The Use of Product Model Data in Building Construction Process

Ilkka Romo
The Confederation of the Finnish Construction Industries,
(email: ilkka.romo@rakennusteollisuus.fi)
Kari Karstila
Eurostepsys Oy (email:kari.karstila@eurostep.fi)
Lauri Melvasalo
Laurimark Oy (email:lauri@laurimark.fi)
Seppo Niemioja
Arkkitehtitoimisto Innovarch Oy (email:seppo.niemioja@innovarch.fi)
Kristiina Sulankivi
VTT – Technical Research Centre of Finland (email:kristiina.sulankivi@vtt.fi)

Abstract

For the different parties of a building construction project, product modelling is an efficient data management method. Product model based data can be utilised and exchanged in various ways in and between different sectors of design, construction site management, and product industry. The product models of the different parties in a construction project can be integrated into a shared model which is augmented with data as the project progresses. In designing, both common product libraries and company-specific product libraries are used, enabling the transfer of product data from design to manufacturing. Creating guidelines for architectural, structural and HVAC design is necessary in order to make sure that data is stored in a concise way and that each designer can make use of the other designers' plans. In addition to design guidelines, another important prerequisite for this is IFC, a data transmission standard that allows information to be trustworthily stored and transferred between different software. Product model based construction process has been tested in several pilot projects where the results have been promising. Developing common principles and operating methods further will speed up and streamline product modelling in the building construction industry. As a whole, a product model -based process will improve companies' customer service, productivity, and construction quality.

Keywords: product model, data transfer, product component libraries, IFC data transmission standard

1. Introduction

During years 2003 and 2004, the Finnish construction industry has developed design, construction and maintenance in the building construction process based on product modelling. The development has taken place within the framework of a technology project called Pro IT –

Product Model Data in the Construction Process, in which businesses, research organizations, governmental organizations as well as interest organizations have participated. More information on this technology project can be found in a recent article [1].

A product model means a description of the building in such a way that, in addition to the geometrical 3-D visualisation, the model contains data defining the building and its components. The data may apply for example to the finishing structures in spaces, the characteristics of the materials, fire-resistance, colours, environmental impacts or sound insulation.

A product model is composed of product components, which can be modelled either on a case-by-case basis or by using ready-made product component descriptions in a product library. A product library is a collection of product components in an electronic form. The libraries contain the components commonly used in design, such as walls, doors and windows. It is also possible to make libraries of other product components, such as furniture and interior design accessories.

In the Pro IT project, a standardised method is developed for the design of a product model in the stages of architectural, structural and HVAC design. The starting point in the different design stages is the model created by an architect. The data exchange between the parties is developed on the basis of the international Industry Foundation Classes standard (henceforth referred to by the abbreviation IFC [2]). The main advantage of the IFC standard is that a number of designers from different fields can take part in construction projects irrespective of the software and file formats they use.

In construction industry, product modelling is still a relatively young technology and is not in widespread use. Despite the shortage of published information on or studies about practical applications and working methods of product modelling, there are some pilot projects on which the method has been tested with good results.

This paper proceeds as follows. In section 2, the benefits of the construction process based on product modelling as opposed to traditional processes are described, before the new process is briefly summarized. Subsequently, the need for developing general guidelines for product modelling designers is established in section 3, and the existing design guidelines as well as those still under development are described. Section 4 examines the IFC data transmission standard which is essential for the practical exploitation of product modelling, and section 5 casts a brief look into the different product libraries currently being developed. Section 6 sheds light on the pilot testing of the project. Finally, the conclusion summarises the essential points about product modelling and sets some directions for future development of the method in construction industry.

