

# APPLICATION OF IFC IN DESIGN AND PRODUCTION OF PRECAST CONCRETE CONSTRUCTIONS

SUBMITTED: December 2002

REVISED: April 2003

PUBLISHED: July 2003 at <http://www.itcon.org/2003/13>

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**SUMMARY:** *This paper describes one of the prototypes of the ITBoF project "Implementations of Product Models based on IFC and BSAB" where a design software for the precast industry, IMPACT, has been used to demonstrate product model data exchange. The exchange is based on IFC version 2.0 and the Swedish construction industry classification system BSAB 96. The objective of the project was to explore information exchange between architects (and/or HVAC engineers) and precast concrete designers using existing versions of IFC in commercially available software. The IMPACT prototype imports the wall geometry from the architectural design with openings for windows, doors etc. The precast designer uses the geometry to create precast concrete elements that make-up the composed walls. The refined model, containing precast elements, can be exported according to the IFC standard where the BSAB classification codes is adapted on to the IfcWall object as an IfcClassificationList. The BSAB classification codes can then be used to exchange information with estimation and scheduling programs. The exchange scenario clearly demonstrates the use of information exchange in the design of precast concrete elements. Also information exchange based on IFC 2.0 can with relatively small efforts be introduced in commercially available design tools such as IMPACT. However, future development must also focus on automatic adjustment of the product model data to reduce the supplementary work needed in the precast design process, especially in the exchange between the architect and the precast designer.*

**KEYWORDS:** *IFC, BSAB, Precast concrete construction, Precast design.*

## 1. INTRODUCTION

### 1.1 Background

IT-tools have increasingly been used to facilitate information management and information transfer in the construction process. Computer networking, document management systems, the Internet, database technologies and data standards are examples of such technologies. However, the potential of these technologies for data sharing has not been fully utilized in the construction industry, but has rather been used for just exchanging traditional documents in a digital format (Laitinen, 1998). Information management using computer-based tools is today the focus for many construction research projects on a national level (VERA, 2002, ITBoF ,2002) and on an international level (BLIS, 2000, IST in Construction, 2002).

New tools for project analysis and management emerge by combining 3D CAD models and shared databases with scheduling, cost analysis applications (Retik, 1997, Alkinci et al., 1998, Koo and Fischer, 2000, Songer et al., 2001, Rönneblad & Olofsson, 2002).

The development of electronic communication standards for building and construction is administrated by the International Alliance for Interoperability (IAI). The IAI is an open international consortium of architects, engineers, contractors, manufacturers, researchers and CAD vendors, such as Graphisoft, Autodesk, Bentley, Nemetschek, Microsoft etc. The goal is to develop product data models for sharing information between software tools that are utilized throughout the building industry (IAI, 2002). The Industry Foundation Classes

(IFC) or rather the class definitions that form these models are called IFC models. Work on the IFC model development has led to various releases of the model; IFC R1.0, IFC R1.5, IFC R1.5.1, IFC R2.0 and the release of IFC R2x, (IAI, 2002).

The development of the IFC Object Model (IAI, 2002), including its architecture, is based on experience from earlier projects, most notably, ATLAS (ATLAS, 1993), COMBINE (COMBINE, 1995), and VEGA (VEGA, 1999), and the ISO 10303 – STandard for the Exchange of Product model data (STEP-1, 1994). Also two early generic models should be mentioned; The General AEC Reference Model – GARM (Gielingh, 1988) and the Building Systems Model – BSM (Turner, 1990). The GARM, developed for the STEP project, provides a first basic concept by introducing the “Product Definition Unit” (PDU) and its subtypes “functional unit” and “technical solution”. The BSM model has a top down strategy to model a building. It introduces functional systems as, e.g., enclosure, structural, mechanical, etc. and their entities.

The Swedish IAI Forum (SIAI) is aimed at influencing the international development of IFC. One goal is to integrate the well-established Swedish construction industry classification system, BSAB 96, into the IFC development (Svensk Byggtjänst, 1999). The BSAB classification system, based on ISO 12006-2, has a long tradition in Sweden and is widely adopted in the building industry. BSAB is based on a global view on the information needed and produced during the whole lifecycle of a construction entity. In a study conducted by the Swedish Building Center it is shown that it is possible to integrate IFC and BSAB, but that there are a considerable number of issues that have to be addressed (Ekholm et al., 2000). These issues are related to ISO 12006-3, the framework for object-oriented information exchange (ISO, 2001).

An example of a performed design and construction project, using a product modeling approach, is the HUT-600, Helsinki University of Technology Auditorium Hall 600 in Finland, (Fischer and Kam, 2002). The project was running in parallel to a conventional design and construction project. The project demonstrate that owners could choose among comprehensive life-cycle alternatives, end-users could provide input to the facility design in a timely manner, and project team members could differentiate themselves from their competitors with higher efficiency, quality, and more effective application of their expertise (Fischer and Kam, 2002). Major error in sharing through IFC is declared as the outcome for the exchange between the architect and structural engineer. The Shortcomings is not separately declared in the PM4D final report, but a general statement includes geometric misrepresentation, loss of object information, confusion in interdisciplinary revisions, large file size, and specific application requirements.

This paper describes one of the prototypes of the ITBoF project ”Implementations of Product Models based on IFC and BSAB” where design software for the precast industry, IMPACT, has been used to demonstrate product model data exchange based on IFC and BSAB standards. IMPACT is a product developed and marketed by the company Structural Design Software.

## **1.2 Company and product information**

Structural Design Software (StruSoft), a former part of Skanska IT Solutions, is a software development company with offices in Sweden (Stockholm and Malmö) and Hungary (Budapest). The aim of the company is to develop advanced design programs and CAD applications for structural designers. The company also undertakes assignments and consulting work, such as software development and engineering design.

IMPACT, developed by StruSoft, is a software package for the precast industry in Sweden that has been used in production during the last decade. IMPACT has been constructed to serve the generation of drawings, bill of quantities and other reports from the design, construction to the production of precast structures. All information in the product model is managed and stored in an online database server, see Fig. 1 (IMPACT, 2002).

