD research project will start on the application and possibilities of XML technology for the building industry as part of e-Construct project (Tolman).

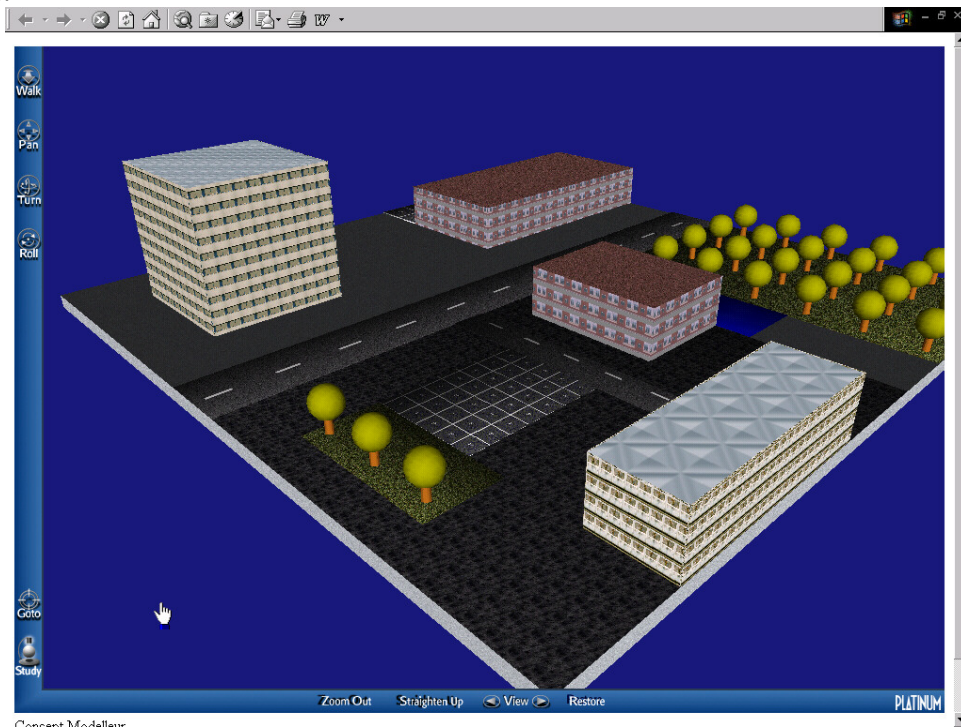


Figure 13.3: The conceptual design modeller for hospital design (Schevers).

A new theory called Neutral Object Trees has been developed for meaningful electronic communication in design, planning and realisation of complex Building and Construction projects. It is currently being applied in the High Speed Railroad (HSL) project in the Netherlands. This work influences the communication of hundreds of workers (managers, designers, planners, contractors) all being involved in the project. A new shape algorithm was developed that enables the semantical description of complex crossings and such including the underground and all the road furniture (Nederveen).

