ARCHITECTURAL PRODUCT MODELLING
A CASE STUDY

Jos P. van Leeuwen and Rob H.M. van Zutphen
Eindhoven University of Technology,
faculty of Architecture, Planning and Management,
dept. of Computer Science for Architecture,
Eindhoven, The Netherlands.
email: jos@baub.bwk.tue.nl, rob@baub.bwk.tue.nl

Abstract

This paper demonstrates the approach followed in the NOBI Building Model project to introduce the concept of Product Modelling in today's practice of the construction industry, mainly in architectural design. It presents the development of a conceptual model based on previous research and the benefits of the incremental development of a prototype CAD-application based on this model.

keywords: Computer aided design, Construction industry, Information modelling, Product model, Building model, Incremental development, Prototyping.

1. INTRODUCTION

In the construction industry, we observe a growing importance to control the flow of information about the building product. Among commonly known aspects of influence on this development are the concurrent participation of multiple actors in the process of design and construction and the need for improved communication between these actors. The integration of information in the different stages of the building's life cycle, both horizontal and vertical, is an important aspect, as is the need to formalise design and construction knowledge in order to improve speed and quality of information management and consequently the building process itself. [Björk 1992; van Nederveen & Tolman 1992; Eastman 1993]
The growing complexity of the construction-process and the building product not only results in an increasing flow of information, but also requires a decisive structuring of information-models.
This paper presents the results and approach of a recent development by the Calibre Institute in co-operation with the Dutch association for architectural automation, VCA. This development intends to contribute to the developments on product modelling for the construction industry and to demonstrate the advantages of product modelling for the architect in communication with other participants of the construction process.

1.1 A GAP BETWEEN I.T. AND ARCHITECTURAL PRACTICE.

The latest developments in information technologies (IT) offer efficient methods, techniques, and tools for the purpose of structuring and implementing information-models. In several engineering disciplines, these facilities are applied with growing success, good examples are found in the process-industries and mechanical engineering.
In the field of construction engineering and architectural design, the introduction of these techniques is confronted with several problems. The building industry is a very differential sector and does not have the common goal of rationalisation, i.e. the development of commonly accepted process- and datamodels [Wagter and Schaefer 1992].
A widely developed insight of the construction practice in the potentials of IT is currently still lacking. In coherence with this, compared to other industries we also see a shortage of financial support for the development and introduction of new information techniques in the construction industry.
In the Netherlands, and presumably likewise elsewhere, diminishing this gap between IT developments and practical application is considered to be of great importance.

1.2 DEVELOPMENT OF STANDARDS FOR I.T.

An important part of international developments in IT for the construction industry focuses on the development of standards.

1.2.1 Dutch developments.

In the Netherlands, a research project called Building Information Model in the period 1987-1989 [van Merendonk & van Dissel 1989], has shown that a pure theoretical development of complete process- and data-models for the entire construction industry does not automatically lead to a broad adoption of these models and application in daily practice. This project was developed in a scientific co-operation of universities and research institutes, but was not carried by the construction industry itself.
The level of abstraction of the models was much too high, and the level of coherence of the detailmodels too low for the models to be considered practically applicable. Although this research has delivered some theoretical, potentially valuable results, it never reached the level of practice they were meant to reach, due to the lack of support from practice.
Wagter, in a review of IT in the construction industry, emphasises the need to acquire sufficiently wide support for the developments of IT in construction, the need for important changes of mentality and organisational structure [Wagter and Schaefer 1992]. This is true for the discipline of architectural design in particular.

On standardisation, several recent developments in the Netherlands seem to be more successful. Among these are the Dutch draft document NEN 2660 on information modelling for the construction industry (NEN = Netherlands Norm) [NNI

1993]; and the Dutch contribution to ISO TC59 SC13 WG2: draft technical report on classification of information in the construction industry [ISO 1993].
Also to be mentioned here, is the Dutch participation in large international research projects, such as COMBINE [Augenbroe 1993].

1.2.2 STEP developments.

Internationally, the developments of the STEP standard for the exchange of product definition data, by the ISO, undoubtedly are defining the future integration of information technologies. Although the STEP project started in 1984, its objectives are currently still being discussed, due to its dynamic nature. Focus has shifted from data exchange to data sharing, and along with the conceptual developments, implementation aspects came more and more into the scope of the project.
In a view of STEP, Wilson [1993] mentions two objectives of the STEP developments:

1. to specify a standard method of representing the information necessary to define a product from its conception to its time of retirement.
2. to specify standard methods for electronically exchanging the data representing this information.

In this introduction we'll call the first scope of product modelling efforts PMIS, for the development of Product Model based Information Systems. The second scope of product modelling is known as PDI, for Product Data Interchange. In our opinion, both approaches are essential for the development of information management in the construction industry.

1.2.3 Product Model based Information Systems (PMIS).

PDI developments have already shown the immense problems of defining standards for exchange of data. The development of PMIS actually involve much more. First, information modelling is more complicated than data modelling, since information includes semantic knowledge about data. Second, where PDI leaves the data processing systems intact, in PMIS we need to redefine the information system itself, which includes redefining organisational models, task models, user models, etcetera. This will have an impact on activities and structures within organisations.

For these purposes it is necessary to establish a definition of what information constitutes a complete definition of a product; to gain acceptance of the developments of such a standard information model; and to improve implementation of computer technologies for support of these developments [Wilson 1993].

