The influence of the compliance rate, which is the percentage of the pedestrians following the adaptive guidance, is also tested. In this analysis, the update interval of 15 s is selected because the adaptive guidance has the strongest effect on the evacuation and the change due to the compliance rates could be observed more clearly. As usual, the cases of 100 and 1,000 pedestrians are not affected by the adaptive guidance because no congestion was detected. By comparing the compliance rates of 75%, 50%, and 25%, it can be observed that the compliance rate of 50% has the lowest maximum evacuation times. This result is not very surprising because in this particular example most of the alternative routes are relatively close to the original shortest routes. As a result, splitting the pedestrians equally into two nearby routes has the greatest improvement. Note that the analysis for the compliance rate is not complete and it should be noted that the optimal compliance rate of 50% only apply to this example.

Finally, **Figure 3** shows the simulation after 60 s under the adaptive guidance with an update interval of 15 s and a compliance rate of 50%. The case was chosen because its performance is the best and the effects of the adaptive guidance are easier to observe. The figure is useful for an overall understanding of the performance of the guidance system. The adaptive guidance that indicates alternative routes are shown in the figure as arrows. Compared to the fixed guidance, half of the pedestrians are taking advantage of the alternative routes to bypass the congestion areas and the reduction of the congestion areas is significant. It is noteworthy that most of the alternative routes provided by adaptive guidance are close to the original routes from the fixed guidance for this example. The implication is that the adaptive guidance and the fixed guidance are identical for the most part, and the adaptive guidance is required only next to the congestion areas. It implies that the implementation of the methodology would be straightforward and feasible. The exception of the above observation is represented by the solid line (original route) and the dashed line (alternative route) in the figure. The original route shows that the shortest path to the exit without considering the congestion is via the top right stairway. However, the congestion areas marked with the dashed circle completely blocks the corridor. As a result, the adaptive guidance guides the pedestrians to take the alternative route that leads to the lower right stairway. As a result, the associated adaptive guidance is relatively far from the congestion area, which is difficult to obtain without the help of a systematic approach proposed in this research.

CONCLUSION AND FUTURE RESEARCH

This paper proposes a method for planning adaptive emergency evacuation guidance to support pre-determined, fixed guidance systems that provide static information and do not respond to the real-time situations. Using the techniques of digital image processing, the congestion areas in the facility can be identified. By considering these areas as virtual obstacles, the adaptive guidance that instructs the pedestrians to take the alternative routes and bypass the congestion can be generated. The methodology is validated with a numerical example and the benefit of introducing adaptive guidance is significant when the number of pedestrians is large. In addition, reducing the update interval of the adaptive guidance improves the maximum evacuation times. The example also finds that the compliance rate has impact on the evacuation times and should be considered when the adaptive guidance is designed.

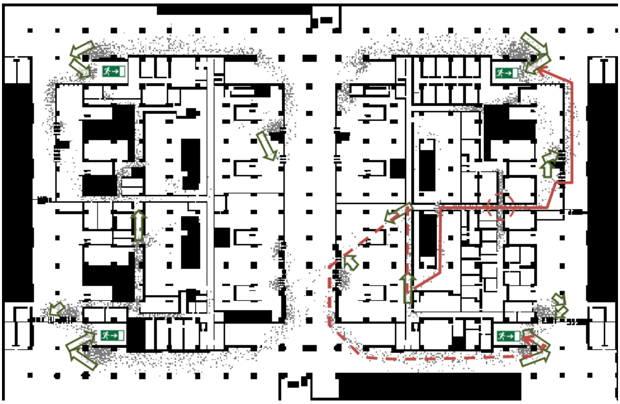

Figure 3. Simulation under both fixed and adaptive guidance

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IMPROVING THE ROBUSTNESS OF MODEL EXCHANGES USING PRODUCT MODELING 'CONCEPTS' FOR IFC SCHEMA

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ABSTRACT

Empirical approaches to define Model View Definitions (MVD) for exchange specifications exist and are expensive to build, test, and maintain. This paper presents the novel idea of developing modular and reusable MVDs from IFC Product Modeling Concepts. The need and application for defining model views in a more logical manner is illustrated with examples from current MVD development. A particular focus of this paper is on precast entities in a building system. Presented is a set of criteria to define fundamental semantic concepts articulated within the Industry Foundation Classes (IFC) to improve the robustness of model exchanges.