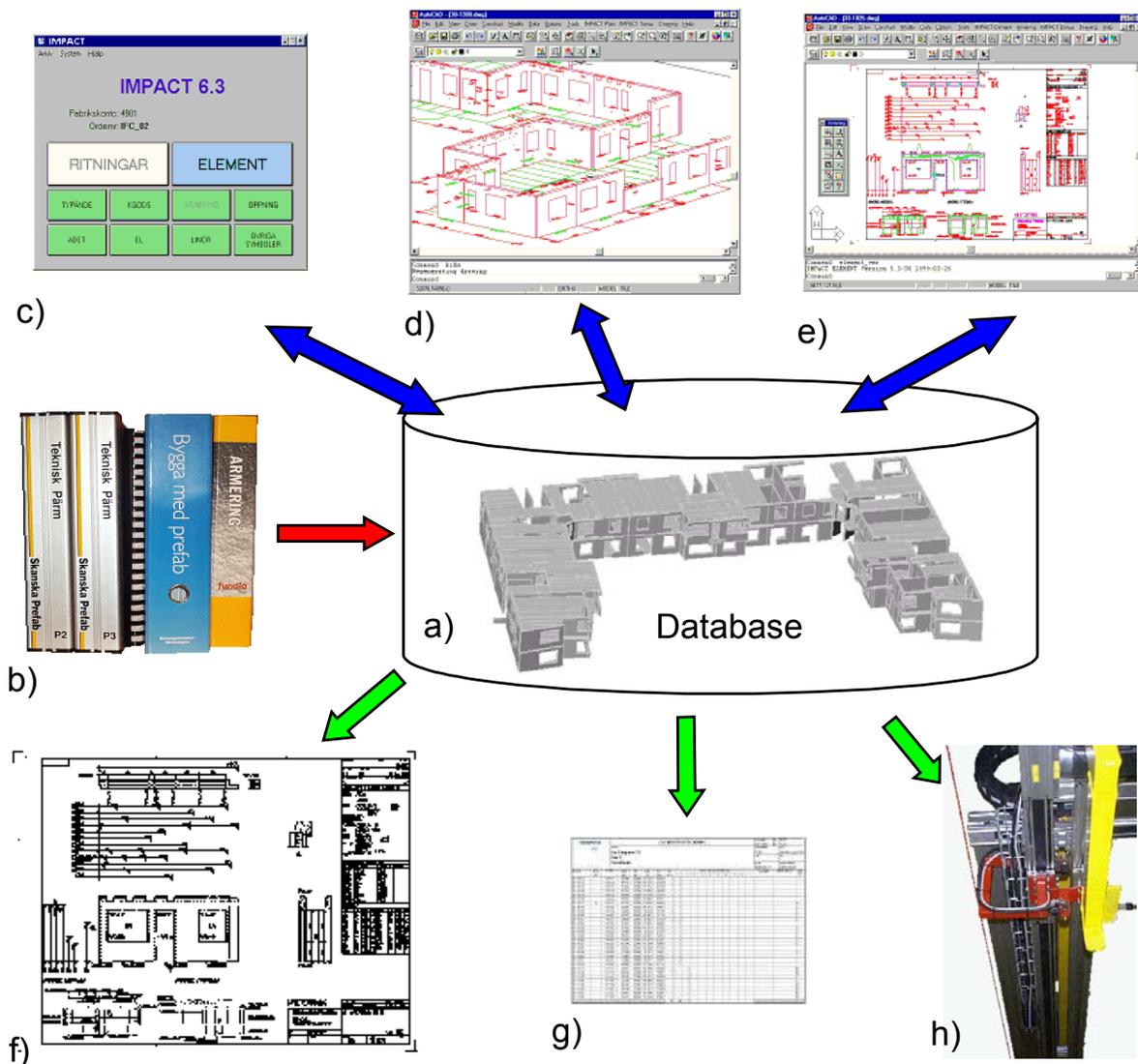


FIG. 1: Structure of IMPACT in a) IMPACT database server, b) defined company- and factory standards, c) project administration application, d) framework modeler application, e) element design application, f) drawings, g) bills of quantities and h) connections to plant automation showing a form plotter device.

### 1.3 The precast concrete construction design process

It is important to make a clear distinction between the role of the structural engineer and the precast designer. The structural engineer has a more general role in the project and is often the actor responsible for the co-operation between different component suppliers, especially concerning the framework design and the building technology used. The precast designer is only responsible for the precast construction. In some projects the structural engineer and the precast designer is the same person.

In Fig. 2 a typical precast concrete construction design process is described in IDEF0 notation (Integration Definition for Function Modeling). The process is divided into *Dimensioning*, *Framework modeling design*, *Document production* and an *Administration* phase. In the *Dimensioning* phase, the precast designer calculates the structural dimensions to fulfill the demand on load carrying capacity. The *framework modeling* phase is often the most work intensive phase. In IMPACT a 3-dimensional model is used for dividing the construction into precast elements and for grouping the elements. In the *Document production* phase, production documents such as assembly plan drawings (used on building sites), manufacturing drawings (used in the factory) and reports (list data e.g. reinforcement-, cast in material-, drawing schedule- and element summary reports) are produced.

Finally, *Administration* handles revisions (to ensure that all documents are up-to-date) and distribution of the documents to all involved actors.

