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# NETWORK-ENABLED PRODUCT MODELS FOR COLLABORATIVE STRUCTURAL AND BUILDING PHYSICS ENGINEERING

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## ABSTRACT

In this paper two integrated software concepts to support the planning process in the field of structural engineering as well as in the field of building physics engineering are introduced. An object-oriented approach is based for generation of product models and methods for the management of product models and the integration of specific software tools in computer network\, are in corporated.

**Keywords:** planning, building physics, object oriented, product model, structural engineering.

## 1. INTRODUCTION

In the planning process for civil and building engineering a variety of computer-based tools are currently used in order to support the planning partner in his specific task [Rueppel, Meissner, 1996]. In most cases, these tools can be classified into CAD-systems for design tasks e.g. construction plans, calculation programs for the numerical analysis and legal proofs and software for the tender phase, managing the calculation of costs. Due to the different tasks of the planning partners various views containing graphical and numerical information of the building are generated in the planning process. These technical information are not compatible to each other as discussed in [1].

The dependencies between different steps of the planning process lead to a high need of information exchange, which takes into account the different views of the planning partners. This co-operation can be established using digital product models in combination with modern communication technology [1]. In practice utilisation of this information exchange is mostly performed in a document-based manner, where files are used to transfer the necessary information. In the field of structural planning, CAD-plans with two-dimensional graphical information are still commonly used, which have to be interpreted by the recipient [2]. This information as a restricted drawing data subset does not represent a consistent building model. Further semantic information about structural elements, their properties concerning building

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physical aspects and their relations to other elements, loads and boundary conditions are frequently lost during the information exchange [2]. These missing information need to be regenerated by the engineer using his experience and his knowledge. Due to misinterpretations, mistakes may occur in the planning process which lead to a lower quality of the building construction.

## 2. PARADIGMS IN SOFTWARE DEVELOPMENT

The methods for software development have enormously changed in the last 10 years, Figure 1. Ten years ago the procedural programming dominated the concepts for analyzing and implementing software. Software Development only aimed at the specification of algorithms and data structures.

The upcoming methods for the object oriented analysis and design in combination with the object oriented programming languages introduced a new paradigm which lead to a new generation of software as it became possible to create an abstraction of the real world in computer-based models which could deal with the complexity of the objects in civil engineering. These objects could be aggregated to complex object hierarchies based on different types of relationships between objects, especially inheritance and associations [3]. Furthermore these objects were able to use interfaces which could pass messages to other objects and hide the interior attributes of the object.

The availability of computer networks offers new possibilities in the planning of buildings. Computer models can be distributed across the network so that a co-operation of planning partners based on consistent planning information is performed [4]. Furthermore a new generation of software tools is currently developed which enables a direct network-based communication between the planning partners, a dynamical exchange of engineering and construction knowledge by means of software methods and the distribution of legal rules, e.g. proofs for specific tasks in civil engineering.