Keywords: Building Information Modeling (BIM), Product/Process Modeling, Model View Definition (MVD), Industry Foundation Class (IFC).

INTRODUCTION

Building Information Modeling (BIM) tools serving the Architecture, Engineering, Construction (AEC) and Facilities Management (FM) industry cover various domains and have different internal data model representation to suit each domain. Data exchange is possible mostly by hard-coding translation rules. This method is costly to implement and maintain on an individual system-to-system basis. NIST has estimated that information copying and recreation is costing the industry 15.8 billion dollars a year (NIST, 2004). The Industry Foundation Classes (IFC) schema is widely recognized as the common data exchange format for interoperability within the AEC industry (Eastman et al. 2008). Although IFC is a rich product-modeling schema, it is highly redundant, offering multiple ways to define objects, relations and attributes. Thus, data exchanges are not reliable due to inconsistencies in the assumptions made in exported and imported data, posing a barrier to the advance of BIM (Eastman et al. 2010). The National BIM Standard (NBIMS) initiative (NIBS, 2008) proposes facilitating information exchanges through model view definitions (MVD) (Hietanen, 2006). Empirical approaches to define MVD's for exchange specifications exist and are expensive to build, test, and maintain (Venugopal et al. 2010). The authors' experience in developing Precast BIM standard (Precast MVD, 2010), which is one of the early NBIMS, has given insights into the advantages and disadvantages of the MVD approach. Some of the deficiencies of current approaches are explained in this paper to illustrate the need for a formal and rigorous approach to model view development. We explore a novel idea of developing modular and reusable MVDs from IFC Product Modeling Concepts. Presented is a set of criteria to define fundamental semantic concepts articulated within the Industry Foundation Classes (IFC) to improve the robustness of model exchanges.

NBIMS PROCESS

Effective exchanges require providing a layer of specificity over the top of an IFC exchange schema or other exchange schema. The purpose of this layer of information is to select and specify the appropriate information entities from a schema for particular uses. Such a subset of the IFC schema that is needed to satisfy one or many exchange requirements of the AEC industry is defined as a Model View Definition by buildingSMART organization (NIBS 2008). The National BIM Standard Version 1 Part 1 outlines a draft of procedural steps to be followed in the case of developing model views. The NBIMS process is shown in Figure 1. The focus of this paper is on the translation from the *Design* to *Construct* stage in the model view development process in Figure 1. The Design phase rigorously defines the model view. This involves translation of exchange requirements from the textual form so that they can be bound to a particular exchange schema. A model view is a collection of such information modules, which will be implemented by the software companies. Example MVDs include