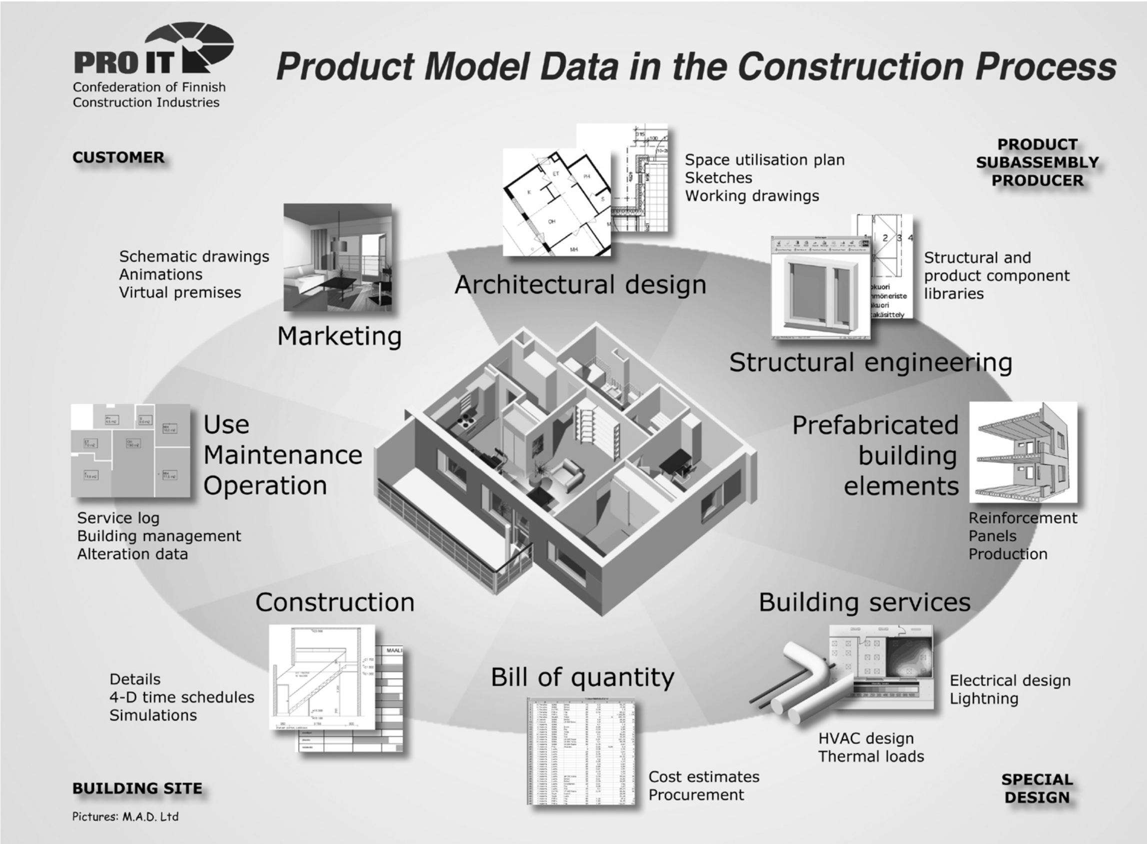

Figure 1. Product model-based data management for a construction project integrates the data needed for design, product manufacturing, construction, and the use and maintenance of the building.

2. The Advantages of the Product Model Based Process

2.1 Product Model Based Data Management

With the help of a product model, it is easier to keep under control all the data needed for the design, construction, usage and maintenance of buildings. The data can be managed in real time and in an intelligent and graphical form. The huge quantity of information needed in the successful realisation of a construction project can be transmitted between participants as well as managed more reliably and efficiently than before. An important possibility is to employ the structure and data content of the standardised product model to streamline and speed up the planning and control of construction projects. One of the most tangible direct advantages of standardised product models is that bills of quantities can be generated directly from the model for use in cost estimating, production planning and procurement.

The product data used in product modelling opens up a number of possible applications for the product industry [3]. Using a product description selected from a product library as part of a plan ensures a good technical and economical result, transfers the product data to manufacturing in good time, and also serves as a marketing tool.

Product modelling transforms building design from traditional line-drawings to visual 3-D design. In addition, a product model has in-built information available about the spaces, structures and furnishings it consists of. The structures of a product model such as walls and slabs contain information for instance on the materials they are made of, the measurements needed, and their thermal insulation, strength and environmental qualities.