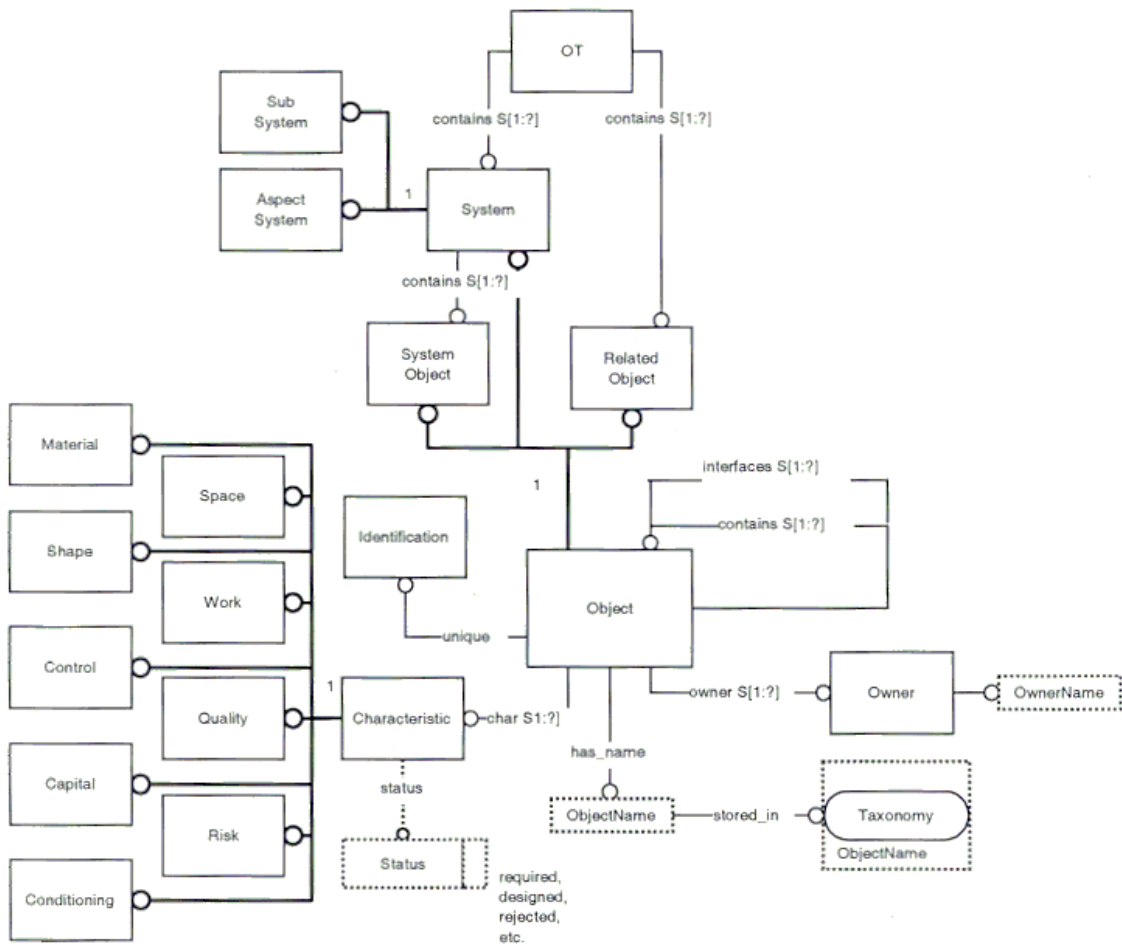


Figure 13.4: The basic principle of the Neutral Object Trees.

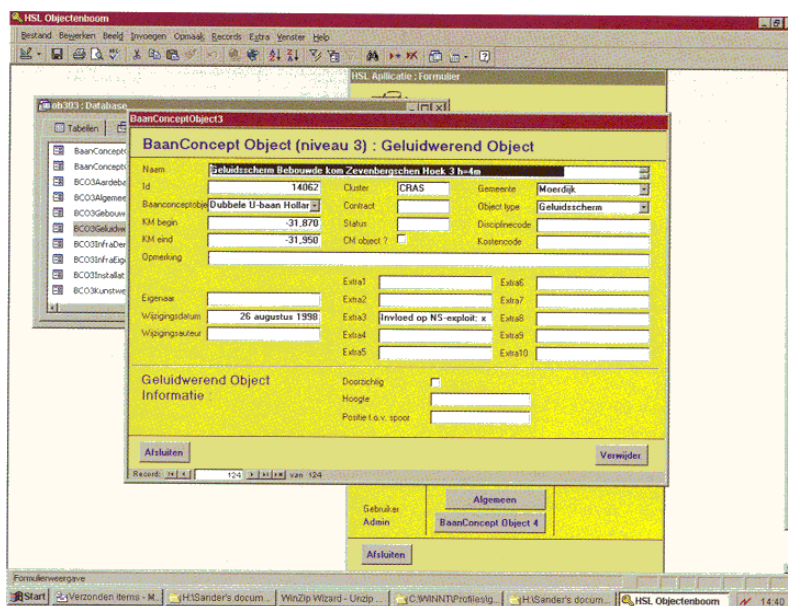


Figure 13.5: Application of the Neutral Object Trees for HSL project.

