A case study of the conceptual product modelling of buildings: Prefabricated Reinforced Concrete Structure

William F. Danner
Center for Building Technology
National Institute of Standards and Technology, USA
Pekka Leppanen
Laboratory of Structural Engineering
Technical Research Center of Finland

Abstract

Building product models will play a central role in the computer integrated construction environment of the future. At present, many research projects are developing the conceptual modelling methods needed for the definition of product models. The goal of the research project presented in this paper was to develop a computer sensible model of actual construction components. The modelling domain was a prefabricated reinforced concrete structure including foundations. The project made use of conventional design drawings, tables of component properties, and information analysis methods. The aim was to specify the information requirements of actual building components and to develop a conceptual building product model based on those requirements through the interaction between an expert in structural engineering and an expert in information analysis. The study was conducted at the National Institute of Standards and Technology (NIST) as a cooperative project between NIST and the Technical Research Centre of Finland (VTT).

1. Background: Computer Integrated Construction

The construction industry has just begun to understand the potential of Computer Integrated Construction (CIC) technology. A principal benefit expected from CIC technology is the ability to manage information as rigorously and intelligently as other business assets in order to obtain gains in productivity. A principal concern is the appropriate time for investment in CIC systems as practical tools for actual building projects. CIC technology will inevitably change building industry practice among all the participants. For this impact to be realized in an optimally beneficial manner, there are four principal components of CIC systems that must be in place.

Building Product Model	Consensus conceptual models that meet building information requirements.
Building Industry Data Bases	Sources of general, project independent construction information such as codes, standards, materials, and building product data produced by industry suppliers.
Data Exchange Systems	Mechanisms for the complete exchange of product model data between the participants in a building project.
Application Software	Applications that both meet the functional needs of the building project participants and provide appropriate user interfaces to building product model data, building industry data bases, and data exchange systems.

Progress is being made on each of these components. Building industry data bases are beginning to be developed for building materials. There are already some working product data exchange systems like those based on the Finnish BEC approach as well as development within the International Organization for Standardization (ISO) to provide broadly based capabilities for all products (i.e., STEP, the Standard for the Exchange of Product Model Data). Application software is, to a significant degree, demand driven. As user requirements are precisely articulated progress will follow.

The development of consensus building product models that meet the needs of building information requires the active participation of the building industry. Aimed at contributing to the development of building product models, the research project presented here concentrated on the definition of a conceptual model for actual construction components. The objective was to identify as completely as possible, the construction information associated with components in a well defined context and to develop a practical model of the product data in that context.