When a 3-D product model and a time schedule are combined, the result is 4-D design. It enables site management to determine the most advantageous order of construction and the most economical time schedule from within an array of possible options. 4-D design also visualises the flow of worksite production and particularly problematic stages which demand more attention than usual from the site management.

After the planning and implementation phase of a construction project, it is possible to use product modelling to create a data store covering the entire life cycle of a building. The final product model shows all the materials and products used for the building, and can be updated when needed.

2.2 Product Model Based Operating Process

When one changes over from 2-D drawing to 3-D modelling, the production and management of designs are made more efficient: there is less routine work and fewer design flaws. Input data, such as quantities, are obtained automatically for various purposes and in the form of time-saving lists. The design geometry and dimensional accuracy come in handy in the design and manufacture of components.

Expertise from various fields of design and construction specialists is, through product modelling, usable in a practical form from the start to the end of a construction project. The inclusion of construction specialists in the design process improves cost-awareness and the possibility to figure in technical aspects of installation and manufacturing as well as allows room for innovative solutions. Instead of viewing the economy of a building in separate parts, it can be planned and assessed as a whole.

The last but not least of the ways in which product modelling improves construction processes is that it helps to achieve the goals the construction industry sets for customer satisfaction. It is crucial that the clients and end users of buildings are aware of the characteristics of the buildings built for them, that the buildings as end results correspond to their needs, and that unpleasant surprises are kept to a minimum. With the help of product modelling, the clients and end users of the building are provided with more information and specialist assistance to support their decision-making. The techniques used for this are visualisation and simulation.

2.3 Description of the Product Model Based Construction Process

The product model-based process supports exchanging and sharing data throughout the life cycle of a building. The ultimate aim is a process in which the product model data is produced, exchanged and utilised in an easy-to-use digital format between different software packages and participants. In order to arrive at this aim, it has been deemed most necessary that the participants of construction projects and the flows of information between them are systematically listed and described with respect to the different stages of projects.

The product model-based process has therefore been described by a systematic method (so-called IDEF0), in which the process is divided into sections. These are pictured as compatible diagrams which constitute a hierarchy. The diagrams represent the functions of each section, the programs used, the participating partners, and the data flows between them and their design software. The process model covers the life cycle of the construction project and the building from the preliminary design to the operating and maintenance.

3. Design Guidelines

3.1 Basics and Objectives

Uniform modelling guidelines for various designers of the construction process are necessary in order to transfer product models from one program to another. Being able to transfer product models between programs is a prerequisite for clash detection analyses of the models created by different designers and for ensuring that the bills of quantities extracted from the models are accurate. Furthermore, the data on the characteristics of product structures stored in a product model should be defined by a commonly shared method.

The modelling guidelines for the architect are the most crucial and demanding, as the model made by the architect serves as the input data for quantity surveying, for structural and building services design, and for marketing. It must therefore contain information for many different purposes – for example, spaces, building components and the principles of their connections. It is particularly important to transfer measurements to other plans correctly.

A key aim of the modelling guidelines for structural design is to provide basic data and instructions for the product-model-based description of structures and to influence that computer programs and the libraries on structural parts, details and joints are drawn up in line with the same principles of product modelling. General modelling guidelines also serves as an aid for drawing up project-specific modelling instructions. The guidelines can also be used to harmonise and standardise terminology, operating procedures and working methods.

So far, the third version of the guidelines of architectural design has been published in Finnish under the name Product Model Design Guidelines for Architects – General Rules and Fundamentals [4]. The first version of the guidelines for structural modelling has been completed, and at the moment it is being tested on real construction projects. The guidelines for modelling building services have also been started: currently, the content of the guidelines is being defined.