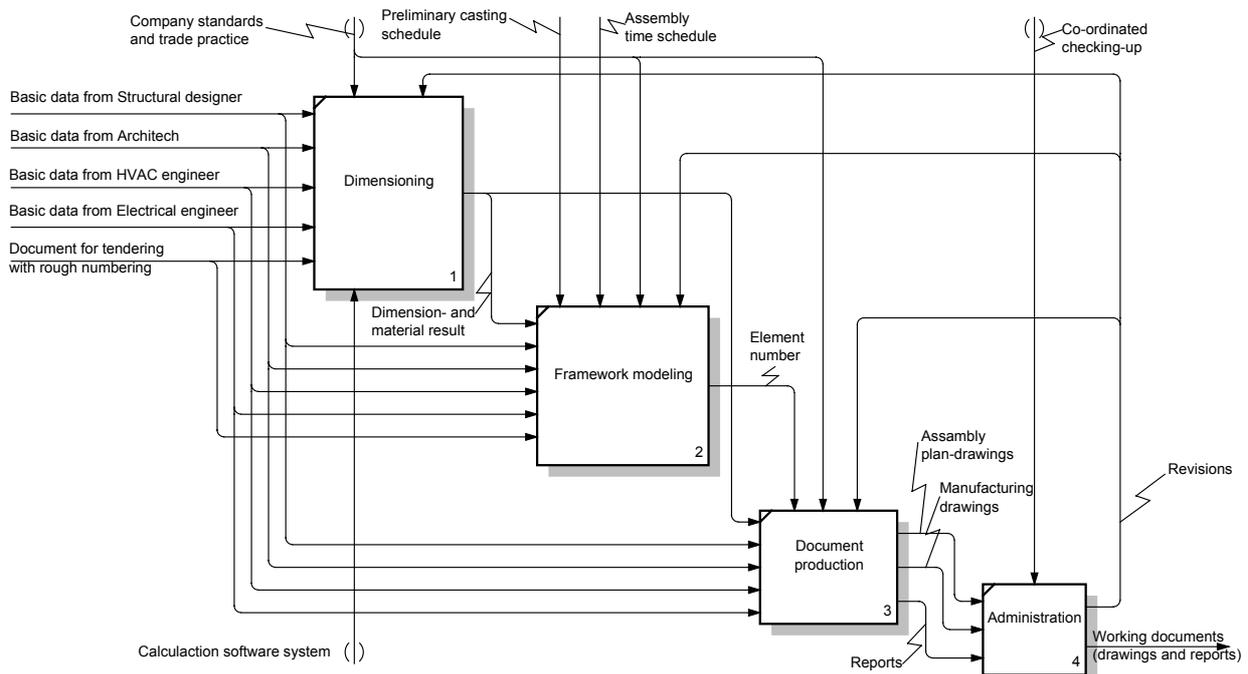


FIG. 2: The process of precast concrete construction design.

## 2. PROJECT DESCRIPTION

### 2.1 Goals, methods and target groups

The objective of the project was to explore information exchange between architects (and/or HVAC engineers) and precast concrete designers using existing versions of IFC in commercially available software.

A prototype of the IMPACT framework application was extended to handle IFC import/export to:

- Investigate the need for of information in exchange scenarios between architects and precast design engineers.
- Demonstrate the use of information exchange in the precast concrete construction design process.

The IFC model was extended to include the Swedish building classification standard, BSAB, for material take-off and cost estimation applications.

The implementation also gives the opportunity to demonstrate the result to the precast industry and to promote a useful debate about working methods. The long-term goal is to give the actors in the precast concrete construction design process tools for sharing information and more efficient design methods.

Swedish vendors of CAD software, planning, material take-off and cost estimation systems and software for real estate management have collaborated in the project to share and refine the information in a common product model.

### 2.2 IFC information exchange scenario

A large part of the design work is focused on the coordination of openings and holes for the precast concrete elements. The input data such as window and door openings comes mainly from architects, structural designers and HVAC consultants, e.g. ventilation shafts. A lot of work can be saved if the precast designer can import the holing requirements from the other actors before the final design of the precast concrete framework is made.

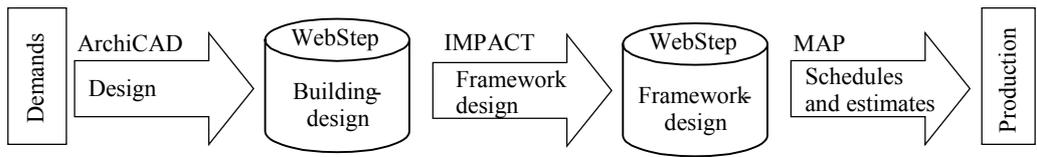


FIG. 3: Part of the IFC exchange scenario in ITBoF project "Implementations of Product Models based on IFC and BSAB".

The building design model, created using ArchiCAD, is uploads the IFC2.0 product model to the common product model server; the WebStep product model server. IMPACT imports the building design from the server for the detailed design work of the precast concrete framework. When the framework design of the precast framework is finished the refined IFC model is stored on the server. Finally, the refined IFC model is used by a cost estimate and planning program, MAP, to create production planning and bill of quantities, see Fig. 3.

The IMPACT prototype imports the wall geometry with holes and openings. The precast designer uses the geometry to create precast concrete elements with aggregates is the composed walls. The element size, form and connection type is governed by factory standards and transport facilities from factory to building site. Finally, openings and holes are added to the precast element and stored in the IMPACT server. The refined model containing the elements ready for assembly on the building site can now be exported according to the IFC 2.0 Schema, see Fig. 4.

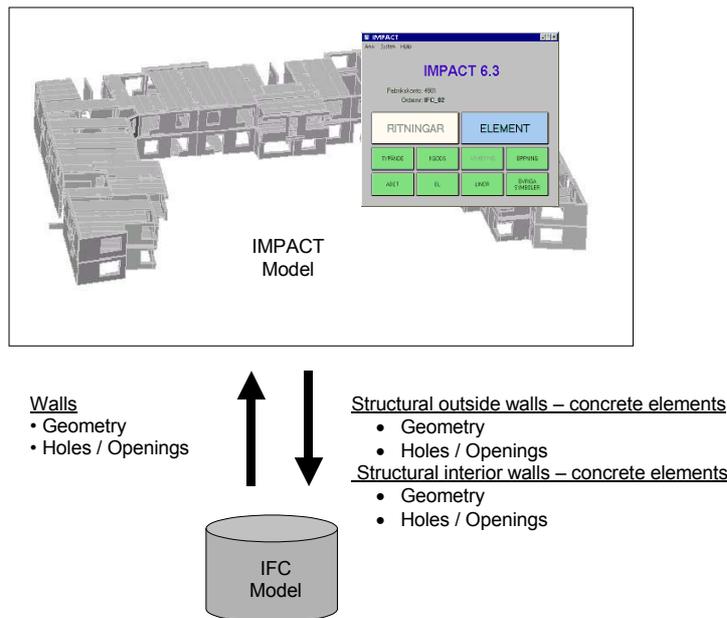


FIG. 4: Communication between IMPACT and IFC model stored in the WebStep model server.