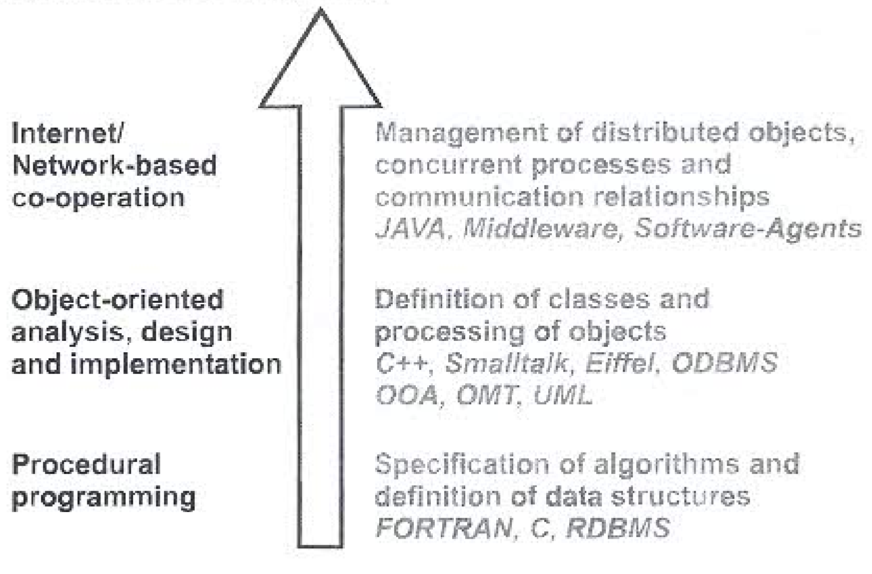


Figure 1 Evolution of paradigms in software development

## 3. THE NEED FOR A NETWORK-BASED, IT-SUPPORTED PLANNING PROCESS IN CIVIL ENGINEERING

The increasing complexity of the required proofs in the planning process leads to an improved modeling of the statical and physical conditions of the building so that the results of the proofs can be used for a decision support in the planning process. Nevertheless, the more detailed analysis of the statical and energetic properties result in the fact that the proofs can hardly be done manually any more, even if the structure of the building is not very sophisticated. In addition, the requirements of the users concerning climatic comfort and healthy living conditions as well as special demands for the architectonic design lead to sophisticated building physical solutions [5]. Even in the climatic regions in central Europe often the necessity of summer heat protection measures are underestimated in comparison to the conventional winter conditions. Often building physical aspects are not adequately considered during the whole planning process given the fact that the proof required by law does not take into account all building physical requirements. Therefore, a permanent interaction between building physical regulations and the other design conditions is needed to ensure a sufficient impact of building physical requirements on the planning process.

## 4. PRODUCT MODELING IN CIVIL ENGINEERING

For an integrated, computer-supported structural planning holistic product models are provided for the management and the exchange of structural information. A building product model is defined as an abstraction of reality and consists of the specification of digital information describing all phases in the planning process which can be exchanged and automatically processed by software-tools, Figure 2. The model contains all necessary information required for the planning, the design, the construction and the usage of a building. The complexity can be reduced by a hierarchy of sub-product models. By splitting the complete planning process into appropriate sub-tasks a system of complementary sub-product models can be defined. Based on inter-operable interfaces the sub-product models can be combined to fulfill the requirements of an integrated approach supporting seamless data exchange and sharing [6].

### *4.1 Product modeling in structural engineering*

In the field of structural engineering five different sub-tasks have been identified. Using object-oriented methods five sub-product models have been defined which are related to the specific sub-task:

#### *4.1.1 Structural model*

The Structural Model, derived from the Architectural Model, contains all structural elements including their geometrical representation created by the CAAD-System of the architect. In addition, this model offers specifications about materials and their material attributes.

#### *4.1.2 Statical model*

The Statical Model consists of a specialized geometric representation of the load-bearing elements and their relevant loads and boundary conditions as well as specialized structural elements (e.g. frames).