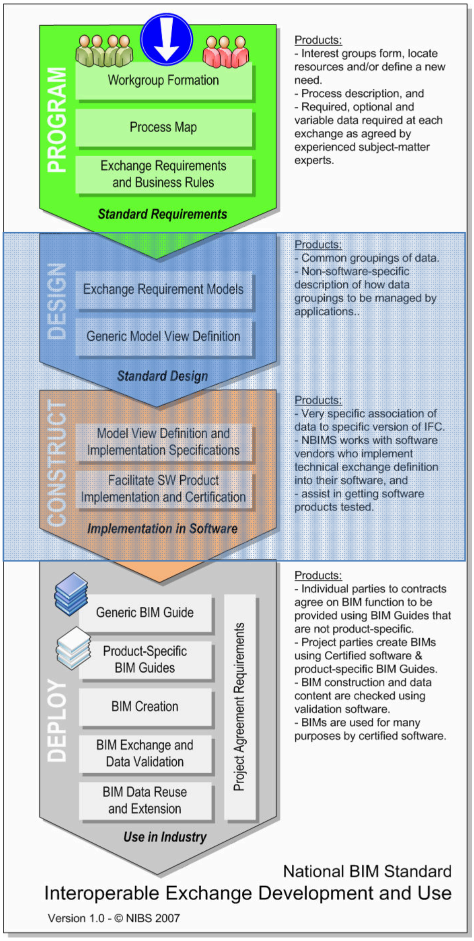


Figure 1. Outline of NBIMS model view development process. This research is aimed at improving the Design and Construct stages of this process.

those supporting concept level design review by GSA (GSA, 2010), for structural steel exchanges by steel fabricators (Eastman et al, 2005), all the exchanges needed to support precast concrete exchanges from design to fabrication and erection (PCI, 2009), and the pass-off of building information from the contractor to the facility owner or operator (COBIE2) and others. The Construct phase involves working with the software companies to implement the model views. This involves creating mapping of model views into internal data structures. The following section illustrates the potential barriers of the model view approach and explains the need of a different approach.

NEED FOR A FORMAL AND ROBUST MVD APPROACH

IFC is based on EXPRESS language, which is known to be highly expressive but lacks a formal definition (Guarino et al. 1997). For example, no standard model view has been proposed in which a precast architectural facade is modeled and mapped to and from the IFC schema (Jeong et al. 2009), leading to ad hoc and varied results. Performance studies of BIM data bases designed to create partial models and run queries show a strong need for both identifying model views for specific exchanges, as well as for specifying the exchange protocols in a stricter manner (Nour 2009; Sacks et al. 2010). The translation from exchange requirements to model views in NBIMS process is currently done manually and error prone. Moreover, it is time consuming and expensive. The base entities from which model views can be defined are not strictly defined. The model views developed are not based on logic foundations, hence no possibility of applying reasoning mechanisms. Moreover, the required level of detail of model exchanges is an issue, which is not specified in current approaches.

In preparing a set of MVDs, information modelers must determine the appropriate level of meaning and the typing structure. The structure of a model view for exchange of product model data between various BIM application tools depends on the extent to which building function, engineering, fabrication and production semantics will be embedded in the exchange model. At one end of the spectrum, an exchange model can carry only the basic solid geometry and material data of the building model exchanged. The export routines at this level are simple and the exchanges are generic. In this case, for any use beyond a simple geometry clash check, importing software would need to interpret the geometry and associate the meaning using internal representations of the objects received in terms of its own native objects. At the other end of the spectrum, an exchange file can be structured to represent piece-type aggregations or hierarchies that define design intent, procurement groupings, production methods and phasing, and other pertinent information about the building and its parts. In this case, the importing software can generate native objects in its own schema with minimum effort, based upon predefined libraries of profiles, catalogue pieces, surface finishes, and materials and do not require explicit geometry or other data in every exchange. The export routines at this level must be carefully customized for each case since the information must be structured so that they are suitable for the importing applications supporting each use case. Different use cases require different information structures. For example, an architect might group a set of precast façade panels according to the patterns to be fabricated on their surfaces, manipulating the pattern as a family; an engineer might group them according to their weights and the resulting connections to the supporting structure; a fabricator might group them according to fabrication and delivery dates. In order for the importing application to infer knowledge from the exchange, the exporting application should structure the data based on the ordering scheme accepted at the receiving end. This is an important requirement and needs to be taken into account when the model exchange requirements are specified.

The level of detail in the provided and exchanged models for each information unit can vary based on the project stage, purpose of model exchange, model recipient, and local practices. Further, different delivery methods impose changes in roles and responsibilities of project parties, which considerably change project deliverables at each stage for each discipline involved in the project. Current MVD approaches do not specify such a level of detail requirement for each phase of the project.