## 2.3 Limitations

### 2.3.1 Geometrical representation

To save the amount of work in developing the prototype, only the simplest form of geometrical representation is handled, the so-called bounding box. Much of the detailed information vital for the construction of precast elements will be lost, e.g. end connections. However, in the demonstration exchange scenario this information was not relevant.

### 2.3.2 Coordinate system

IMPACT handles only one coordinate system. This restricted the import and export function to only use the World Coordinate System, WCS in the AutoCAD system.

### 2.3.3 Classification according to BSAB

The classification of the walls according to BSAB was done using the `IfcClassificationList`. During the project the use of property sets was also discussed, but no implementation guides, in this ITBoF project, were available for IFC property sets at the time.

### 2.3.4 Relation between elements and the original wall geometry

In the exported IFC-model there are no relations between the original walls and the exported walls composed of element assemblies created by IMPACT. IMPACT does not use this type of relation because the imported boundary of the wall is only used as basic data (snap points) so the global ID for the wall is not stored in the IMPACT model.

## 3. IMPLEMENTATION

### 3.1 The IFC programming interface

An external developed IFC toolbox called “Eurostep Classic toolbox IFC 2.0” has been used to reduce the programming work (Eurostep, 2002). The IFC Classic Toolbox is a C++ class library toolbox, which has been widely adopted by the international building and research community. It provides object oriented programming methodology to access IFC data. IFC Classic Toolbox implements a unified C++ early binding interface to provide an easy access to files based on the IFC schema for both reading and writing.

### 3.2 User interface

#### 3.2.1 Import of walls and holes

The Framework design module was extended to handle IFC import. Walls together with related holes/openings are imported storey by storey to the IMPACT model. The user can choose among the project, site, building and building storey defined in the IFC model, see Fig. 5.

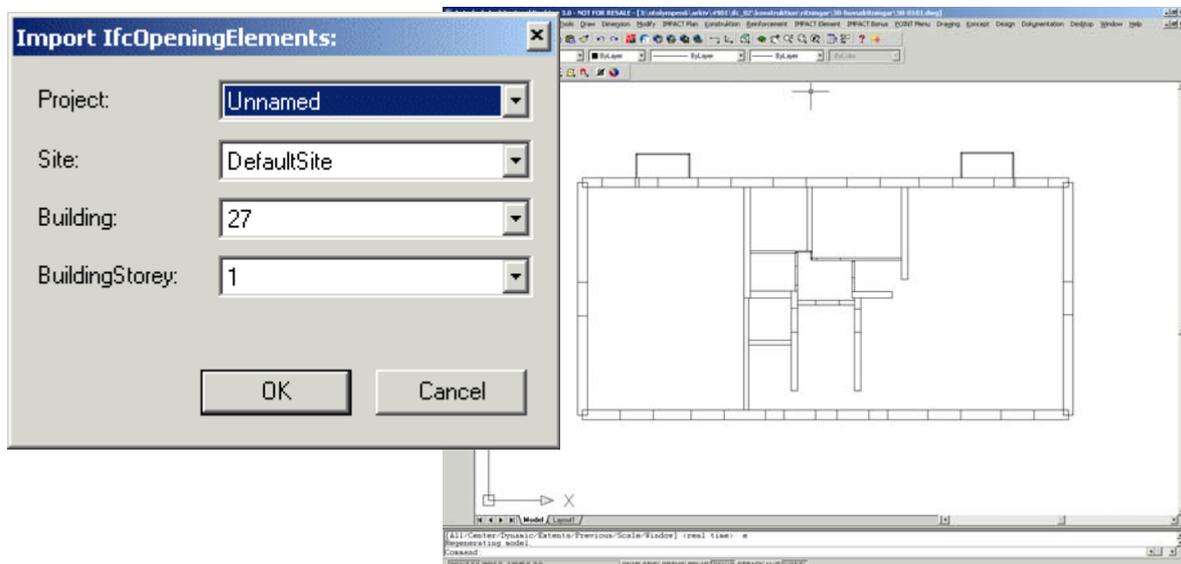


FIG. 5: User interface for import of a building storey in IMPACT.

Ordinary AutoCAD line objects represent the boundary representations of the imported walls. The line objects are used as basis information (snap points) while the precast wall elements are created by IMPACT. The

imported holes/openings (IfcOpeningElement) are however defined as IMPACT objects, so-called “box-out hole” objects.

### 3.2.2 Converting to openings

Opening objects for doors and windows includes information about precast manufacturing process such as formwork equipment and cast in material. There are therefore three different types of holes defined in the IMPACT product model.

- Box-out hole. This hole has straight end caps. Holes for HVAC and electric equipment are examples where this kind of hole is used in a construction.
- Door opening. This hole is created by formwork equipment and built up with three non-straight end caps sides.
- Window opening. This hole is created by formwork equipment and built up with four non-straight end caps sides.

The IFC import function creates a so called “box-out hole” i.e. with straight end caps for all imported hole objects. A consequence of this is that more complicated objects have to be converted to the requested object type. A new conversion function was added to extract the height and the width values from the selected “box-out hole” object. If a matched door or window opening is found in the database the conversion function suggests the user to convert the hole to the predefined opening. The user can even choose to create a new opening definition that includes all needed information such as the end caps needed for the formwork equipment, see Fig. 6.