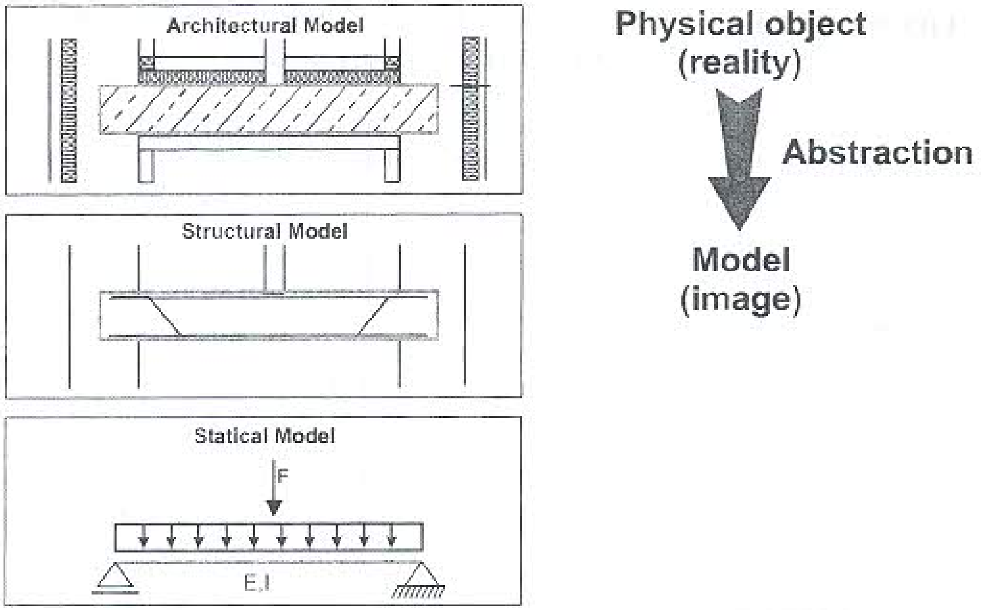


Figure 2 Sub-product models derived from physical objects in civil engineering

*4.1.5 Construction model*

The Construction Model is the mapping of all aspects and results into an appropriate model of the structural design. This model is the basis for CAD-drawings used on the construction site.

Up to now there is no international standard for a consistent exchange of sub-product model data in civil and building engineering. Only structural models can be represented in an object-oriented, standardized way using the standard ISO 10303, Application Protocol 225 "Structural Elements using explicit shape representation". The geometrical representation of the Structural Model refers to this standard. All sub-product models have been specified using the *Unified Modeling Language*, which has become the standard technique of object-oriented modeling [7].

*4.2 Product modeling in building physics engineering*

For an integration of energetic aspects in the planning process a holistic approach has to be chosen. In order to reach this goal the described structural model for structural engineering has been enhanced for use in the field of building physics and facility management. The derived product models have to describe the structural building elements, its usage as well as heating, ventilation and air conditioning systems. Furthermore, information about the climatic environmental conditions and the ecological aspects (amounts of primary energy) have to be provided. Based on an object-oriented analysis three different models have been specified which reflect different views on the building [5].

*4.2.1 Structural model*

The Structural Model describes the holistic structure of the building, consisting of the three-dimensional geometrical representation of the structural elements and the associated information such as types and layers of structural elements, materials, location, orientation and information about their surfaces, Figure3.

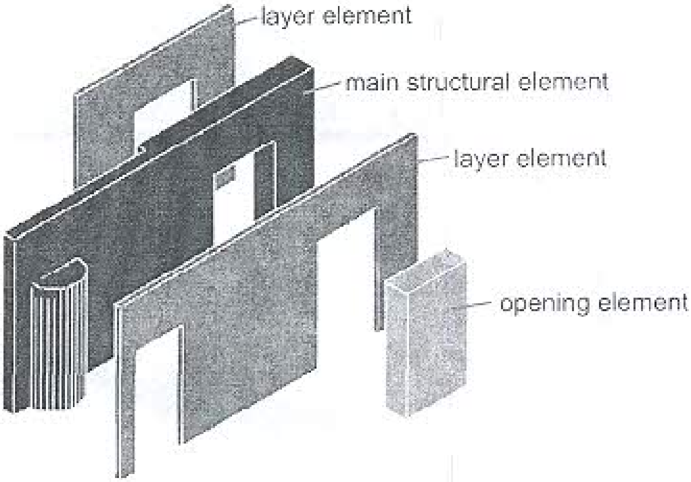


Figure 3 The structural model as a top-down decomposition of structural elements

*4.2.2 Room-based model*

The Room-based model is a projection of the usage of the building. Therefore several objects have been specified in order to classify the building in parts, floors, zones and rooms. These definitions have been combined with the necessary information concerning the usage structures and the technical equipment. Furthermore, the room definitions are associated with the building elements, so that a geometrical representation of the boundaries of the rooms and the zones can be generated automatically. These geometrical information are needed in order to determine the parts (and their volumes) of the building which have the same usage structure, an information required by the energetic proofs (in Germany the *EnEV*-proof).