2. The Test Building

The construction industry expert was a structural engineer. A simple building structure was developed as the test building (Fig. 1). A prefabricated reinforced concrete structure was chosen because of the complexity of detail, its real-world applicability, and its relation to ongoing work at VTT concerning new industrialized apartment and office building systems. The test building as presented in the design drawings and associated tables is realistic in the sense that it would fulfill all the normal requirements as a part of a multi-story building and could be constructed from the available information.
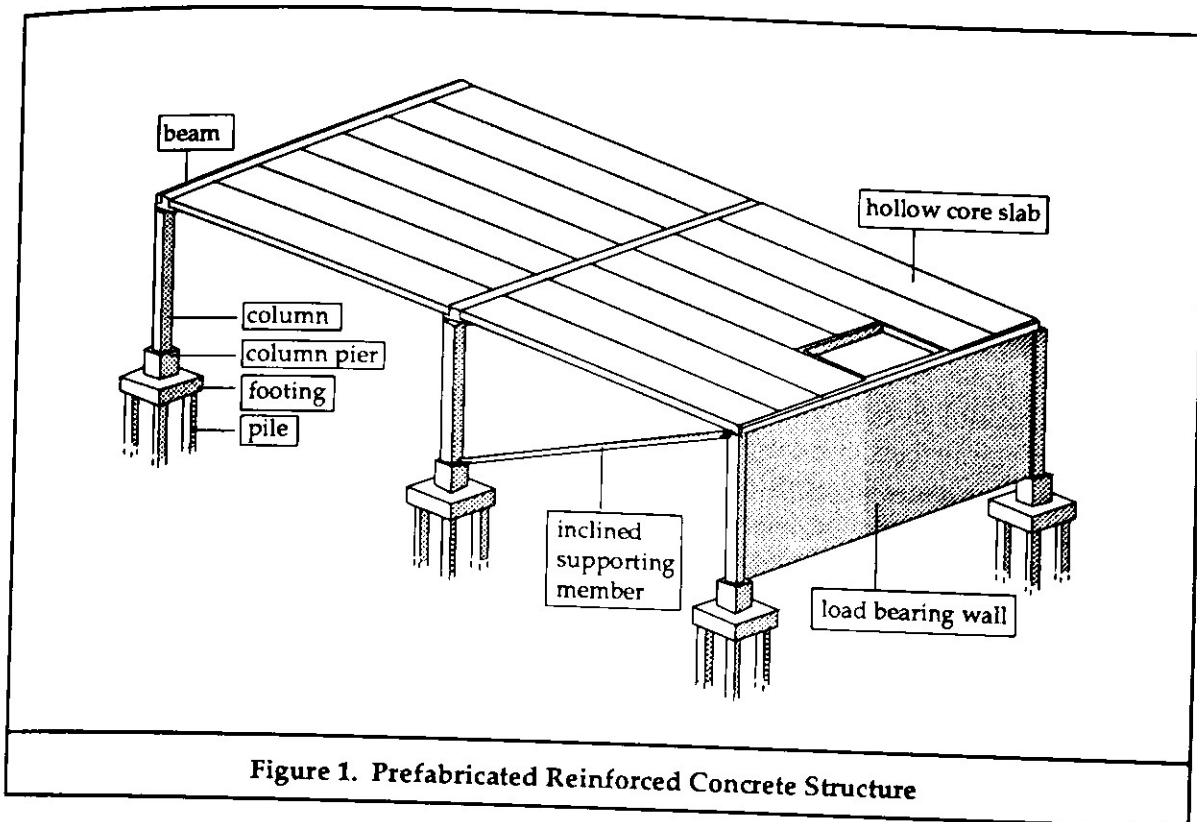
Figure 1. Prefabricated Reinforced Concrete Structure

3. The Test Building Information

Conventional structural drawings were made of the test building (27 drawings in all). Additional specifications (e.g., qualities of materials) were provided. However, for the purpose of information analysis by a data modelling expert, these materials proved to be insufficient. A major portion of the information was implicit in the drawings and the interpretation of these drawings in terms of the additional information provided. The documentation required domain expert interpretation. The goal of the information analysis was to make this information explicit and to represent the information in terms of a product data model that could be stored within a computer data base system.

As an initial phase of the project, the domain expert was instructed in basic data modelling principles and graphical representations of data models. An initial effort was made to allow the domain expert to use directly the graphical representation of a model as a means of communication between the domain and modelling expert. This approach focused efforts toward a discussion of data modelling rather than building information requirements.

The second phase of the project redirected the effort toward the development of tables of explicit information derived from the drawings and supporting documentation. Fifty pages of tables were generated by the domain expert to capture the information contained within the drawings.

The third phase of the project involved extensive discussions between the domain and data modelling experts covering the information contained within the design drawings, supporting documentation, and tables. This required the development of a common vocabulary among participants to describe building components, interactions (e.g., connections) among the components, component characteristics, and component representations.

4. The Test Building Product Model

The product model developed for the test building is specific to the context of a prefabricated reinforced concrete structure. The principles used to develop this model are more generally applicable.

Four major categories of information were identified. These included the type of components within the test building, the use made of the components in the test building, the definition of those components in terms of characteristics, and the representation of the shape of the test building and each of its components.