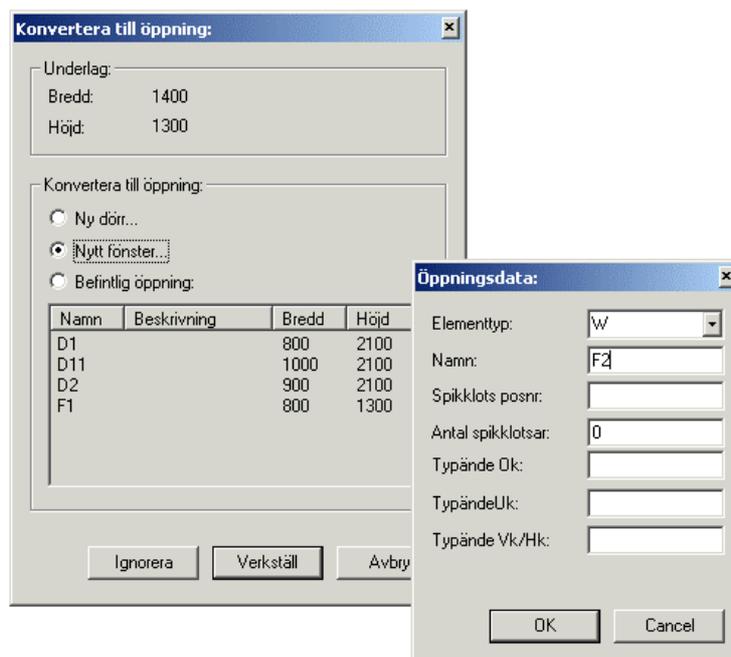


FIG. 6: User interface for converting “box-out hole” to door or window openings. The user can choose a predefined opening or create a new opening definition in the dialog box.

### 3.2.3 Creating precast concrete elements

The ordinary IMPACT command “draw element” is used for creating precast concrete elements. The imported IFC walls are used as basis information when the structural designer divides the walls into precast elements. The draw function automatically finds all “box-out holes” and the door/window objects located inside the boundary of the element. Finally, the system assigns each of the elements an administration code/number that is used in the production and assembly of the framework. Fig. 7 shows the finished precast production model in 2D and 3D.

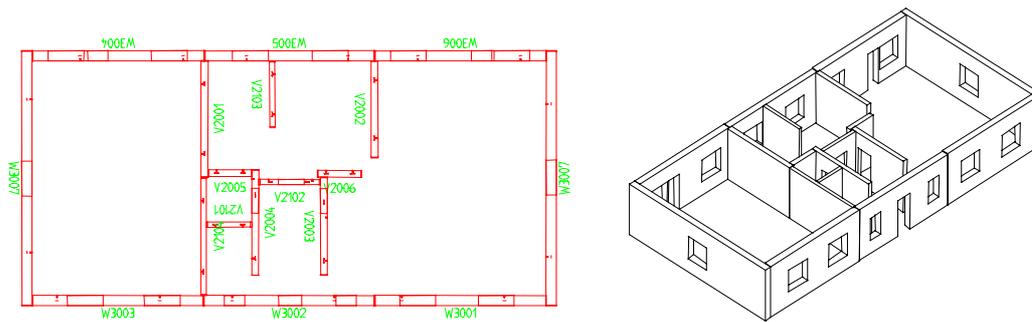


FIG. 7: The model after the walls has been divided into precast concrete elements. a) plan view b) 3D view.

All the manufacturing drawings for each element can now be generated automatically, see Fig. 8.

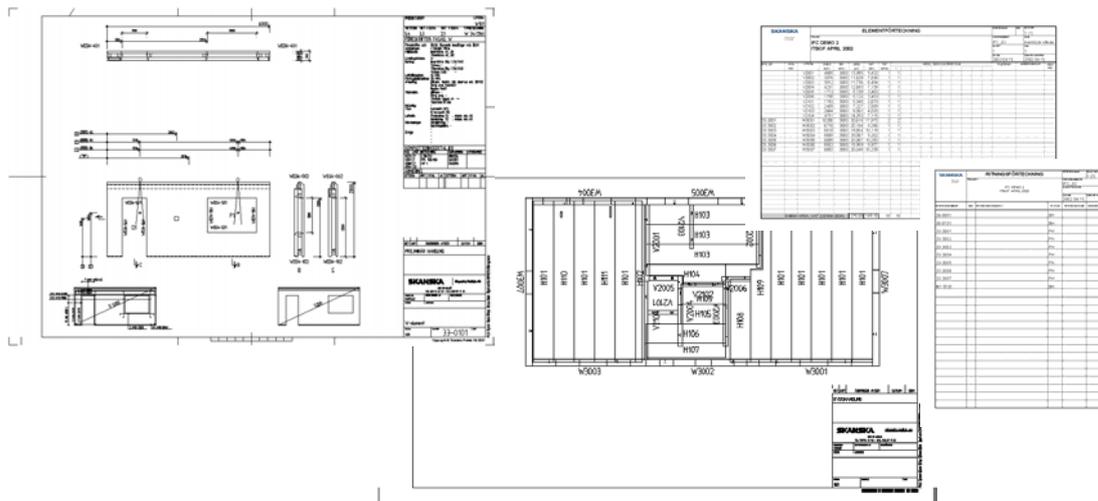


FIG. 8: Completed manufacturing drawings, assembly/montage drawings and reports/lists generated automatically by IMPACT.