A theory on Computer Integrated Structural Analysis was developed that describes how structural engineers can participate in co-operative design/engineering processes of complex structures. The basis is a two-dimensional cross section of a building in the CAD-system Allplan of Nemetschek Programmsystem GmbH. Allplan is not a drawing system; it is a product-model based CAD-system that is able to automatically derive such a cross section from the three-dimensional product model (image by courtesy of Nemetschek Program system GmbH). Geometric modelling systems offer the same support as drawing systems on a somewhat higher level. Geometric modelling systems also only support the specification of the (final) solution.

Figure 13.6 gives a typical example of a three-dimensional model. To a certain degree geometric modelling systems support the generation of solutions, especially for details in routine design. Often such systems use a three-dimensional model (or a simple product model) internally but can only produce two-dimensional views and cross sections or bending schedules for communication purposes. CAD8110, the system used in the case described here, is a good example of this. It is a suite of tools to analyse reinforced-concrete (Re) frames, and to design and detail reinforcement. Its modules 'understand' structural engineering concepts like load, concrete grade, bending moment, shear force and bar diameter. This understanding enables the modules to analyse frames, and design and detail reinforcement. However, the modules don't use an internal product model. All this structural engineering knowledge is hard-coded into the modules (Bakkeren).

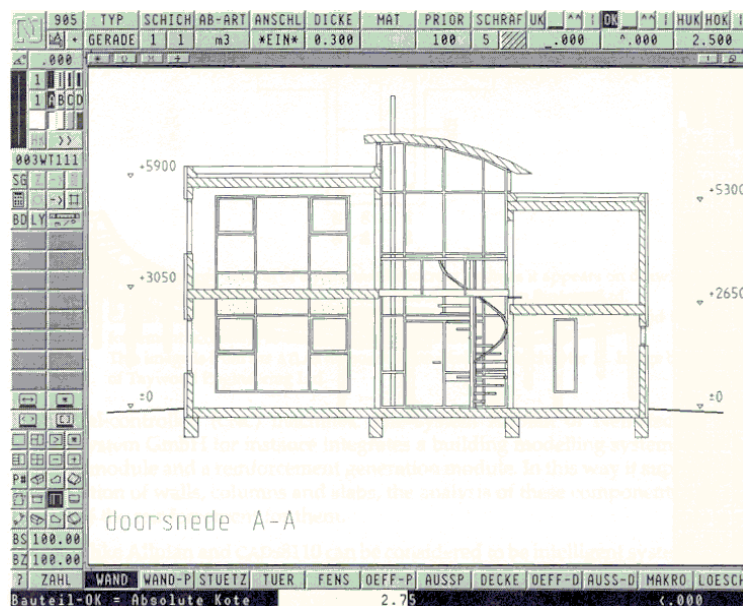


Figure 13.6: The Computer Integrated Structural Analysis Modeller.

Referring to the second research aim, an important accomplishment is noted: in the Building & Construction IT theme the group won a 25 man-year European project for Concurrent Engineering in Building and Construction, called CONCUR. The proposal was written by Tolman (chair of building informatics), who also formed the consortium and is the technical project leader. The aim of CONCUR is to provide two-way electronic communication between Clients and Main Contractors (and every party in between) with the aim (1) to reduce the costs of tendering with at least 50% and (2) to increase the hit-rate with at least 30%.