1.3 NOBI FRAMEWORK.

The NOBI is a framework of research institutes which is managed by the Dutch foundation for building research, SBR. In the NOBI framework, several research projects are co-ordinated to co-operate and integrate efforts on product modelling. A characteristic of the approach of these projects is the cyclic interaction between theory, process- and datamodels, software, and the daily practice of the construction-industry.
A development which was initiated by NOBI is called NOBI/ABI [TNO 1993]. This project aims to offer an information infrastructure for developments on IT for

construction. This infrastructure mainly consists of a set of conventions on conceptual models and the communication between participants.
Besides the input from construction-theories and theories of IT, several practical pilot-projects in the NOBI framework form an important source for these conventions.
These pilot-projects aim at:

- getting insight in the complexity of the product and its life cycle processes;
- testing the suitability of existing and new standards;
- getting an insight in information modelling, as enhancement of data modelling;
- demonstrating the benefits and feasibility of these developments to policy makers and software producing organisations.

One of these projects is the Building Model project, discussed in this paper.

1.4 INTERACTION OF THEORY AND PRACTICE.

Previous research projects showed that the traditional life-cycle approach to software development is not very suitable for the development of information modelling systems. The rigid sequential progression in stages, from requirements analysis to implementation, operation, and maintenance, may be suited for well-understood automation projects; it is less applicable for ill-defined research problems.
The development of product model based information systems (PMIS) is characterised by an ill-defined problem field, a lack of resources and generally accepted standards, and a lack of dedicated information modelling tools.
This leads to the assumption that an incremental development, short steps in development, with constant feedback from daily practice via prototyping, will improve the results of the research. Inadequacies and incompletenesses are found earlier in the development process. Prototyping [Bischofberger & Pomberger 1992] results in more concrete research outcome, which can be communicated more easily than abstract schema's for processes and information structures. However the quality of the results can still be secured using structured analysis and schema techniques.
In combination with an evolutionary approach, i.e. using knowledge and results of previous projects, this may lead to an easier understanding of the problem field.
We'll refer to the approach of the described research as an evolutionary incremental development.

2. THE NOBI / BUILDING MODEL PROJECT.

Besides the expected direct benefits for research as summarised in the previous paragraph, the NOBI Building Model project, NOBI/BM, was built upon the assumption that an early introduction in construction practice of the developments of IT for the construction industry can stimulate a more active participation, a wider support of new developments and application of the new techniques in practice.

2.1 PREVIOUS PROJECTS

The projects taking part in the NOBI-framework involve inter-disciplinary communication in the construction-industry. Each project presents a view of a specific discipline. Two of these projects are VABI and BBB.

VABI concentrates on the view of HVAC consultance and engineering, defining a data-exchange system for communication of HVAC information within this discipline as well as with other disciplines.
BBB is a project developing a model and prototype for cost-engineering. The project aims to provide a common method for cost-estimations based on information available during the different design-stages.
The models of both projects will be discussed in more detail in the next section.

2.2 OBJECTIVES OF NOBI/BM.

For the view of the architect, a Building Model project was started, aiming to run, in a short time, a complete cycle of developing a conceptual building model, developing a prototype CAD-application, and demonstrating both to construction practice.
The main objectives of the described project, NOBI/BM, are:

- the development of a conceptual building-model for the view of the architect, which supports the communication with the existing models of the VABI- and BBB-projects;
- the development a prototype CAD-application to allow input and manipulation of this model, and communication to applications developed for VABI and BBB;
- demonstration of the model and the prototype to potential software-developers and users of future product modelling systems in construction practice;
- proceed through the complete cycle of developing the conceptual model and prototype in a short time-span.

This project does not aim to develop a complete kernel model for integration of architectural information in the entire construction communication process. The project describes a sub-view model for an architect's view on a specific building, including the information needed for the architect to communicate with two other participants in the construction-process: an HVAC engineer and a cost engineer.

3. APPROACH, RAPID DEVELOPMENT.

The development cycle of both the conceptual model and the prototype was planned in a short time-span, including the demonstration and evaluation of the model and the prototype with interaction of the construction practice.
In order to arrive at the stage of prototyping, the development of the conceptual model needed to be a rapid development which was based on the results of other research in product modelling for the construction industry. Three conceptual models where analysed and interpreted.

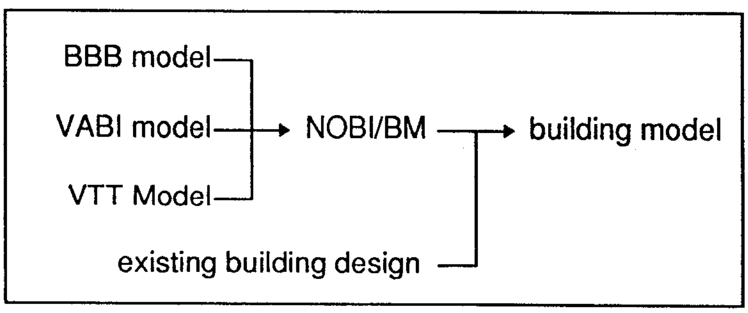

Fig.1 Approach to the development of NOBI/BM.

3.1 THE MODELS AS POINTS OF DEPARTURE.

This section describes three models, from BBB, VABI, and VTT, that have been used as the basis for the newly developed building model, NOBI/BM. Elements of these three models that were considered to be of interest for the new model, have been interpreted and presented in EXPRESS-G schema's.
From these interpretations, the new conceptual model, NOBI/BM, was defined for the view of the architect in communication with the two other disciplines. This conceptual model was then used to build a prototype CAD-application. Using the design-information of an existing building, an instance of the conceptual building model was created as an actual building model. This approach is represented in figure 1.

3.1.1 BBB model for cost-engineering.

A recent development in the NOBI-framework was called BBB and resulted in a data-model and prototype for advanced cost-engineering [van Zutphen *et al.* 1994]. The BBB research aims to develop a generic method for cost-estimation by architects and cost-engineers in the different design-stages, and to develop a prototype computer-application to present this method and to effectively collect and process comments on the method.

The BBB model defines cost carriers on different levels of abstractions. The cost-information for these entities can be specified by reference to a referencemodel, or by input of the specific data for the project being modelled.