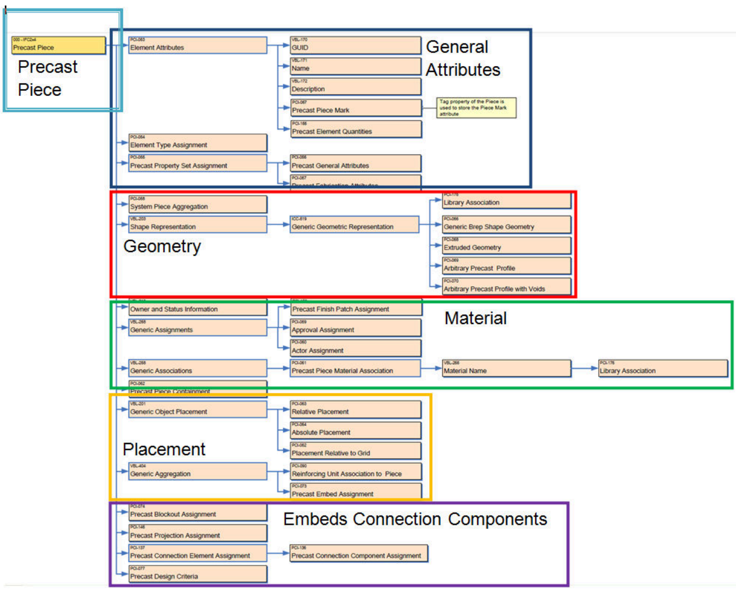
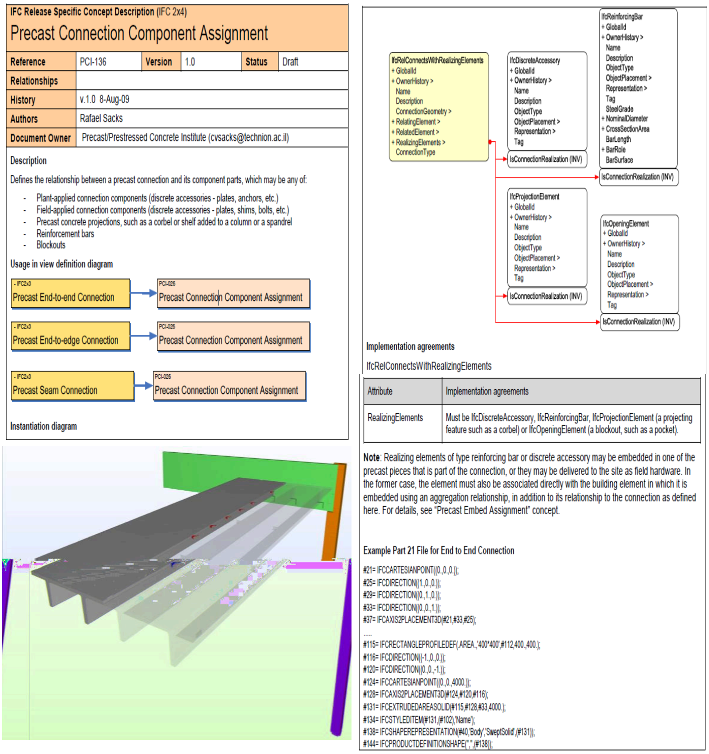


Figure 2. Formulation of Product Model Concepts for a Precast Piece

PRODUCT MODEL 'CONCEPTS'

The idea of Product Model Concept is introduced as a means of modularizing MVD development and also for improving re-usability. Concepts in the areas of engineering and design are particular, in the sense that they define a mixture of partial specifications of reality, the expected function and behavior of that reality, and the reality of physical systems. Concepts regarding the different levels of realization are needed to distinguish between definitions and objects within our domain.