Components included structural, connection set, reinforced concrete, and steel components. Component use included composition (whole to part relationship between components) and connection (connectivity relationship between components). Component characteristics included material properties, location, and shape. Component shapes were represented as sets of parameters.

The description of the test building was generally consistent with the integration framework of the STEP project within ISO [1]. Five levels of product data are described in the ISO Framework.

Product Definition Context	Establishes the frame of reference of a product definition.
Product Definition	Establishes a product definition for a given product and product version as well as providing for the use of that product definition.
Property Definition	Establishes fundamental traits and characteristics applicable to a product definition.
Property Representation	Establishes a computer sensible image of a property definition (e.g., shape).
Property Presentation	Establishes a human interpretable image of a property definition.

The five levels of the STEP Framework define the architecture of a context independent Generic Product Data Model (GPDM) which forms the foundation for the description of context dependent models [2].

The building product model developed for the test building established the context as a prefabricated reinforced concrete structure. It established product definitions for specific components within the context. It established composition and connection as two central component uses. And it described relevant component characteristics. A brief summary of the information classifications for the test building follows[1]

<u>component</u>

structural component
beam
column
column pier
footing
hollow core slab
inclined support
load bearing wall
pile
reinforced concrete component
concrete filler
reinforcement bar
splice
steel component
plate
rod
connection set component
bolt set component
bolt
nut
washer
weld set component
weld

<u>component use</u>

composition
components can be part of other components
connection
structural components can be connected using a connection set

<u>component characteristic</u>

material property
location
shape

<u>characteristic representation</u>

shape parameter

Each of the components of the test building was described in terms of its composition from more fundamental components. Thus, the building structure was composed of structural components, connection sets, and connections. Structural components were composed of reinforced concrete components some of which were in turn composed of steel components. Connection sets were composed of connection set components.

Structural components and connection sets were used to describe the connections contained within the test building. Component characteristics including material properties, location, and shape of components were defined. Shape was represented by parameters[2] in order to satisfy requirements for completeness of specification adequate for construction of the test building.

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[1] "Component use" necessarily includes the description of rules that relate one product definition to another. The descriptions presented are for illustrative purposes only.

[2] Shape parameters consistent with the Finish BEC specification were used to represent the shape property of all components.

5. Observations

The development of systems that implement CIC technology requires that consensus vocabularies be established. Initially vocabularies will be developed for each context, but ultimately communication across contexts will require a common vocabulary. This responsibility rests largely on the building industry. It should, however, be a cooperative effort between industry and information analysis experts with a focus on building information requirements.

Inherent in such vocabularies are multiple opportunities for classification. Perhaps one of the most difficult and important tasks in developing product data models is the appropriate use of classifications. It is at this point that the responsibilities of the data modelling experts become apparent. Creating appropriate product definitions for components augmented by specific component uses is essential.

Identifying and developing methods of specifying component characteristics is also required in order to develop adequate building product models. Of particular importance in this project was the consideration of shape parameters used in the representation of building components. Design drawings can accommodate any adequate combination of parameters to fully specify a shape since expert interpretation is assumed in its presentation to a user. Computer systems, however, have considerable difficulty with such a wide array of possibilities. Consensus agreement on standard shape parameters for given building components could vastly simplify the task of capturing building product models.

Finally, it is the active cooperation between building industry experts and information analysis experts that will lead to solutions to the challenges inherent in the transition from today's technology to that of CIC technology. The opportunity for a detailed understanding of building industry needs that are to be met by CIC technology begins with the development of consensus building product models.

References

[1] Danner, W.F.; Proposed Integration Framework for STEP (Standard for the Exchange of Product Model Data), NISTIR 90-4295, National Institute of Standards and Technology, April 1990.

[1] Danner, W.F. and Yang, Y.; The Generic Product Data Model (GPDM), Version 0.5, National Institute of Standards and Technology, in progress.