The model contains different levels of abstraction, in which the building is first decomposed into 'elements', which have a functional specification. Elements then are decomposed into 'components', which have more technical details specified.
The materialisation of these components is described in recipes that contain the composition of components out of project-independent 'means'.

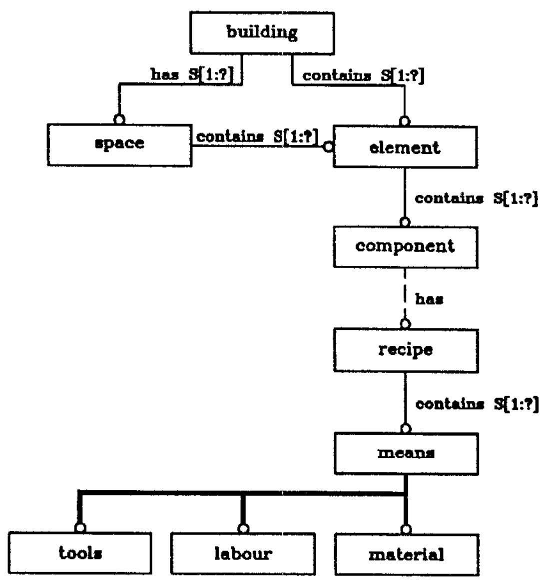

Fig.2 Interpretation of BBB cost-engineering model.

An interpretation of the BBB model is given in EXPRESS-G, see figure 2.

3.1.2 VABI model for HVAC engineering.

The contribution of one of the participants in the NOBI research-frame, the exchange-model of VABI [VABI 1993], was taken as basis for the view of HVAC-engineering. VABI is an institute for HVAC engineering. One of its objectives is to develop a data-exchange system for building-information that needs to be exchanged by participants in the discipline of HVAC engineering. Both external communications (e.g. to other disciplines), and internal communications (e.g. between parties in HVAC) are considered. The current state of this project supports mainly the exchange of specific HVAC-data.

One of the aspect-type models described in this project is intended for exchange of data between architect, building-physics consultant, and HVAC-engineer.

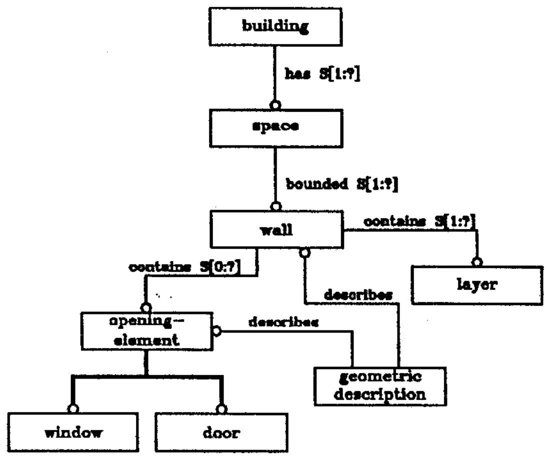

Fig.3 Interpretation of VABI model for HVAC.

This model contains entities for physical parts of the building, related to each other, which allow input from architectural information into applications for physics-calculations such as heat-loss.
The properties of these entities are defined by functional and technical specifications, similar to the General AEC Reference Model (GARM) [Gielingh 1988]. An interpretation of the VABI model is given in EXPRESS-G, see figure 3.

3.1.3 VTT synthesis model.

For the view of the architect, several models have been developed in past research-projects. Recently, some of these models have been analysed at VTT by Björk [1992]. This analysis resulted in an integration of four models into one conceptual model for spaces, space boundaries and enclosing structures.

The four models analysed by Björk are the RATAS model as implemented by VTT (Finland), the House Model of de Waard (Netherlands), the Synthesis Model of the GSD (France), and the Integrated Data Model of the COMBINE project.

Figure 4 shows an abstract EXPRESS-G schema of our interpretation of the model of Björk. This schema mainly shows the relationships between spaces, space boundaries and enclosing structures, which we needed for the integration of the architect's view with the models of cost-engineering and HVAC-engineering.

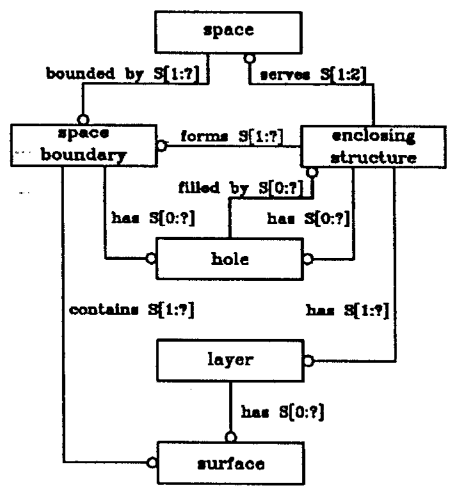

Fig.4 Interpretation of the VTT synthesis model.

4. THE MODEL NOBI/BM.

This section will describe briefly some of the concepts that are included in the NOBI/BM model. The conceptual model itself is presented in a NIAM information diagram.

4.1 CONCEPTS OF THE BUILDING MODEL.

Integration of the three models discussed above, resulted in a conceptual building model for the view of an architect. The model is, however, restricted to communication of the architect in a final phase of design, and to communication with cost-engineers and HVAC-engineers only. Communication to other participants is of course very relevant, but in this stage of the research left out of scope.

4.1.1 Abstraction and generalisation of entities.

Integrating the models initially involved integrating the space-oriented model for HVAC by VABI with the component-oriented model for cost-engineering by BBB. This required a generalisation of entities in both models into entities that could be defined as being compatible to both models. For instance, the 'wall' entity in the VABI model was generalised to 'bounding component', which, as a more generic entity, fitted well with the cost-engineering model.
This type of integration already shows in the VTT model, which made this model very useful as a basis for our research.
The interpretation of the three models also resulted in abstraction of entities, which was based on the restrictions laid upon the research project. It was not necessary to create an aggregation model, a model that contains all aspects of the three disciplines, but rather a kind of kernel model, that supports the supply of information by the architect to cost-engineers and HVAC-engineers.
For instance, the 'layer' entity as presented in the VABI model and in the VTT model, was not considered necessary as distinct entity in the building model, but was abstracted to the decomposition of components into means.