*4.2.3 Energy model.*

The energy model takes the surrounding conditions of the building into account. It defines the climatic data of the environment consisting of location information and data about outer climatic conditions like temperatures, rainfall and solar radiation. Furthermore, parameters about ecological aspects have to be stored.

The unification of these three models leads to the building physical model, providing a holistic view on the building, which is the prerequisite of the energy-aware planning of buildings.

## 5. MANAGEMENT OF PRODUCT MODELS IN CIVIL ENGINEERING

In order to manage the various models in structural engineering an **O**bject-**O**riented **M**odel **M**anagement system (OOMM) has been developed, Figure 4. This management system enables the planning partner to create and manipulate the sub-product models interactively. Furthermore it offers a three-dimensional visualization of all sub-product models and it gains access to the control layer, which manages the persistent and consistent storage in an object-oriented database.

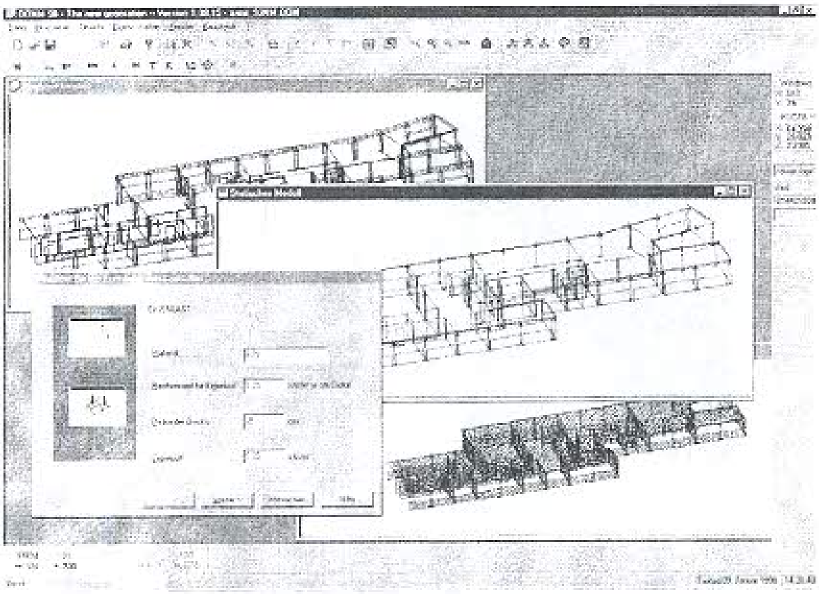

Figure 4 Sub-product models for structural engineering within the oomm-system

The planning process in structural engineering is characterized by a high degree of information exchange. The sequential generation process of a new subsequent sub-product model requires a large amount of data which is located in the previous models. Especially the Dimensioning and the Construction Model require information of all other models with regard to the types of utilization and the environmental conditions (Architectural Model), the geometrical representation and load conditions (Structural Model), and the statical elements and their resultants (Statical Model). In order to keep all sub-product models in a consistent state, there is a necessity to establish a communication between these models. During the process of planning and construction, many iteration steps have to be executed to adapt changes in one model to the other sub-product models.

In order to supervise and regulate the internal data exchange a control layer has been developed within the OOMM-System, centralizing the requests from the sub-product models, Figure 5. Using the control layer, all information necessary for the access and manipulation of a sub-product model can be obtained without deeper knowledge of the internal structure of related models.

The advantages of the control layer become obvious during the interactive modeling of live loads. Although the various load combinations, including different factors of safety, are part of the dimensioning standards, the methods concerning the generation of the relevant stress resultants, which are independent from specific standards, have to be integrated into the Statical Model. Using a semi-automatic algorithm distributed dynamic loads are modeled by a specialized module within the OOMM-system. This module consists of a mesh generator, which divides the load area into sub regions, and an interactive modeling tool enabling the structural engineer to survey the generation of the load distribution.