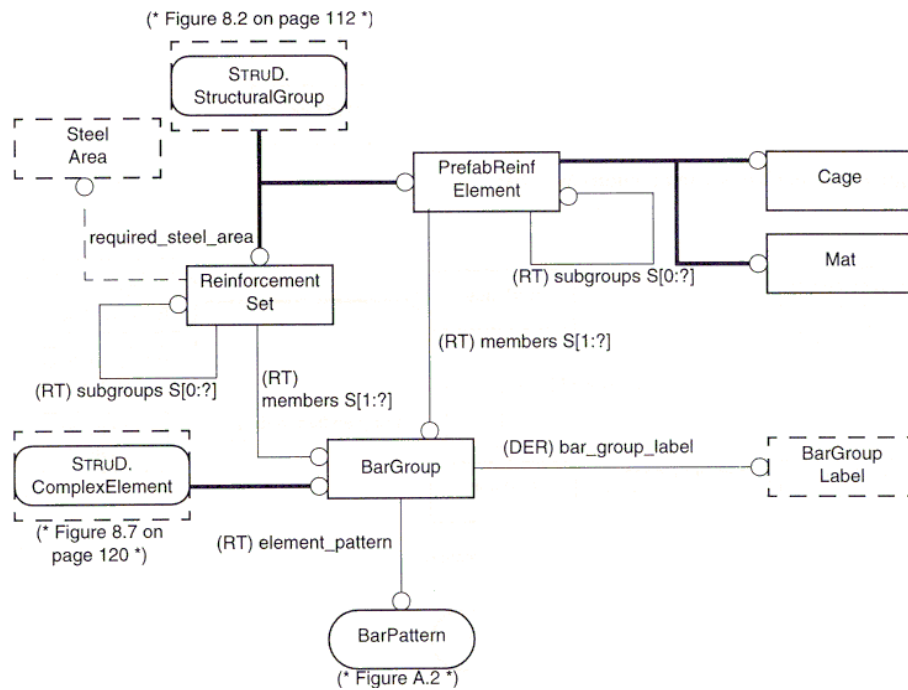


Figure 13.7: Reinforcement set, prefabricated reinforcement element and bar group.

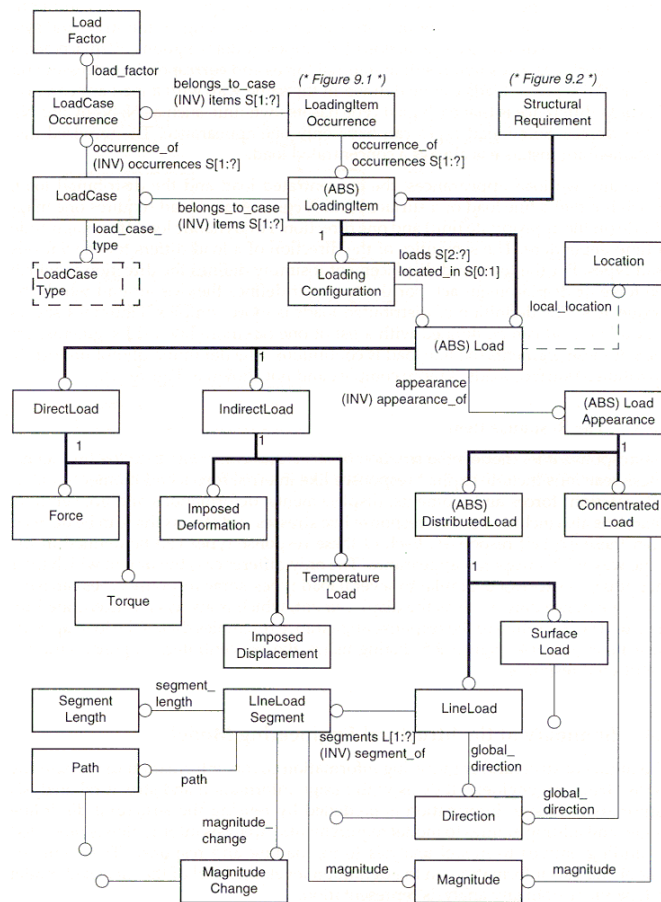


Figure 13.8: Express-G entity level diagram. A model of loading information.

As a recent accomplishment Tolman succeeded to win a major EU-contract for the European “eConstruct” project (IST 10303). This 25 man-year project was again initiated by the group. The focus is on the development of a new Communication Technology based on XML for the next generation Internet (van Rees). Referring to the third research aim it is noted that most of the research produces prototype software which is frequently used by partners in practise.

Also research and development is being carried out for the development of a Space Frame Modeller using product-modelling technology (PDT). The modeller will be a tool for designing large-scale space frame structures. The modeller will among others be a tool for designing, calculating, as well as architectural design and facility planning of such building systems.

Work is also done on formulating a research proposal for developing a functional design modeller based on product data technology. This tool will benefit from an earlier tool VLEK3 developed earlier as a prototype using clustering techniques and algorithms. The new proposal aims at investigating the possibility of using genetic algorithms instead (Beheshti).