The notion of a *Concept* is that it is a subset of a product model schema that can be used to create various, higher-level, Model View Definitions (MVD). These modular sub-units or *Concepts* can be tested for correctness and completeness separately, easing validation. A related but different purpose for defining product model sub-schemas is for querying and accessing part of the instance data associated with a target sub-schema.



IFC Release Specific Concept Description (IFC 2x4)

Precast Connection Component Assignment

Reference	PCI-136	**Version**	1.0	**Status**	Draft
Relationships					
History	v.1.0 8-Aug-09				
Authors	Rafael Sacks				
Document Owner	Precast/Prestressed Concrete Institute (cvsacks@technion.ac.il)				

Description

Defines the relationship between a precast connection and its component parts, which may be any of:

- Plant-applied connection components (discrete accessories - plates, anchors, etc.)
- Field-applied connection components (discrete accessories - plates, shims, bolts, etc.)
- Precast concrete projections, such as a corbel or shelf added to a column or a spandrel
- Reinforcement bars
- Blockouts

Usage in view definition diagram

Instantiation diagram

Implementation agreements

IfcRelConnectsWithRealizingElements

Attribute	Implementation agreements
RealizingElements	Must be IfcDiscreteAccessory, IfcReinforcingBar, IfcProjectionElement (a projecting feature such as a corbel) or IfcOpeningElement (a blockout, such as a pocket).

Note: Realizing elements of type reinforcing bar or discrete accessory may be embedded in one of the precast pieces that is part of the connection, or they may be delivered to the site as field hardware. In the former case, the element must also be associated directly with the building element in which it is embedded using an aggregation relationship, in addition to its relationship to the connection as defined here. For details, see "Precast Embed Assignment" concept.

Example Part 21 File for End to End Connection

```
#21= IFCCARTESIANPOINT((0.,0.,0.));
#25= IFCDIRECTION((1.,0.,0.));
#29= IFCDIRECTION((0.,1.,0.));
#33= IFCDIRECTION((0.,0.,1.));
#37= IFCAXIS2PLACEMENT3D(#21,#33,#25);
.....
#115= IFCRECTANGLEPROFILEDEF(.AREA.,'400*400',#112,400.,400.);
#116= IFCDIRECTION((-1.,0.,0.));
#120= IFCDIRECTION((0.,0.,-1.));
#124= IFCCARTESIANPOINT((0.,0.,4000.));
#128= IFCAXIS2PLACEMENT3D(#124,#120,#116);
#131= IFCEXTRUDEDAREASOLID(#115,#128,#33,4000.);
#134= IFCSTYLEDITEM(#131,(#102),'Name');
#138= IFCSHAPEREPRESENTATION(#40,'Body','SweptSolid',(#131));
#144= IFCPRODUCTDEFINITIONSHAPE('','',(#138));
```

Figure 3. A binding document prepared for precast connection component showing usage info, mapping to IFC, 3D representation, business rules, and sample part-21 file snippet.

Initial Test Model: The main criterion of *Concepts* is that they need to be stand-alone and testable from the completeness point of view. Concepts should be a complete subschema that has no broken links or references. Further, this also applies to retrievable queries. This requirement of completeness is strongly influenced by the optional versus mandatory property of some data fields. This may have to be adjusted for IFC to work well with concepts. Figure 2 shows a grouping of various *concepts* for a precast piece. A second and important requirement, which was identified during the current model view work, is the need to avoid redundancy and rework in terms of development and testing of model views. Hence, concepts should be generated following strict guidelines so that they are testable and standalone. For new MVD development, these should be in a plug-and-play form. Retesting, which is expensive and time consuming needs to be avoided. Moreover, the *Concept* structure developed should support querying of content-based data from a product model or from a model server. The current terminological and semantic ambiguities need to be removed by the formal structure so that it minimizes semantic mismatch during querying for various applications. Accomplishing this task requires the concept definitions and constraints (business rules) to be represented rigorously. Figure 3 shows such a binding diagram for Precast Connection Components. The first part shows the details about the concept, such as title which is a unique identifier, description, IFC release to which the binding conforms, history, references, authors, etc., and usage in view definition. The usage in view definition shows the reuse of this concept in different places in a model view. The second part shows a sample 3D representation of the same, followed by the IFC binding relationships. Additional business rules for implementation and an example part-21 file snippet are also provided to help the implementers. The business rules tries to answer questions such as, Are the attributes Required or Optional? Is the attribute referencing a Select or Enumerated type? In the latter case, what are the allowable values? Are there naming conventions to be followed?, etc. These are called the implementation agreements and the sample part-21 file is populated with values illustrating these agreements.