4.1.2 Space-element duality.

The concept of modelling a building in both spaces and elements is important for several reasons. The view of an architect on a building would never be restricted to either one. In the synthesis model of VTT, a space is defined by its physical separations from other spaces, but also as the locus of a homogenous activity. The definition of functional spaces is especially important in the early stages of architectural design.
The definition of a space in relation to its physical separations is important in the communication with HVAC engineering. For the heat-loss calculations for spaces in the building it is necessary for instance to maintain the topological relations between spaces and their enclosing structures, and the relation of one space to another via these enclosing structures.
In the BBB cost-engineering model, the price of a building project is calculated on the basis of elements and their decompositions. The total building costs are however recalculated over spaces and assemblies of spaces (building parts) for the purposes of evaluation and future building management.

Other disciplines, which were not directly involved in this research, for instance acoustic specialists, also require the integration of the space-based concept and the component-based concept.

4.1.3 Space boundaries

The relation of the functional spaces with the element-concept of modelling a building is made explicit by the definition of space boundaries. Space boundaries were introduced in the House Model by de Waard [1992], representing the shell of a space, which can be both physical or non-physical. Space boundaries represent a functional separation of one space from another. Where physical space boundaries have a relation with enclosing structures, non-physical space boundaries are used for purely functional separations of spaces.
In the NOBI/BM model the distinction between physical and non-physical space boundaries is not made explicit in the model by defining two different sub-entities, as the VTT model does. In the NOBI/BM a space boundary can be made physical simply by relating it to a component. For this purpose, components are specialised into bounding components and non-bounding components.

4.1.4 Decomposition of elements into components.

Although some product modelling research propose a non-hierarchical model of components [Harfmann & Chen 1993], in this research it is considered necessary to distinguish different levels of physical parts of a building. In correspondence with the normative developments, both Dutch [NNI 1993] and international [ISO 1993], a distinction was made in three levels of physical components of a building.
The first level contains 'elements' which describe a building in terms of functional specifications. This level is especially important in the programming phase of a construction project, as the requirements are specified, and in the early stages of design, when choices of material and construction methods have not yet been made.
As the design process progresses, the functional specifications of elements are further specialised into components that constitute the elements. These components can be modelled either by functional specification, similar to elements but more detailed, or by technical solution. These two different approaches to modelling are represented in a meta-model for the structure of attributes of entities, as shown in figure A1 in the appendix of this paper.
The distinction between states of information 'as required', 'as designed', and 'as built', are taken from the General AEC Reference Model (GARM) [Gielingh 1988]. Other states that are distinguished in GARM are 'as planned', 'as used', 'as altered', and 'as demolished'. These states are meant for the view of participants which do not fall in the scope of this research, and therefore are not part of the meta-model.
In BBB cost-engineering, the component-level of physical parts of a building is used to make cost-estimations. As long as the components have not yet been determined, the costs of a building are estimated by reference, via the level of elements, to components from similar projects. As soon as the design is materialised, the prices of referred components can be replaced by the prices of the actual design-components.

4.1.5 Materialisation vs. specification.

As indicated in the previous paragraph, in early phases of design the building is described in terms of specifications, as required and as designed. As more details become available, specifications of elements will be decomposed into specifications of components.

When choices for materials or products have been made, the components can be modelled by their technical properties, which can be matched against the specifications of components. This process is called materialisation of components.