### 3.2.4 Export to IFC file

When the object in the IFC file is imported and converted to a one storey IMPACT model, the information about current project, site, building, building storey and the name/path of the original IFC file is also stored. The IFC export function is using this information to create a new IFC part 21 file. The new objects, created by IMPACT are stored in the new IFC file with the same selections as the originally objects. IMPACT does not store the whole imported IFC file in the model so the export function has to reopen the original file and add the new objects to it. The completed IFC file can be saved with a new file name. Precast concrete elements are not included in version 2.0 of the IFC standard; the exported elements must therefore be stored as IfcWall objects. However, relevant information such as end caps and cast in material is missing in the IfcWall class so this data cannot be exported. The geometric representation of the precast elements is the physical extent of the objects, i.e. the export function only uses the so-called IfcBoundingBox representation. The new IFC model includes the objects created by the architect (or by the structural designer of the project) as well as the elements created by the precast designer because they represent different views of the same functional parts in the assembled construction.

```

#4815 = IFCMATERIAL ('Insulation -material', $, (), ());
#4816 = IFCMATERIALLAYER (#4815, 180., 150.);
#4817 = IFCMATERIALLAYER (#4813, 330., 70.);
#4818 = IFCMATERIALLAYERSET ((#4817, #4816, #4814), .F.);
#4819 = IFCMATERIALLAYERSETUSAGE (#4818, 0., .T.);
BSAB {
#4820 = IFCCONSTRUCTIONNOTATION ('WR:GSC.51', 'Structural outside walls - concrete elements ');
#4821 = IFCCONSTRUCTIONNOTATION ((#4820));
#4822 = IFCCONSTRUCTIONNOTATION ('BSAB 96', 'BSAB96:WR', #4821, ", '1:01');
#4823 = IFCCONSTRUCTIONLIST ((#4822), 0);
#4824 = IFCCARTESIANPOINT ((0., 0., 0.));
#4825 = IFCBOUNDINGBOX (#4824, 3930., 400., 3000.);
#4826 = IFCGEOMETRICREPRESENTATIONCONTEXT ('q*vW70$ENaxXF@ -lgY6l', 'IMPACT Plan', 'Outline', 3, 0.);
#4827 = IFCSHAPEPRESENTATION (#4826, ", 'BoundingBox', (#4 825));
#4828 = IFCPERSON ($, $, $, $, $, (), ());
#4829 = IFCORGANIZATION ('Skanska IT Solutions AB', (), (), $);
#4830 = IFCPERSONANDORGANIZATION (#4828, #4829, ());
#4831 = IFCAPPLICATION ('IMPACT', 'IMPACT', '6.2', #4829);
#4832 = IFCOWNERHISTORY (#4830, #4831, "10", $, $, $);
#4833 = IFCPRODUCTDEFINITIONSHAPE ('DkGDsJF7@& -d>y:BK_<y', #4832, $, $, (#4827));
#4834 = IFCCARTESIANPOINT ((400.2000093460083, 6267.798657933829, 0.));
#4835 = IFCDIRECTION ((0., 0., 1.));
#4836 = IFCDIRECTION ((6.123031769111886 E-017, 1., 0.));
#4837 = IFCAXIS2PLACEMENT3D (#4834, #4835, #4836);
#4838 = IFCLOCALPLACEMENT ('Q[YSLXf#G1&4a*=k<)$2', #4832, 'IMPACT Wall, Nbr: LITT, Handle: A163', #30, #4837);
IfcWall {
#4839 = IFCWALL ('wnPZINyhJagVvCbIiF', #4832, 'IMPACT Wall, Nbr: LITT, Hand le: A163', $, (), #4838, (#4833), #4823, *, #4819, $, $);
#4840 = IFCMATERIALLAYER (#4813, 0., 180.);
#4841 = IFCMATERIALLAYER (#4815, 180., 150.);
#4842 = IFCMATERIALLAYER (#4813, 330., 70.);
#4843 = IFCMATERIALLAYERSET ((#4842, #4841, #4840), .F.);

```

FIG. 9: Example of an exported IFC file, containing precast objects with BSAB classification.

To make a distinction between the different views, specified BSAB classification codes are applied on the precast elements, see Table 1. In the BSAB classification semantics a precast element is a so-called work result. A work result (WR) represents the construction result made up from worked and mounted construction products. A work result must not be mixed up with the class element which is defined by the function in the completed building (Ekholm et al., 2000). The BSAB classification is adapted on to the IfcWall object as an IfcClassificationList.

TABLE 1: Notation for the class IfcNotationFacet. The values are based on the BSAB 96 classification system.

Notation value	Purpose
WR:GSC.51	Structural outside walls – concrete elements
WR:GSC.52	Structural interior walls – concrete elements

#### 4. DISCUSSION

Using the class IfcRelAssemblesElements, see Fig. 10, a relation between the original IfcWall and the precast elements can be made.

The elements in an IfcRelAssemblesElements relationship must have a strong semantic and topological relationship and make up a new component within the AEC product. This objectified relationship does not carry additional geometry i.e. there is no geometry use definition. It is therefore uncertain if IfcRelAssemblesElements can be used in real projects depending on the actors' different views. An architect (or the structural designer) can split up walls in different objects depending on an architectural purpose that does not necessarily correspond to the demands of the precast designer.

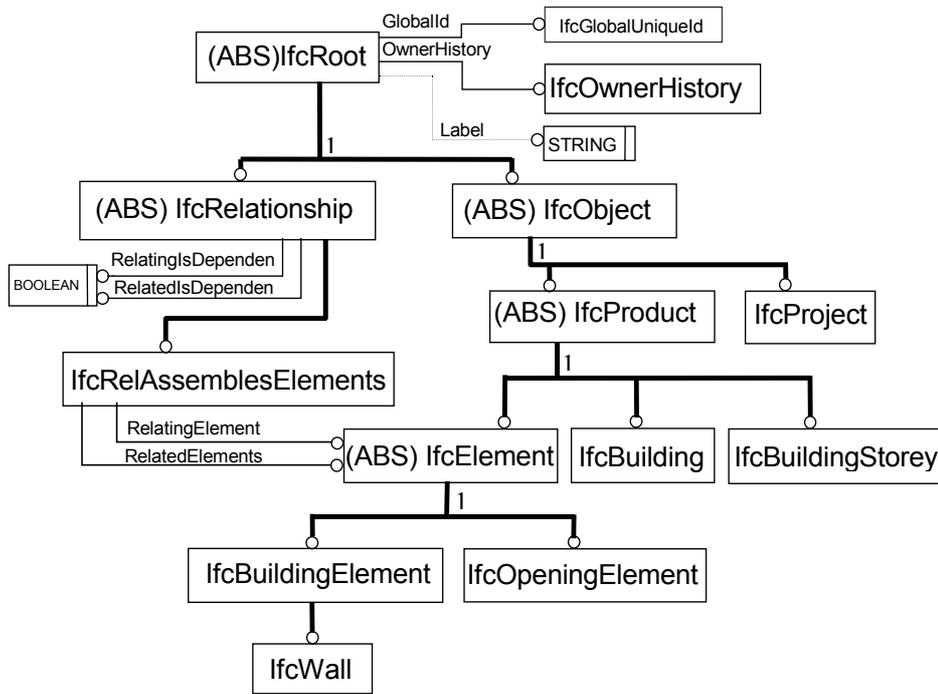


FIG. 10: EXPRESS-G notation of the class *IfcRelAssemblesElements*. Some of the details are omitted.