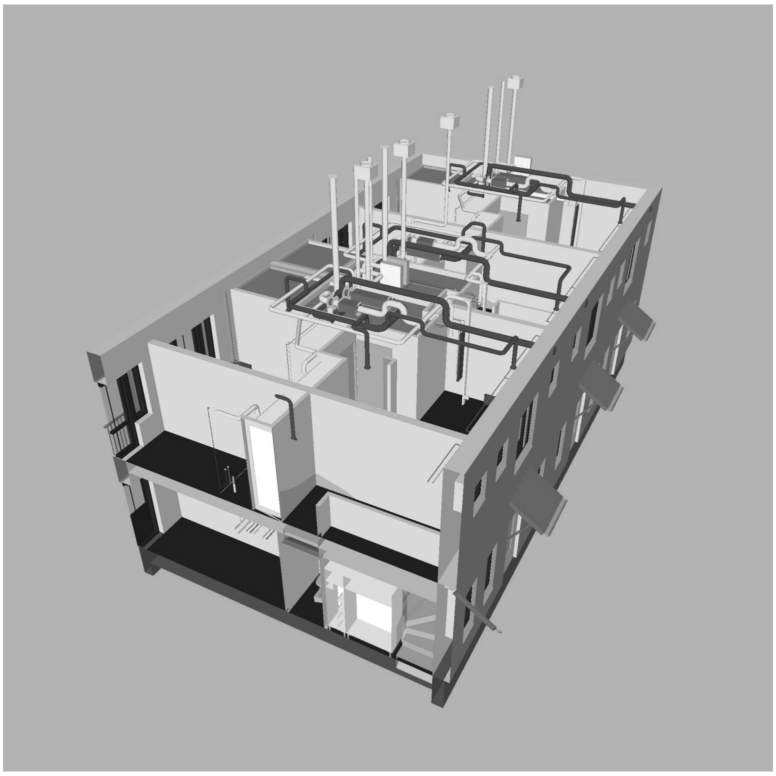

Figure 2. Combining the architect’s model and the building services model and clash detection analysis reduces errors on the worksite.

3.2 Stages of Product Modelling

The designing of product models is divided into stages in accordance with the construction process as a whole. Descriptive terms have been agreed on for the different stages. These differ from the conventional terms, because product model-based design does not comply with traditional practice. The design model includes four stages: the requirement model, the space model, the preliminary building element model and the final building element model. The requirement model may be for instance a description of the client’s needs and the building authorities' requirements, as well as the parameters set by conditions. This model may be represented in a spreadsheet application or other digital format.

The space model, in its turn, covers spatial solutions. The model does not yet necessarily include walls distinguishing the spaces from one another. The basis for formulating this model is the space utilisation plan together with its data on the individual spaces.

The preliminary building element model includes the elements which delimit the spaces and correspond to drafts in present-day design practice. Requirements are set for the elements, such as the fire class and thermal conductivity, but the structural solution is not yet selected. The building elements are defined at a construction type level. Ready-made construction types from the general product libraries can be used to create this model.

In the final building element model, the construction types shown are building elements together with product data, like the actual products of suppliers. In this model, supplier-specific data have been added to all the elements, accessories and so forth. The final element model may also include other information, such as time schedules and job plans. The models following the four actual stages of the design model are the as-built model together with site and installation data and the maintenance model in a life-cycle program. The maintenance model can later be updated with spatial alterations and additional construction.

4. Data Exchange and the IFC Standard

4.1 Data Exchange Use Cases

One of the key aspects in the product model-based building process is the interoperability of computer programs, and the support for the life cycle of the building information throughout the construction and operation process. A prerequisite for the realisation of this is to enable the digital data exchange of building information between the participants of the process and their programs. Then information once created by a participant and his or her program can be exchanged and shared with the downstream programs of other participants.

To enable the support for the many required data exchanges within the multidisciplinary building process, these exchanges need to be first defined, and then implemented as data exchange interfaces in the programs. The definition of the exchanges can be done by so-called *data exchange use cases*. A data exchange use case is 1) an identification of a business need for the data exchange, 2) definition of the information to be exchanged, and 3) definition of its implementation, for example, using a data exchange standard.

In the pursuit of advancing the practical product model data exchange, the Pro IT project has defined a set of necessary data exchange use cases. The use cases defined include the following exchanges:

- from architectural design to quantity take-off and cost estimation
- from architectural design to HVAC design
- from architectural design to structural design
- from various designers to design coordination and clash detection
- general quantity information exchange, e.g. from quantity take-off to tendering
- from product libraries to various programs.