4.2 REPRESENTATION OF THE BUILDING MODEL.

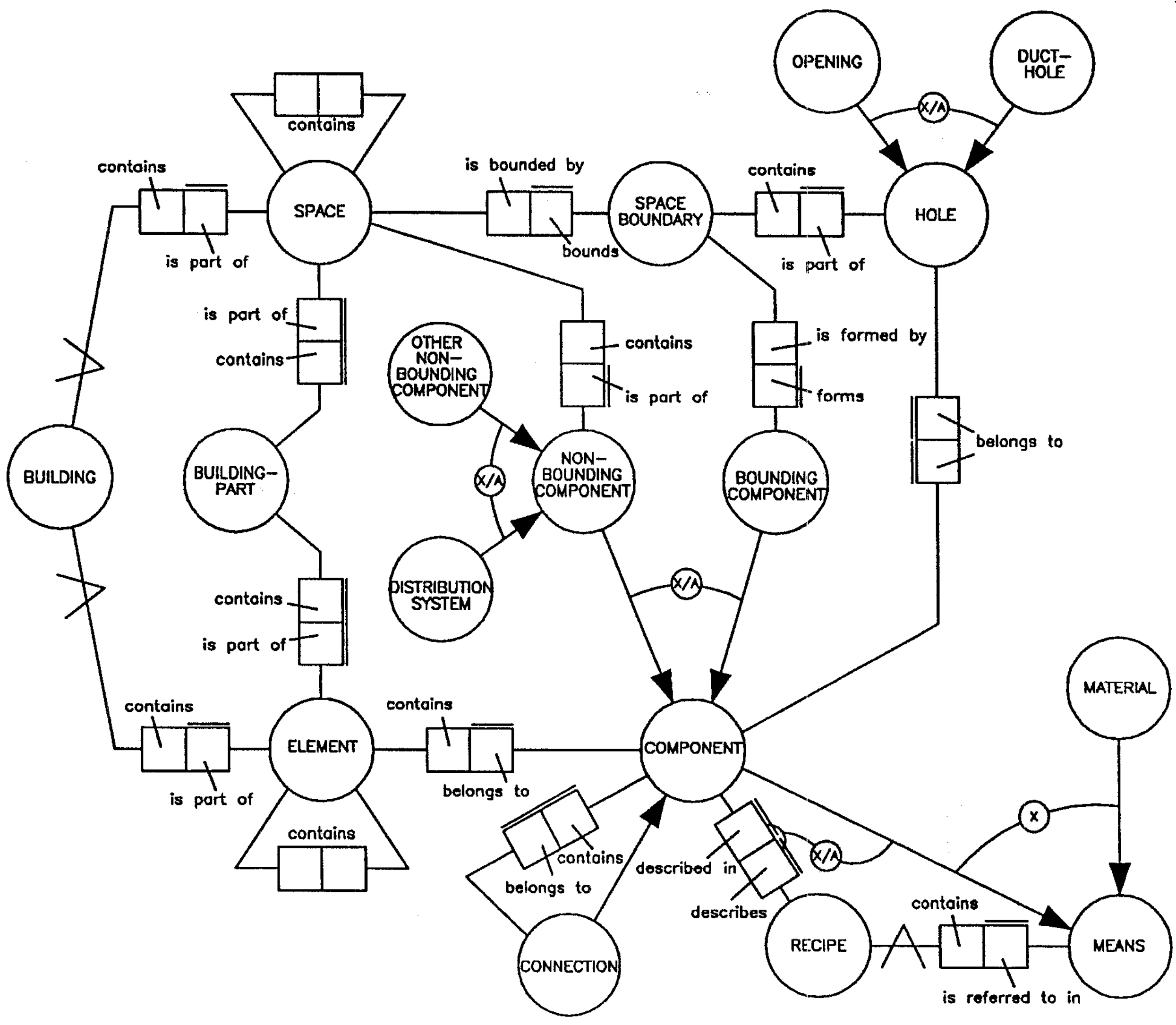

Fig.5 NOBI/BM information diagram (NIAM).

The above figure shows a NIAM representation of the NOBI/BM conceptual model.

In the early stages of development of the model, EXPRESS-G was used as schema-technique. As more details became important, especially on relations between entities, NIAM was used to represent the model, because it allows representation of constraints on relations between entities. It was important for instance to define that a component that is described in a recipe can not be a means in the same recipe, because this would be a recursive decomposition.

5. THE PROTOTYPE.

Integrated in the process of development, as described earlier in this paper, a prototype CAD-application was developed for direct evaluation of the conceptual model. This prototype was used for evaluation by the developers of the conceptual model in an early stage, and as such had a certain influence on this conceptual development. Demonstrations of the prototype to participants of construction practice were expected to result in useful feedback and critical comments. This section briefly describes the contents of the prototype and the influence it had on the development of the model.

5.1 OBJECTIVES OF EARLY PROTOTYPING

One of the main objectives of the prototype CAD-application as built in this early stage of conceptual development, was to demonstrate the outcomes of the research to the construction practice. These demonstrations were planned for several reasons. One reason was to inform participants in construction practice of the kind of research that is currently being developed in many research-teams. This goal of demonstrating prototypes corresponds to the need for construction practice to change mentality and organisational structure as indicate before in this paper.

Another objective for prototyping in an early stage of conceptual development, was to evaluate the results of these developments in a practical situation. This forced the research team to be very explicit in defining the different parts of the model, and, at the same time, resulted in practical problems that did not arise in the process until then.

This leads to another reason for demonstrating the results of early prototyping to construction practice, which was to obtain practical feedback in this early stage of conceptual developments. A partly operational prototype of a computer system based on an information structure that is completely new to people who are likely to use these kind of systems in the future, offers them a much more direct possibility to react on this structure. Showing the same structure in abstract schema's like the NIAM diagram in figure 5, asks an effort which non-IT-specialists are not likely to support.

For these objectives of prototyping, the requirements of the prototype are not to build a complete operational system representing all the details of the building model, but rather a system which demonstrates the main concepts and impacts of these concepts on modelling practice.

5.2 CONTENTS OF THE PROTOTYPE.

The prototype CAD-application for the NOBI/Building Model allows the architectural user to model a building based on the conceptual model as shown before.

This includes modelling the building in both spaces and physical components. The system demonstrates the following concepts:

- modelling elements and components by functional specifications

This involves the input of a large set of functional specifications, based on many different sources, such as normative prescriptions, project requirements, and architectural principles. It is important that the system allows flexible and elaborate specification of functional requirements.

- modelling components by technical solution

For components, the functional specifications can be translated to technical solutions. This can be done by specifying the different technical specifications that are implied by a chosen solution, i.e. materialisation.
Another way of modelling technical solutions is to refer to a library of technical solutions delivered by manufacturers. The prototype shows both methods and demonstrates the importance of sufficient flexibility in using both mechanisms.

- modelling of space-boundaries

Space boundaries can be defined by explicit modelling of their geometry. This is useful for the early stages of design, when the enclosing structures of spaces can not yet be determined. At a later stage, it is useful to be able to model space boundaries implicitly by modelling the bounding components. Thus, placing a wall as a bounding component at the same time places a boundary of the spaces adjacent to the wall. This mechanism ensures the consistency of the model in both the space-based concept and the component-based concept.
The same mechanism is used to model holes in space boundaries implicitly by placing opening-components in a bounding component.

- querying the model for information on spaces and components

Adequate feedback of the modelling system to the user is crucial for the acceptation of the system by the user. For the purpose of demonstrating, it was important for the prototype to allow interactive consultance of the model for the extensive information it contains.

Dealing with architectural information in a design process, unarguably requires sufficient graphical feedback to the user of a CAD-system. A graphical interface not only involves a graphical representation of the model as it is built by the user, but also includes extensive, graphical interactivity between user and system. This graphical interactivity is important for adequate support of design decisions, for instance while choosing components from a library or positioning components in the model. Examples of these aspects are presented in the prototype, as shown in the figures A2 and A3 in the appendix of this paper.