A precast element can in some cases be a part of more than one wall, see Fig. 11. To be able to use the class *IfcRelAssemblesElements* the architect must adapt the architectural model to the demand from the precast designer.

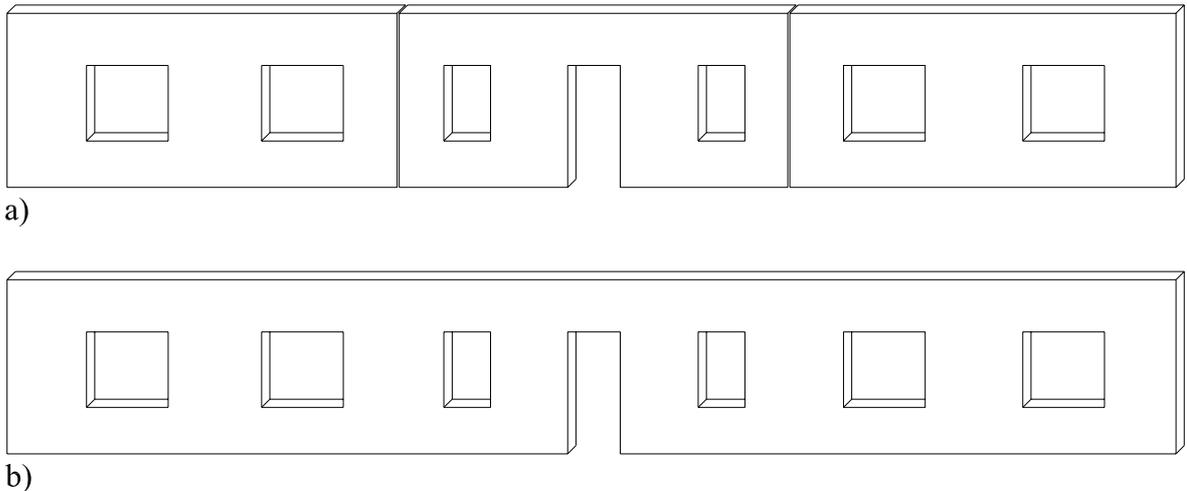


FIG 11: Relationship defined by the class *IfcRelAssemblesElements* a) *RelatedElements* are the entities that are the parts of the assembly (precast elements in this case). b) *RelatingElement* is the entity that is defined as the outcome after the assembly defined by the relationship (the wall defined by the architect in this case).

Ekholm et al., 2000, states that:

“There is a big need to be realistic about IFC. It is not something ‘magical’. It is a system built by many people from many countries during a relatively short period of time. This fact is strongly reflected in the model; it is very large and not fully consistent and has a variety of details in different parts and different solutions to similar problems within different areas. It is hard to get an overview of the model and it takes a lot of time and effort to understand it. The main criticism that can be addressed to IFC is the prominent lack of an expressed basic philosophy and pedagogical descriptions related to practical needs“.

There are several ongoing discussions about the development process of IFC. The previous quoted paragraph by Ekholm is one example. The development of IFC is however going in the right direction, but an enormous amount of effort is still needed in the future before the full potential of a common standard product model for the whole of the AEC sector is reached. Also the development of IFC is based on project-funded support, which gives a very weak control of the development process. However the IFC development in relation to product models, at the time of this research, is the most prominent candidate to reach that goal.

It is today not possible to use IFC standard exchange for the precast industry. However, the Industry Alliance for Interoperability (IAI) has recently initiated a project, "Precast Concrete Constructions IFC – ST3" (Serén, 2002), to define an acceptable international exchange standard for the precast industry where our (StruSoft) participation is aimed at:

- Review of the definitions in order to assure their applicability to the Swedish market.
- Participation into the demonstration scenario as an implementer using IMPACT.
- Take part in the actual definition work

The ST-3 project includes the definition of typical elements in a concrete framework construction such as beams, columns, structural floor elements, facings etc., its geometrical representation, (shape and location in 3D), with belonging connections. The concrete elements are in turn aggregates of concrete, reinforcement, cast in materials, insulation etc. Also information about boundary conditions and structural loads can be applied on component level. This information can later be used in structural calculations on part of or on the whole framework. The ST-3 project does not include the result of structural analyses; this part is covered by the ST-4 project, Structural analysis model and steel construction project (IAI ST-4, 2002).

The prototype described in this paper, deal with information created by the architect that is basic data for the precast design process. The ST-3 project on the other, deal with detail precast concrete information. An example of a scenario in the ST3 project is exchange from precast element design to manufacturing plant.

## 5. CONCLUSION

The IFC standard has the potential to fulfill important functions for all actors in the construction industry. It is of great importance for the industry that various systems are able to exchange information with each other, even when the model is to be used for different purposes. The user of precast design tools, such as IMPACT, must have the possibility to exchange information with architects, structural designers and HVAC engineers without spending too much time on remodeling the construction. It is therefore important to develop tools for automatic adjustments of the model, according to requirements from the precast industry. It is for example often the case that the heights of the imported walls drawn by the architect are not adapted to the precast element production. A tool for remodeling the height of the walls according to selected standard connection (see Fig. 12) before IMPACT divides the walls into precast elements would be most welcome.

To conclude, the implementation project has clearly demonstrated the use of information exchange in the design of precast concrete elements. Also information exchange based on IFC 2.0 can with relatively small efforts be introduced in commercially available design tools such as IMPACT.