Another task of the control layer is the utilization management of the whole OOMM-System including the user notification. The state of planning inconsistencies as well as errors during the semi-automatic generation of the sub-product models are reported to the users, thus leading to an improved quality of the planning process.

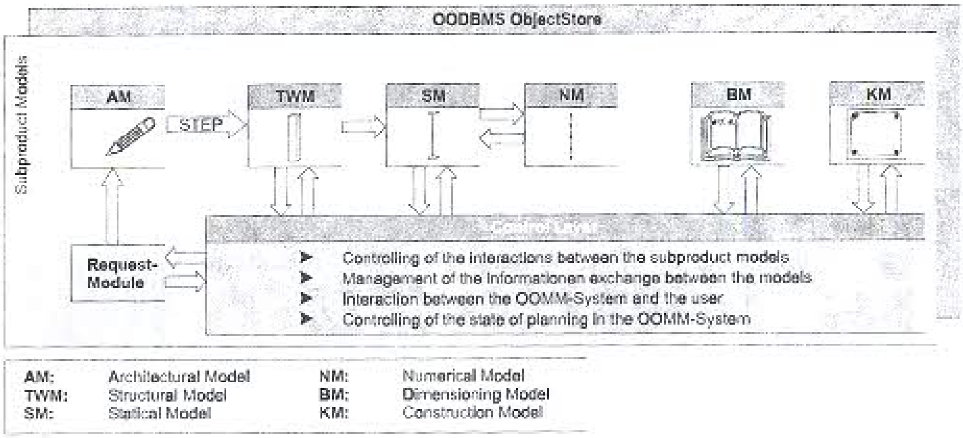


Figure 5 Management of sub-product models in the oomm-system using the control layer

## 6. NETWORK-BASED DISTRIBUTED SYSTEMS FOR THE PLANNING PROCESS OF BUILDINGS

*6.1 Distribution of product models*

In order to support the co-operative work where the planning partners manipulate their sub-product models with different software tools the CORBA-technology has been implemented [8]. The specified sub-product models have been enhanced by interfaces using the IDL-language, thus a network-based activation of the models by the Object Request Broker has become possible. The described distribution of product models enables a dynamic actualization of changes in one model across the network, Figure 6. With regard to the co-operative work of the partners in the planning process, a consistent storage of the product models is very important [9]. Thus, an independent component has been developed which is able to store the complex object hierarchies with all their associations and relations in an object-oriented database system (*ObjectStore*). Furthermore, the database management system has the capability to deal with different versions of one building model. With this approach, the civil engineer can vary all parameters of the product models and store this newly generated model as a new version which can be used for the proofs and the simulation, so that an iterative optimization can be performed. Furthermore, all steps of the co-operative planning process including all changes in the building model can be reproduced and reported.

*6.2 Network-based integration of building physical aspects in the planning process*

The planning of buildings based on product models requires new methods of information management which directly support the holistic approach. In this field the capability to co-operate in a network-based environment is of major importance: On one hand, a co-operation of different partners in the specific tasks in the planning process can be established, on the other hand the functional division of the entire system into components which work independently from each other can be realized. These components can be linked together dynamically to a virtual planning instrument in the network environment. Regarding the software technology the component architecture has several advantages: The components work together using only their specified interfaces, so that a central maintenance and interchange ability can be realized. This aspect is of great importance since legal proofs like e.g. the *EnEV* are revised regularly, so that an adjustment of the proof components can be implemented easily. Due to these advantages a variety of different software modules have been identified within the *VAMOS* (Distributed Application for Modeling and Optimizing of Building Physical Systems) prototype implementation.