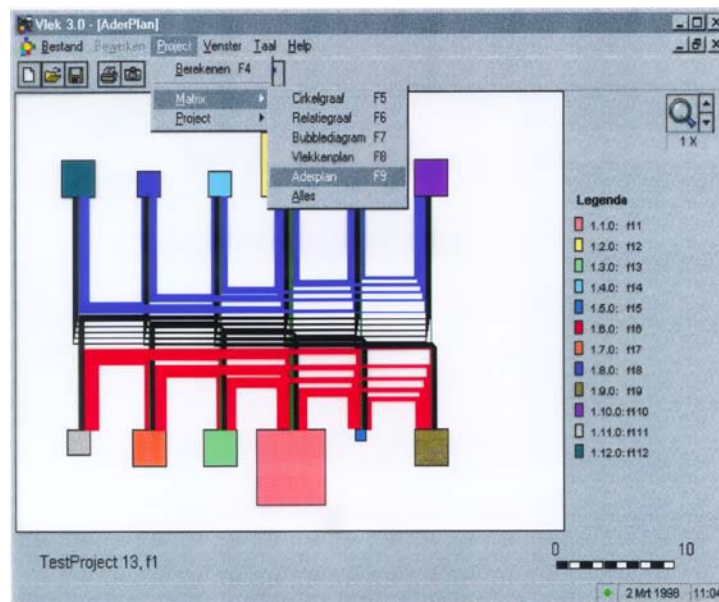


Figure 13.9: The functional design modeller (VLEK3 prototype).

## 13.4 Programme development

In the forthcoming period the mission statement, themes and methods will remain the same. However some accents will be shifted and some points of attention have to be mentioned.

### 13.4.1 Scientific aspects:

In Building & Construction IT the focus of research has shifted recently from the Design/Engineering stage upwards to (1) the Inception and Very Early Design stage and downwards (2) to the Planning and Execution stage, though still sufficiently supporting Design/Engineering to study feed-back and feed-forward information and knowledge flows over the life cycle.

### 13.4.2 Organisational aspects:

The present policy to have each year for 4-6 months a research fellow from a foreign university in the group will be continued since experiences are very fruitful. It is noted that

here will be also a shift in interests as we have slightly shifted some scientific aspects of the main research theme. In this regards during the next year a visiting professor from the university of Caen will participate in our research and education programmes aiming at the exchange of information and setting up EU-level research projects following the steps of groups earlier success such as ATLAS, CONCUR and e-Construct projects (Tolman).

#### ***13.4.3 Publications:***

Besides publication on conferences, which is very fruitful for PhD students from a self-fulfilment point of view (and attractively fast, which is mandatory in our field), more attention will be paid to publishing in the following international journals; (with these journals there are already good relationships since the group members act as reviewers for the journals or are in the editorial boards such as the International Journal of Construction Information Technology, as the International Journal of Design Sciences, the Design Research Internet Magazine, etc.).

#### ***13.4.4 Potential impact of the research***

The potential impact of the research is large as the group always places its research in the context of an industrial project, preferably a European project involving end-user companies (contractors, specification institutes, design offices), ICKT vendor companies and fellow research groups in Europe. This mechanism ensures that the research serves the intended needs and is commercially viable. It is also noted that Building & Construction is a large market. If only a small increase in efficiency and effectiveness can be provided large gains for society result.

#### ***13.4.5 Realised impact of the research***

- Based on research on geometry modelling in the Building Industry, the Dutch Rijkswaterstaat developed design tools for viaducts and tunnels that allowed more geometry freedom. The drilling robot, resulting from construction robot research, has been used to drill many thousands of (unhealthy) holes in underground concrete tunnels.
- Research on Communication Technology resulted in the first international STEP standard for our industry (STEP Building-Construction Core Model, part 106). Related work resulted in the IAI-IFC standard that is now being used in many large-scale building projects all over the world.
- The Neutral Object Tree approach is currently used in the Dutch HSL project.