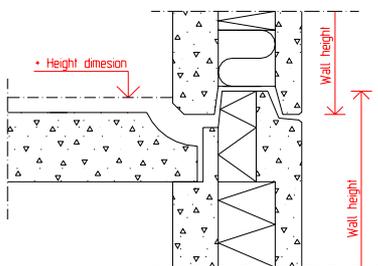


FIG. 12: Vertical section of a standard slab and wall connection.

## 6. ACKNOWLEDGEMENTS

IT Construction & Real Estate 2002 and Skanska AB have provided the financial support for the project. Special attention is given to Mikael Nilsson at StruSoft, for excellent software programming work. Last but not least, Håkan Hansson at StruSoft is acknowledged for the support in software specification.

## 7. REFERENCES

- Alkinci B., Fischer M., Zabelle T. (1998). Proactive Approach for Reducing Non-Value Adding Activities due to Time-Space Conflicts, Proceedings of Sixth Annual Conference of the International Group for Lean Construction (ICGL-6), Sao Paulo, Brazil, 1-16.
- ATLAS (1993) Architecture, Methodology and Tools for Computer-Integrated Large-Scale Engineering - ESPRIT 7280, Home page, Available from Internet: <http://newcastle.cabernet.esprit.ec.org/esp-syn/text/7280.html>
- BLIS (2000). Building Lifecycle Interoperable System (BLIS), Home page, Available from Internet: <http://www.blis-project.org>.
- COMBINE (1995). COmputer Models for the Building INDustry in Europe - JOULE, Home page, Available from Internet: <http://erg.ucd.ie/combine.html>
- Svensk Byggtjänst (1999). BSAB 96 The Swedish construction industry classification system, English version 1999, Stockholm, Sweden.
- Ekholm A., Häggström L., Tarandi V., Thåström O. (2000). Application of IFC in Sweden – phase 2, working report A15, The Swedish Building Centre, Stockholm, Sweden, Available from Internet: <http://www.itbof.com/2002/slutrapporteng.pdf>
- Eurostep (2002). Home page, Available from Internet: <http://www.eurostep.com>
- Fischer M. and Kam C. (2002). PM4D Final Report, CIFE Technical Report Number 143, Stanford University, USA.
- Gieling W. (1988). General AEC Reference Model, ISO TC 184/SC4/WG1 DOC N.3.2.2.1
- IAI, (1999). IFC Object Model Architecture Guide, Available from Internet: [http://radsite.lbl.gov/iai/IFC\\_2.0/specifications/printable/us\\_letter/IFC\\_R2\\_ObjectModelArchitectureGuide\\_Letter.pdf](http://radsite.lbl.gov/iai/IFC_2.0/specifications/printable/us_letter/IFC_R2_ObjectModelArchitectureGuide_Letter.pdf)
- IAI (2002). Industry Foundation Classes, International Alliance for Interoperability, Home page, Available from Internet: <http://www.iai-international.org>
- IAI ST-4 (2002). The ST-4 Project "Structural Analysis Model and Steel Constructions", Volumes 0, I, II, III, III (Example). Home page, Available from Internet: [http://cib.bau.tu-dresden.de/icss/structural\\_papers](http://cib.bau.tu-dresden.de/icss/structural_papers)
- IMPACT (2002). Home page, Available from Internet: <http://www.strusoft.com/impact/>
- IST in Construction (2002). Home page, An overview of IST projects is found on <http://www.cordis.lu/ist/ka2/buildingandconstruction.htm>
- ISO (2001) ISO 12006-3, Organization of information about construction works - Part 3: Framework for object-oriented information exchange, Available from Internet: <http://www.iso.ch>
- ITBoF (2002). Swedish R&D program, IT Construction & Real Estate 2002, Home page, Available from Internet: <http://www.itbof.com>
- Koo B. and Fischer M. (2000). Feasibility Study of 4D in Commercial Construction, Journal of Construction Engineering and Management, 126: 251-260.
- Laitinen J. (1998). Model based construction process management, Royal Institute of Technology (KTH), Construction Management and Economics, PhD Thesis, Stockholm, Sweden.

- Retik A. (1997). Planning and monitoring of construction projects using virtual reality, *International Journal of Project Management*, Volume 3, pp. 28-31.
- Rönneblad A. and Olofsson T. (2002). 4D Modelling of Precast Concrete Building Constructions, *Proceedings of ECPPM 2002, eWork, eBusiness in Architecture, Engineering and Construction*, Portorz, Slovenia, 2002, 203-207.
- Serén K. (2002). Eurostepsys Oy, IFC R3 Extension Information Requirements Specification - [ST-3] Precast Concrete Constructions. Available from Internet:  
[http://www.eurostep.fi/public/PCC\\_IFC/English/R3\\_ST-3\\_D3-4\\_2002-09-24.pdf](http://www.eurostep.fi/public/PCC_IFC/English/R3_ST-3_D3-4_2002-09-24.pdf)
- SPADEX (2001). Short description of the SPADEX Project - Final Report, Available from Internet:  
[http://cic.vtt.fi/vera/documents/SPADEX\\_final\\_report.pdf](http://cic.vtt.fi/vera/documents/SPADEX_final_report.pdf)
- Songer A. D., Diekmann J., Hays B., Al-Rasheed K. (2001). Construction Scheduling using 3-D CAD and Walk-thru, *Construction Innovation*, 1: 191-207.
- STEP-1 (1994). ISO TC184/SC4, IS - ISO 10303, Part1 - Over-view and Fundamentals Principles
- Turner J. (1990). Building Systems Model, ISO TC 184/SC4/WG1 Working paper
- VEGA (1999). Virtual Entreprises using Groupware tools and distibuted Architecture, ESPRIT. Home page, Available from Internet: <http://cic.cstb.fr/ILC/ecprojec/vega/home.htm>
- VERA (2002). Information Networking in the Construction Process - VERA 1997-2002, Home page, Available from Internet: <http://www.tekes.fi/english/vera/>