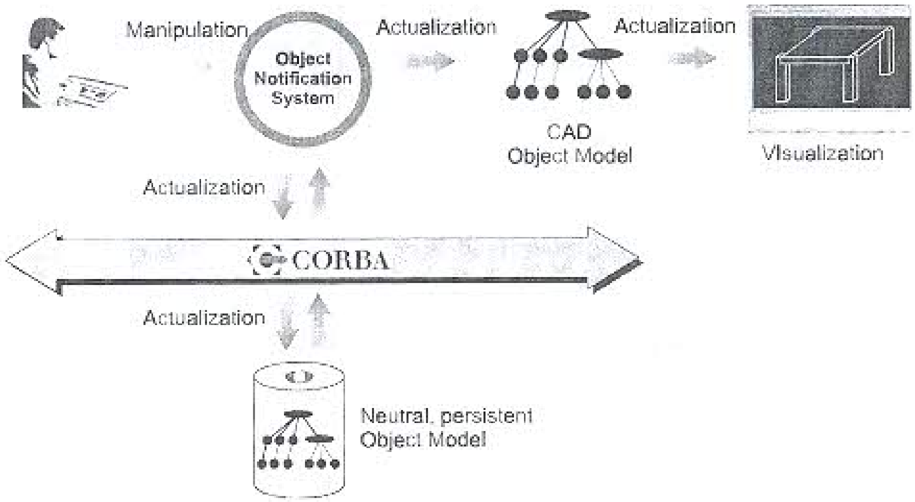


Figure 6 Management of distributed product models

*6.2.1 Model generation, manipulation and management*

This component for the generation and manipulation of the described product models has been developed as a runtime module (*ARX*) for the CAD-System *AutoCAD,* Figure 7. Using this standard tool of civil and building engineering for geometric modeling the existing workflows in the planning process are preserved. Furthermore, the programming interface of the CAD-System enables the access to its complex geometrical capabilities which can be used for generating the structural elements of the building model. The realization of the graphical user interface supports the model-based approach. Figure 8 shows the hierarchical structure of the building model: In addition to the conventional visualization windows of *AutoCAD* a tree view offers further information about the structure of the building, its elements and the associated materials. The implemented material catalogue contains various combinations of different commonly used materials and layered constructions so that the engineer can select an appropriate proposal for taking over into his building model.

*6.2.2 Energetic proofs*

The building physical proofs for energy saving have been implemented using the Java-Applet-technology [10], Figure 8. With this approach, legal regulations can be provided in a platform-independent way, which are transferred to every workstation connected to the network, no matter which hardware components or which operating system are used. Within this component two different regulations have been analyzed: The German *WSchVO* reflects the actual requirements for the heat and energy saving in building, while the new *EnEV*, the successor of the *WSchVO* regulation takes into account various ecological parameters.