4.2 The IFC Standard and How It Works

A data exchange specification called IFC (Industry Foundation Classes, [2]) has an important role within the data exchange use cases defined by the Pro IT project. The use cases define how IFC is used to implement the support for the exchanges.

The IFC is an open specification for AEC/FM interoperability. The scope of IFC is AEC/FM over the life cycle of buildings. IFC is developed by IAI (International Alliance for Interoperability, [5]). IAI's mission is to develop, promote and support the implementation of Industry Foundation Classes.

IFC specifies a neutral format in which programs can exchange digital building information. Using IFC, an architect can for instance send a digital building model created with a model-based CAD programs to an HVAC designer. The HVAC-designer could then use the model, its spaces, building elements, and 3-D geometry directly as input data for the thermal simulation program to calculate thermal loads and requirements. The same building model could also be used by a cost estimation program to automatically extract a bill of quantities and to calculate an initial cost estimate for the building.

All the Pro IT use case definitions follow same content structure: In the first part of it the purpose and scope, typical participants, and their program types are identified. Then the data content or the information requirements of the exchange are defined. The second part of the use case defines the subset of IFC object model which is required to support the use case. Examples and usage rules of the IFC are also given. The use cases are defined using a methodology including re-usable definitions, such that new data exchange use cases can easily be addressed and defined.

The data exchange use cases serve the purpose of a proposed common agreement on how IFC can be used to address real-life exchange requirements. The target audiences for the use cases are on one hand the participants of the construction process, and on the other hand the software developers, who may be implementing exchange interfaces for their design and construction programs.

5. Product Libraries

The Finnish construction industry has sought to standardise the data content and presentation of product structures so that the various participants in the construction process can use them. Both the definition of data with building component cards and product libraries for use in 3-D design are needed, so that designers are able to plan and manage customer demands, builders are able to estimate quantities and costs, and operators are able to use completed buildings and perform maintenance tasks.

One of the completed tasks is creating a structure library common to the construction cluster containing the most frequently used types of structure. The library currently includes over 200 different structures, which are mainly structures used in housing construction. However, the principles used there could be applied in the future to describe other, even totally new structures. With the common product model library as their starting point, companies will be able to create their own product libraries compatible with commonly agreed specifications.

The next challenge in the development of product libraries is to establish a link between common product libraries and specific products included in the product portfolios of manufacturers. The link would make it possible to choose specific products suitable for the design based on the general characteristics defined in common product libraries. The search for the specific products needed could be carried out for example by Internet search devices.

6. Pilot Testing

The piloting of the use and exchange of product-model-based data is an important prerequisite for the broader utilisation of product modelling. The construction companies involved in the Pro IT development project for product modelling are responsible for this. In the course of 2004, two contractors implemented and further developed the model-based process in their own housing output [6]. The software packages used in Skanska Oy's pilot project were ArchiCAD (architectural design), Tekla Structures (structural design), MagiCAD (building services design), Solibri Model Checker (checking models), ScaleCAD (element design) and NavisWorks (integrating different models and clash detection analyses). On NCC Construction Ltd's pilot, Bentley MicroStation Triforma (architectural and structural design) and MagiCAD (building services design) were used. The subjects of the testing were the use of modelling guidelines and product libraries, the transmittance of product models between programs, and the utilisation of product libraries in the design process.

In a pilot project of a shopping centre extension by Lemcon Oy, Tekla Structures software was used to model the structures. After the modelling of the steel frame, precast concrete units and the façade's thermo spar elements, these submodels were combined into a single structural model for the worksite. The main emphasis in the piloting work was on time schedule planning for the frame work stage and on monitoring installation data. By specifying the order of installation of the building components of the 3-D model and by inputting the scheduled installation dates of the building components into the product model, a 4-D model was obtained, containing the time schedule data for the construction project. The product model was placed on the Internet, enabling all the partners in the project to view a real-time 3-D image of the situation for installation on the worksite using nothing more than an Internet browser.