5.3 INFLUENCE OF EARLY PROTOTYPING ON THE DEVELOPMENT OF THE CONCEPTUAL MODEL.

Early prototyping had a significant influence on the development of the conceptual building model in the NOBI/BM project. First, it forced the research team to translate the conceptual model to specifications at the level of prototyping. This involved a practical evaluation of the definitions of entities in the model and of the mutual relations between these entities.

Then, secondly, prototyping also showed clearly the relevance of problems that are related to building modelling, such as how to handle classifications, and more important, the lack of a generally accepted classification of building-information or even of building components only.

5.3.1 Definition of entities.

The process of translating concepts to implementing specifications resulted in improved understanding of, for instance, how to define elements and components. It emphasised the mechanism of decomposition of elements into components and how to define their relations to the models of cost-engineering and HVAC engineering.

Another entity that needed to be defined very explicitly was the space boundary. Although the general notion of space boundaries was clear to the participants of the research project before prototyping had started, it turned out that, still, many definitions were possible within this general notion. A space boundary, in relation to a bounding component, such as a wall, can be defined as a face geometrically positioned at the surfaces of the wall, or at the heart of the wall. In the first case, a wall as bounding component represents at least two space boundaries of two or more spaces. In the latter case however, the space boundary itself is related to two or more spaces. This last solution was chosen to be implemented in the NOBI/BM prototype, because it corresponds better to the HVAC-model for heatloss calculations of spaces, and because it facilitates a more practical manipulation of the space boundaries in all stages of design.

In coherence with the definition of a space boundary, it was necessary to define the meaning of the entity 'hole', together with its relation to space boundaries and bounding components. Prototyping brought up the discussion if a hole is really necessary as a separate entity in the conceptual model, or could the notion of an opening in a space boundary be represented by creating two adjacent space boundaries, each related to different bounding components? At a conceptual level, both solutions seemed possible, but in the communication of building information to HVAC applications, it appeared necessary to define holes as a separate entity, in order to be able to distinguish a hole from a space boundary.

Other discussions on the definition of holes involved discriminating different types of holes and their different relations to both bounding components and non-bounding components.

5.3.2 Multiple classifications.

Another result of prototyping emphasised that new techniques in dealing with architectural information, which are more elaborate than the traditional production of drawings and documents, require new classifications of architectural information. Automation of processes requires more strict classification of information, but as long as these classifications have not been agreed upon, adequate flexibility of computer-systems towards the use of multiple classifications is indispensable. This is especially true when information needs to be communicated to different disciplines, each using their own classifications.

In the NOBI/BM no assumption was made upon which classification should be used in organising spaces, elements and components, but an attempt was made to demonstrate the possibilities of allowing multiple classifications in the same system.

It is noted that not only classifications of spaces and physical parts of a building need to be developed, but that product modelling also requires taxonomies of functional information, such as normative prescriptions, where comparable data need to be represented in a uniform manner.

6. THE DEMONSTRATION.

One of the objectives of doing early prototyping in this research, was to be able to demonstrate the developments of the conceptual model and to discuss the use of this model in construction industry practice. Although the prototype is of course limited as a fully operational system, the effects of demonstrating the possibilities of such a system have shown clearly. This section describes some of the effects of this approach, the learning-effect of the demonstration on participants in the construction industry.

6.1 OPENING DISCUSSIONS.

The model and the prototype were demonstrated initially to the members of the comment-group of the project and to other individuals who are already involved in using IT for the construction industry. The demonstrations for these groups mainly had the effect of opening discussions. The prototype formed a point of departure for more detailed discussions of the problems in the development of the conceptual model. As mentioned before, the definition of entities in the model was stimulated by the practical case study as formed by the building that was modelled with the prototype. The meaning of abstract concepts, such as space boundaries, could be better understood, discussed, and agreed upon, once visible representations of proposed solutions were available.
Moreover, new issues were brought to discussion by the demonstrations of the prototype. The problem of connections between components, although known before the prototype was implemented, came into scope at the time of the demonstration and could be discussed in more detail when the participants had the 3D representation of the spaces and components in front of them. This discussion was also part of the instructive effect of the demonstrations towards participants in practice of the construction industry.

6.2 INSTRUCTIVE EFFECT TOWARDS PARTICIPANTS.

After the first cycle of developing, demonstrating, evaluating and redeveloping both the conceptual model and the prototype, the project was ready for demonstration to participants of the construction industry who were not very deeply involved in IT for the construction industry. The effects of these demonstrations can be summarised by some examples of discussed issues given below:

- elements vs. components: a renewed discussion of an old topic

The functional definition of the entities 'element' and 'component' appeared again point of discussion. The definition of elements as functional aggregation of more detailed components was discussed in relation to the view of purely component-based modelling, in which elements, with a higher level of abstraction, are not defined as distinct entities in the conceptual model.

- connections: a new discussion

In the NOBI/BM, components are related to each other via connections which are defined as a special sub-type of component. Alternatives for this approach to the problem can be found and were brought into discussion after presentation of the model and prototype. Connections might be modelled as distinct type of entity in the model, as alternative to the sub-type component. As a second alternative, instead of defining an entity for connections, this type of relation could be modelled as property of components. The NOBI/BM model and prototype included an entity for connections, mainly to contribute to the awareness of the problem and to open the discussion on how to model connections.

- classification of information

The prototype allows the user to select a classification for elements and components. The selected classification determines part of the interface that the prototype uses to present the hierarchy of elements and components to the user. This phenomenon of the prototype made the audience of the demonstrations recognise the problem that many CAD-applications are based on strict classifications which are implemented in the system in a rigid manner. The users of these systems have no control over the prescribed classifications, which limits the domain of application, especially when current classifications are not suited for advanced modelling techniques such as product modelling.