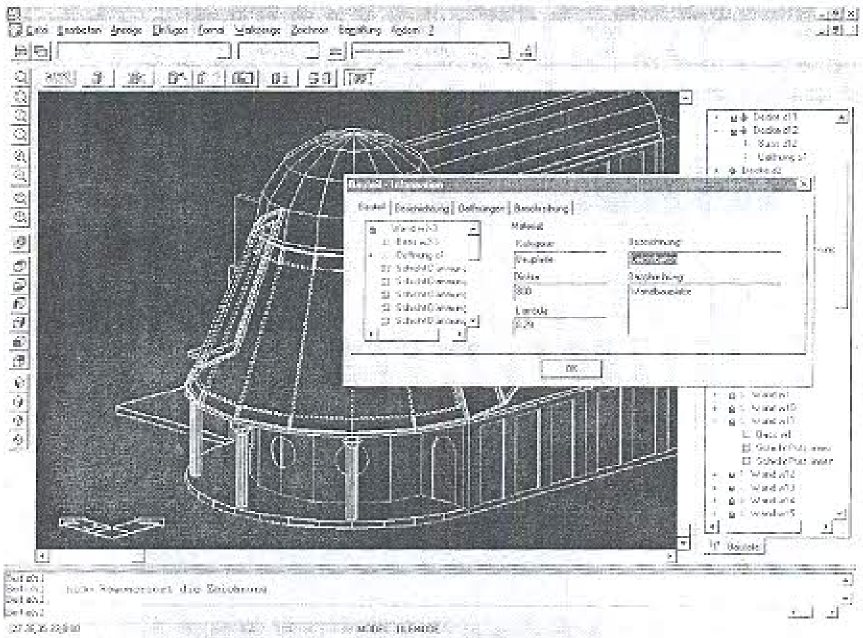

Figure 7 CAD-based component for the generation of building models

*6.2.3 Simulation of the building climate*

In order to simulate the climatic conditions in the buildings and the interactions between different zones the results of the energetic proofs are not sufficient. For a more detailed analysis the simulation program [11] has been enhanced by an interface module, so that the defined structures of the building model can be used directly for the thermal simulation, Figure 8. Thus, in that approach the existing preprocessors in *TRNSYS* (e.g. *PREBID*) are no longer necessary.

## 7. MOBILE SOFTWARE COMPONENTS FOR DYNAMIC INFORMATION RETRIEVAL IN THE INTERNET

The optimization of the properties (e.g. the energetic balance) of buildings is usually performed by varying the geometry of the structure and the materials of structural elements. The material specific parameters depend on the products offered by their manufacturers, so that for an representation of these elements within a computer-based model all necessary information have to be collected and processed. This information retrieval is often done in a conventional way by postal services. Many engineers nowadays use services in the *World Wide Web (WWW)* for retrieval of actual information, e.g. material parameters. This online-collecting of information can take a rather long time until the desired parameters are found in the offered pages in the server of a specific manufacturer, especially if comparisons between different distributors have to be done. Within the VAMOS-project the newly developed technology of *mobile Internet-agents* [12] [13] has been analyzed in order to automate this task. Mobile Internet-agents are computer programs, which can transfer in the network subsequently from one computer to other computers, where they can perform different functions [9]. Thus during their migration through the Internet they can search for the different servers of distributors, where they can retrieve the desired information. The processed and collected information is returned back to the origin, in this case the VAMOS planning system. After the arrival the engineer can import the results of his Internet search in his material catalogue and his building model, Figure 9.