Advantages of product modelling among others that were repeated in different pilot projects were that it facilitated change management as well as the production of bills of quantity and various images and views. In principle, it is possible to generate all the conventional design documentation, such as drawings, from the product models drawn up. Product models have also permitted quantity listings of all the modelled construction components. As an example of the main benefits, it was noted that the time taken to calculate bills of quantities was reduced by an estimated 30-50% when using the new method. It must be admitted, however, that it is a prerequisite for such significant time savings in calculations that the subject building has been modelled comprehensively and extensively enough. The quantity data taken from the model have been estimated to be as much as 80–90% usable in making a time schedule for the construction project. In the project for an extension to a shopping centre, a graphic 4-D model proved itself to be an efficient tool for time schedule planning.

Other advantages include, for example, the possibilities to use three-dimensionality to assist design work and in integrating the work of different fields of design. A further prime advantage of product modelling that has emerged was the reduction in errors. For example, it was possible to eliminate measurement errors from designs almost entirely. It was also possible to use the product model on the worksite in many ways in the management of installation, logistics and complex delivery chains.

Most needs for further development were identified in data exchange between different software packages. Because IFC standard data exchange did not yet run satisfactorily, it was necessary to exchange data also using other, program-specific formats. The piloting will continue in 2005 on projects by four different contractors, in which the operating model and data exchange will be developed on the basis of the feedback received.

7. Conclusions and Directions for Further Development

The experience gained of the use of product modelling in the construction industry indicates that there is considerable scope for increasing efficiency in various subdivisions of the design and construction process made possible by this new method. The increased efficiency requires that common product modelling operating methods and data content definitions are finalised and taken into more widespread use.

The feedback so far indicates that compliance with architectural modelling guidelines and the use of general product libraries facilitates fast and efficient calculations of quantities. On the basis of the quantities, one may separately derive the costs and time schedule data. Quantity calculation and time scheduling are the first widely usable application methods where product modelling has proven its benefits. These methods are increasingly being used by construction companies.

Structural modelling is developing dynamically, and models can already be used not only for design but also for worksite 4-D time scheduling and production management. The structural model yields considerable benefits for the worksite using visualised plans and material listings. A structural model can also be used in the further design of building components, as has been done on the pilot sites of the Pro IT project. Building services modelling provides a visualised image of systems for purposes of installation, and it permits clash detection analysis and the design of the necessary provisions. The building services model can be used, for example, for simulating indoor air conditions and for dimensioning the energy consumption.

The main requirements for the onward development of product modelling relate to data exchange and the improvement of overall levels of expertise. For the development of data exchange, systematic work for the adaptation of the IFC standard must be continued so that it can be used to transfer the data required for different plans and for production between program solutions. Current data exchange is still based on file transfer. In the future, however, efficient team design will require the use of dynamic product model servers. From these servers, each designer will be able to access only the part required and to update the plan back onto the server. The first product model server solutions based on the IFC standard have already been created.

As a whole, the product model-based process is expected to yield substantial benefits to all the parties in the process. However, widespread adoption will still require considerable efforts. Particular attention should be devoted to developing standards for data exchange between design software, determining product attributes and creating product libraries.

Data exchange between different software should be developed by making it possible to widely apply the IFC standard. In practice, this will mean developing and expanding the IFC standard in such a way that it covers all the usage of data exchange required by the industry better than at present. Also, greater efforts on the implementation of the standard will be required of the software industry so that software will support the standard. Therefore, the standard needs to be developed a strong and international one.

The use of product data in the design, construction, use, and maintenance stages of a building requires information on the materials and solutions used as well as efficient and reliable electronic archiving. For it to be possible to create electronic product descriptions on the basis of the product data, the attributes of the product data should be defined internationally. On the basis of common attribute definitions, it will be possible to build jointly used product libraries and product symbols for software and to establish connections from them to different types of product libraries. This kind of product libraries will facilitate efficient marketing and comparisons between different products as well as promoting procurement on a broad level.

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