7. CONCLUSIONS.

Let us start by recognising the fact that this research project only just touched the immense problem field of modelling building information. The project is regarded as an evolutionary incremental development based on the existing models in the NOBI-framework. These models, of course, are based on a broad history of international developments, but are themselves still under development.
It is clear that the kernel model for integration of architectural information with related disciplines can not be developed until international standards for each of the disciplines, including the architectural discipline, have been developed and generally accepted.

The interaction of the developed theory with construction practice, building a prototype and demonstrating it, had an important influence on the research itself: many issues of discussion could be made explicit and were presented in a way which made them easy to comment on. Although there is a risk of being too conservative, the participation of parties directly involved in construction practice gives a more direct practical assessment of conceptual developments.

Combining conceptual developments with prototyping and involving participants of the practice of construction in the research project resulted in the following effects:

- early evaluation of the conceptual model
- early indication of specific problems in application of the model
- instructive effect of demonstration for participants
- stimulus of open discussion and rationalisation-process

The prototype and the demonstrations fulfilled the important role of inspiration and stimulus to more open and direct discussions on issues that before were experienced as being very abstract.
Involving participants from the daily practice of construction stimulates the process of rationalisation of the construction industry. It helps to change the mentality of participants towards new information technologies and it helps to realise that organisational restructuring during the process of automation is not a threatening, but a constructive development.

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APPENDIX

The appendix contains additional figures to the paper, presenting the meta-model for the Building Model entities, and showing a glance of the prototype CAD-application built for NOBI/BM.

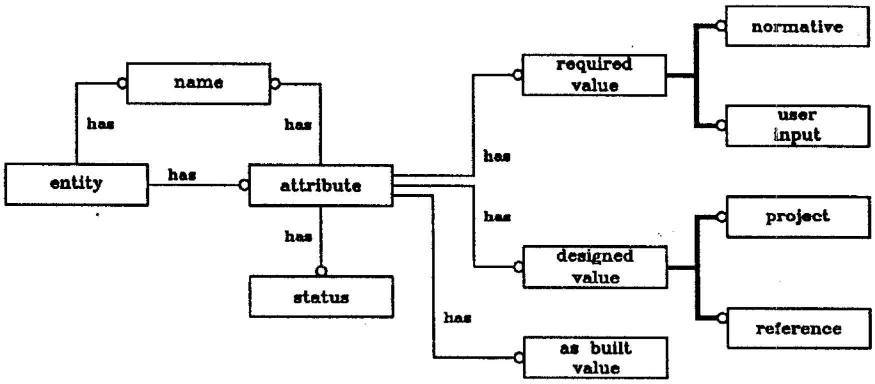

Fig.A1 The Meta-model for NOBI/BM entities showing that attributes of entities have three types of values.

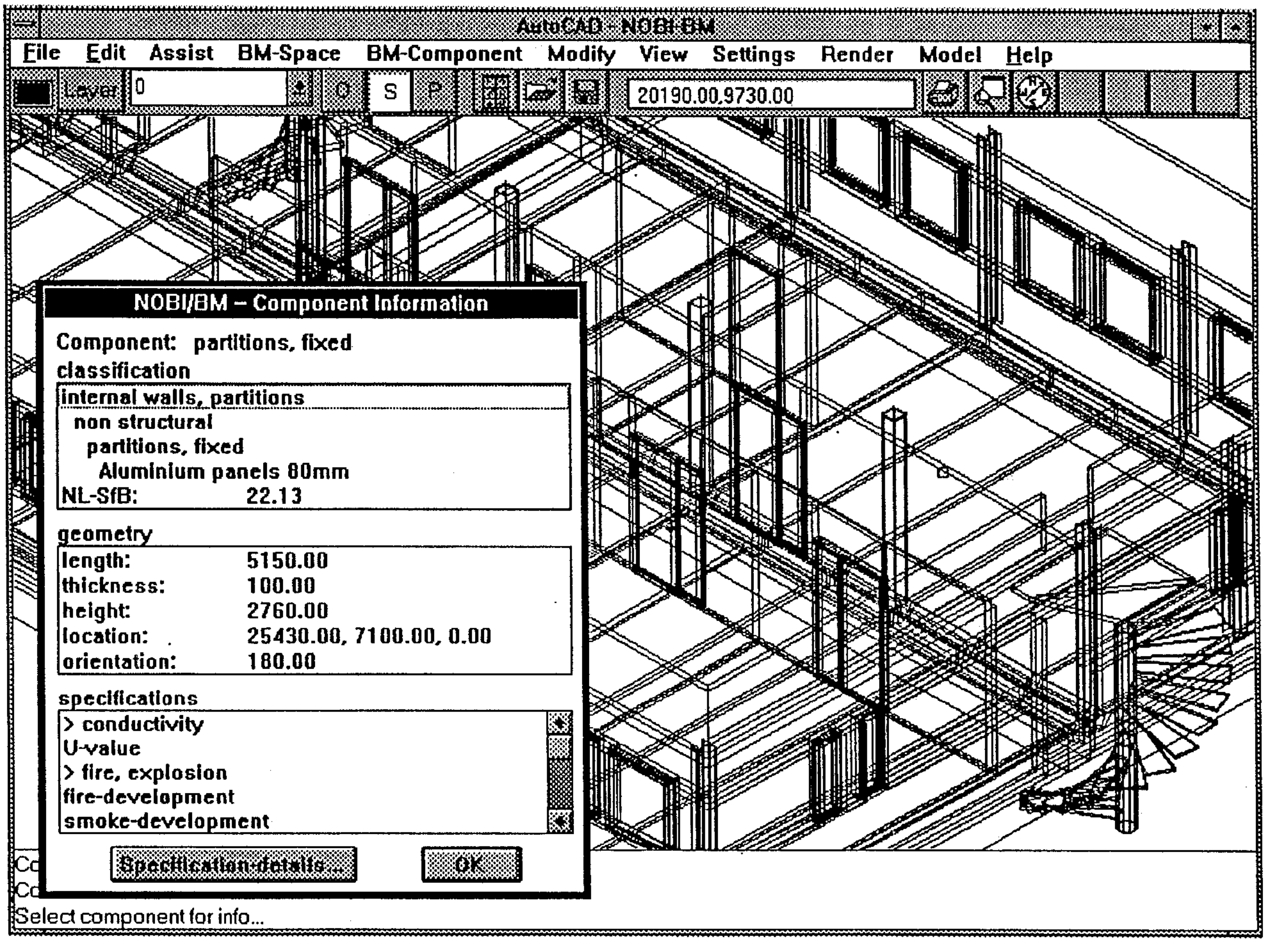

Fig.A2 Image of a screen-display of the NOBI/BM prototype CAD-application.