### **13.5 Conclusions**

In Building and Construction IT, integration plays a major role. Here the emphasis is on integration of different partner roles in building industry, models and methods like product modelling, communication technology and knowledge engineering in order to cope with complex systems. The research in this field is strongly driven by present and long term needs of the building and construction industry. In this research theme some other methods are also used such as expert system technology, database technology, generic algorithms, generic programming and intelligent agent technology.

The group initiated and participates in three European projects: ATLAS, CONCUR and E-Construct. In these projects the group co-operates with different research groups as well as members of building industry. The outcome of research influences education programme offered by the group. The group provides three Building and Construction IT courses at the Faculty of Civil Engineering, respectively on product modelling in Buildings, knowledge

engineering for building and construction as well as application of advanced technologies in building design and construction.

The current situation of this theme is that knowledge for building and construction has deepened and that two PhD research projects deal with studies on Inception Support for large-scale building and construction projects. Research on cost aspects and the required multi-discipline knowledge structure dealt with conflicting knowledge from different sources. Modelling methods for value aspects, both end-user values and general building and construction values, have lead to a first prototype system for the inception of new or renovated hospitals.

The potential impact of the research carried out is large as the group always places its research in the context of an industrial project, preferably a European project involving end-user companies (such as contractors, specification institutes and design offices), ICKT vendor companies and fellow research groups in Europe. This mechanism ensures that the research serves the intended needs and is commercially viable. It is also noted that building and construction is a large market. If only a small increase in efficiency and effectiveness can be provided, it can result in large gains for the building industry.

### ***13.5.1 Appendix 1: Activities***

The following are some of the activities of members of the Building Informatics group:

#### ***F.P. Tolman, Building & Construction IT***

- Editor of the electronic journal ICT in Construction.
- Initiator, editor and technical project leader of EU-project ATLAS.
- Initiator, editor and technical project leader of EU-project CONCUR.
- Initiator, editor and technical project leader of EU-project eConstruct.
- Member Scientific Board STABU.
- Scientific Advisor TNO Building Construction Research.

#### ***R. Beheshti, Building & Construction IT***

- Co-ordinator of Design Informatics Theme of Research School Building and Construction.
- Editor-in-Chief of the International Journal of Design Sciences and Technology.
- Member editorial Board of the journal DriM (Design Research Internet Magazine).
- Member Technical Advisory Board of the International Journal of Construction Information Technology.
- Member Design Research Foundation (chairman of the board).
- Member EuropIA Association (European Association for Advanced Technologies in Design: Artificial Intelligence, Image Processing and Robotics).
- Member EuroGraphics (European Computer Graphics Society).
- Member MCDA (International Association for Multi-criteria Decision Analysis).
- Member Design Research Society (International Society for Advanced Studies in Design).

### ***13.5.2 Appendix 2: Engineering products:***

- Two Construction Robots, one for Drilling holes in concrete tunnel sections and one for brick laying.
- A design system for large-scale linear infrastructure works based on the Shape Deformation Tree.
- A pilot version of a measurement control system.
- A pilot of a dynamic model implemented in Java/Java3D for on-site application integration.
- A pilot of a Knowledge Base System that supports multiple views and non-monotonic design.
- A prototype of an information management system for large-scale projects based on Neutral Object Trees.
- A Concept Modeller for Hospitals.

### ***13.5.3 Appendix 3: Dissertations***

Following the nature of the discipline, the group has taken initiatives to co-operate with colleagues in research and research guidance. As a result of that policy many publications have more than one author and often PhD students have two promotors.

- Koetsveld, M.J. van (1995). *Product Data Interchange States*, Delft.
- Ying Liu (1996). *A Pattern Directed Approach Towards an Object Adaptive Decision Support Environment for Water Resources Management*, Delft.
- Bakkeren, W.J.C. (1997). *Computer-Integrated Structural Engineering*, Delft.
- Krom, R. (1997). *Robots in the Building Industry*, Delft.
- Minns, A.W. (1998). *Artificial Neural Networks as Subsymbolic Process Descriptors*, Delft.
- Willems, P. (1998). *Conceptual Modelling of Structure and Shape of Complex Civil Engineering Projects*, Delft.
- Nederveen, S. (1999). *The Neutral Object Trees*, Delft.