IMPACT OF THIS RESEARCH

The following are the envisioned benefits by performing this research:

- The requirements or a standard criterion for defining the IFC concepts proposed here should be documented to avoid various research teams generating varying implementations.
- Such a standard approach will help in re-use of concepts and thereby resulting in the re-use of MVDs itself.
- *Concepts*, once tested and implemented can provide a mechanism to generate model views directly from exchange requirements. This is a novel idea and is yet to be explored.
- There is a huge potential to reduce the current model view generation – implementation cycle time of 2-3 years to more practical 4-6months by following a modularized approach using concepts.

Concept-based design of modular MVDs and certification process uses concepts as a central component in the methodology. A comparison matrix is envisioned to evaluate the effectiveness of this new methodology. Some of the important criteria for evaluation are shown in Table 1. An MVD, which supports an exchange requirement, can be specified solely based on the concept packages. The exchange requirements have a direct mapping to the concept structure (intuitive) and provide a means to develop new MVDs in a plug-n-play manner. Extensive work and time is saved by this new method. Further, the MVDs developed using this method are more consistent among each other. The testing, validation and certification scenario can benefit from the products of this research.

Table 1. Evaluation Matrix for Concept based applications

Criteria	Description
Expressiveness and Rigor	By using a formal Concept structure, semantics in MVD can be represented in a consistent manner.
Understanding of complex views	Model views represent different levels of detail. Concept based development methodology contributes to a better understanding of model views by providing a concise and object oriented view of the exchange. A view is decomposed in several smaller modular objects that are more manageable.
Traceability	Traceability is very important feature in the development process. A more effective translation and transparency of the user needs into the design of MVDs.
Quality	Better quality of MVD design may be achieved by using concepts that are tested and verified.
Development time and costs	Unnecessary iterations and redundancy avoided due to the front-loading of concept design. Costs are also reduced by early verification of concepts.
Reuse of MVDs	Building a new MVD becomes a matter of combining and configuring predefined components from a concept library.

CONCLUSION

Product model schemas such as IFC are rich, but redundant. In order to build effective exchanges, a new methodology based on formal definition of IFC Concepts is introduced by this research. Based on the analysis, it is shown that MVD development process needs to be transitioned from the current ad-hoc manner to a more rigorous framework and/or methodology similar to the one explained in this research. The semantic meaning of IFC concepts needs to be defined in a rigorous and formal manner with strict guidelines. This can help achieve a uniform mapping to and from internal objects of BIM tools and IFC.

The expressiveness and rigor, where MVD aspects can be represented fully and in a consistent manner is important. Model views represent different levels of detail; hence the new methodology should contribute to a better understanding of model views by providing a concise and object oriented view of the exchange. It should be possible to decompose the view into several modular objects (Concepts) that are more manageable and testable. Moreover, traceability is a very important feature in the development process. A more effective translation and transparency of the user needs (Exchange Requirements) into the design of MVDs are required. Avoiding unnecessary iterations and redundancy of IFC concepts can reduce development time and costs. Work is still in progress in defining the IFC Concepts and validating them. Based on the impact expected from this research, there is a compulsive need to complete this research in a time bound manner to make available the products to the IFC development community.

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