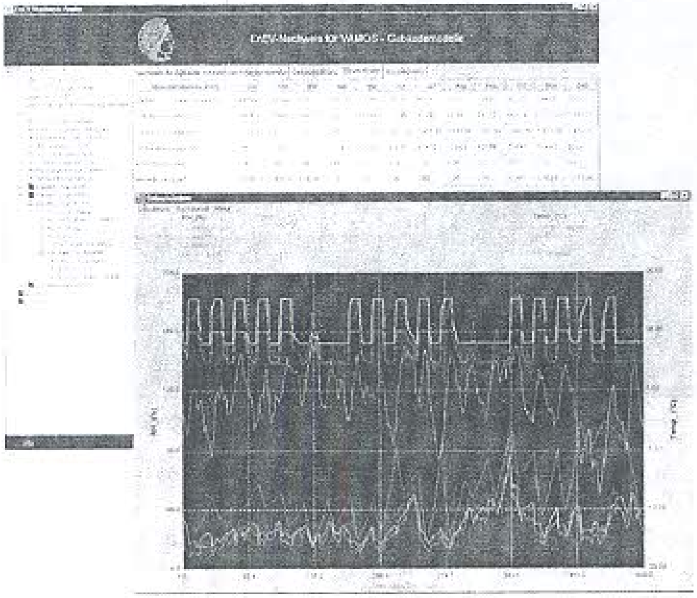

Figure 8 Components for building physical proofs and simulations

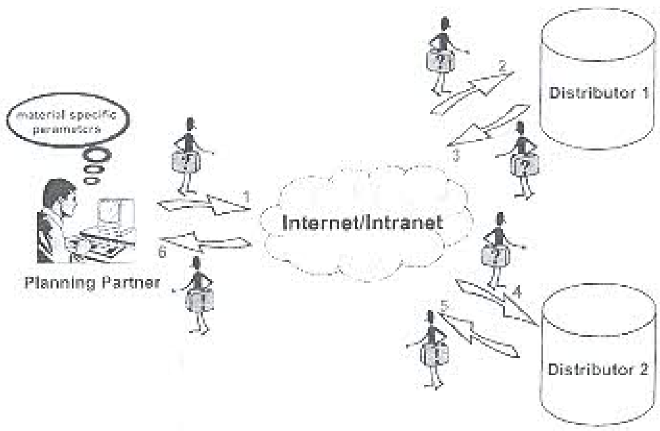


Figure 9 Dynamic information retrieval in the internet

The desired information is specified with keywords by the planning engineer. These keywords are converted into a search request using the XML language which is transmitted by a mobile agent through the internet, Figure 10. In order to security aspects the server database of the distributor is encapsulated by a stationary agent who provides interfaces for the arriving mobile agents. Furthermore, it converts the keywords into a valid database query using SQL and returns the results back to the mobile agent. This mobile agent transfers the results back to the planning system of the engineer where the results can be imported interactively.

## 8. CONCLUSIONS AND PERSPECTIVES

The present paper introduces a new concept of a software system for the integrated planning of buildings. The presented systems use newly developed product models of a building which are distributed in a network-based planning environment. With the presented systems the effects of changes in the building structure can be estimated and calculated, so that the planner gets a decision support in order to improve his planning result and avoid mistakes even in an early stage of the planning process. The new software-technologies offer adequate possibilities for a network-based cooperation of planning partners. Furthermore various tasks of the engineer like information retrieval can be facilitated by using the network-based approach.

In this work the software agent technology has been adopted in the field of information retrieval. It is suitable to solve problems in the heterogeneous environment of the civil engineer concerning the distribution of specific processes as well as the integration of information using dynamic interfaces.

The presented systems have been analyzed and implemented in the field of structural and building physics engineering. An integration of several fields of civil engineering is possible. This leads to a software-supported management of the whole life cycle regarding the planning, the design, the construction, the utilization and the demolition of buildings.

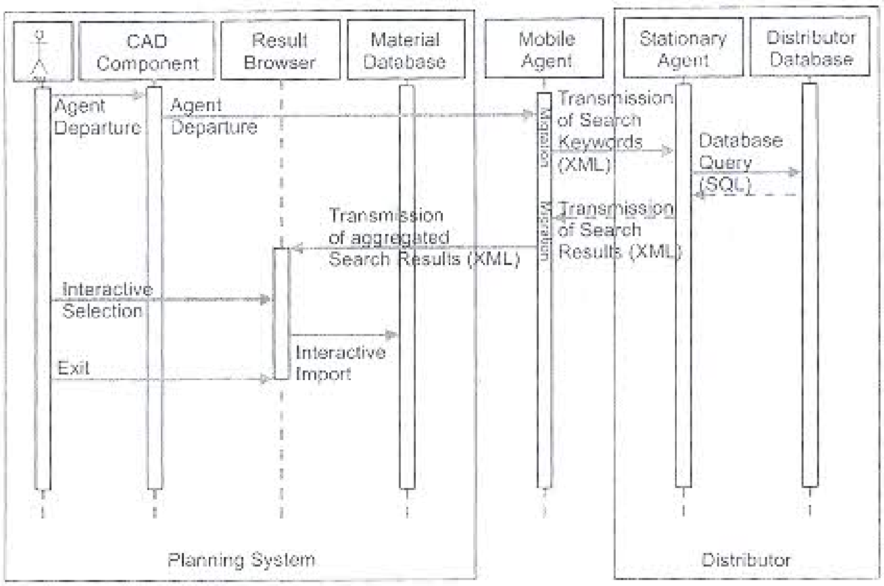


Figure 10 Sequence of the dynamic information retrieval

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