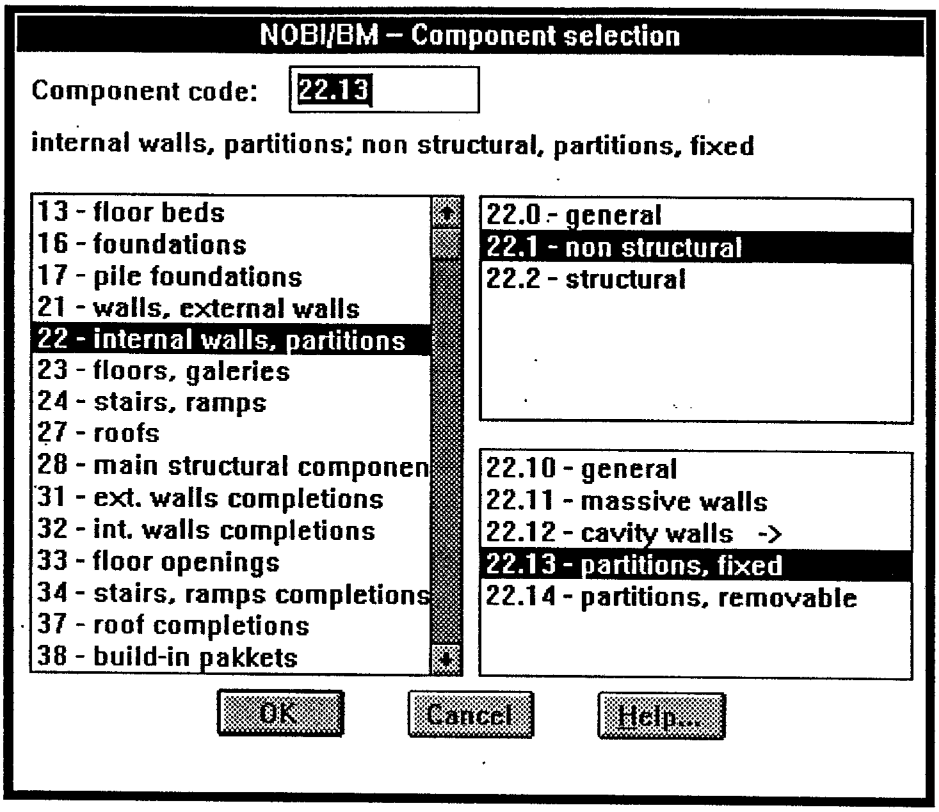

Fig. A3 Dialogue-window in the NOBI/BM prototype: a classification of components.

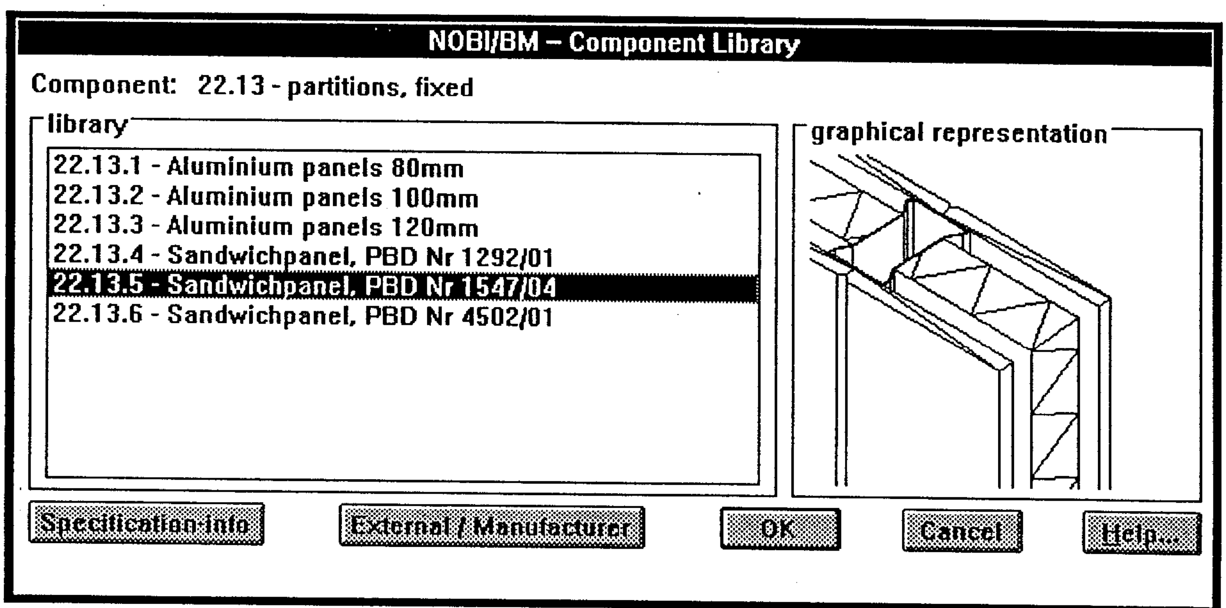

Fig.A4 Dialogue-window in the NOBI/BM prototype: graphical interaction in making selections from a library.