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BUILDING INFORMATION MODELING (BIM) FOR ARCHITECTURAL PRECAST CONCRETE

Final Report

for the

Charles Pankow Foundation

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Table of Contents

List of Figures

EXECUTIVE SUMMARY

This project explored and defined the functional requirements for a BIM standard for architectural precast concrete, focusing on the multiple exchanges between architect and precast contractor. It is now recognized that a BIM standard is needed for any construction business domain (or pair of domains) to ensure that two necessary conditions for interoperability are achieved:

a) that the models created by each discipline are composed of meaningful information structures that can be translated into a neutral file format conformant with buildingSMART's IFC schema, and
b) that each software vendor writes translators that use the same subset of IFC objects in the same way.

Development of national BIM standards (or 'NBIMS') is being coordinated by the National Institute of Building Sciences (NIBS).The research presented here, funded by a grant from the Charles Pankow Foundation, takes an essential pioneering step toward development of such a standard for precast concrete. It has 'kick-started' the lengthy standard development procedure defined by NIBS by completing the first four detailed steps: task group formation (partially complete), requirements specifications, process modeling and preparation of a complete Information Delivery Manual (IDM).

The methods employed consisted of two complementary experiments designed to establish the nature of the information exchanges in a new BIM enabled workflow and to define the detailed information needs for those exchanges.

In the first experiment, two parallel design and detailing processes for the precast concrete facade panels of a twenty story commercial building were studied. The parallel process were architectural design and engineering detailing of the facades using traditional 2D CAD tools, on the one hand, and using advanced 3D BIM tools on the other hand. The workflows were recorded and studied in terms of workflows, information exchanges, and design productivity. The 3D BIM process was found to be as much as 58% more productive than the 2D CAD process for detailing the precast pieces and preparation of shop drawings.

The second experiment involved tests of exchanges of building model data between four leading commercial architectural BIM software tools and two commercial precast fabrication BIM tools. A small structure, comprising a wide variety of precast, steel and CIP pieces with complex geometries, was used as a benchmark model to test the exchanges. This work showed that although the IFC product model schema is available, and five of the six software vendors have provided IFC export and import functions, the exchanges are not yet practical for production use. Because there is no agreed to structure for defining precast objects, each user and each vendor's IFC export function represented the building in different ways. Tests done using SAT file formats showed some advantageous methods for exchanging editable geometry, but SAT is (by design) unable to exchange semantically meaningful information about a building. These tests exposed the need for careful definition of certain specific object classes and relationships that are needed for modeling architectural precast. but are lacking from the IFC schema.

Finally, an Information Delivery Manual (IDM) was compiled. The IDM consists of both high-level and detailed process models for both design-bid-build as for design-build projects. It has use case definitions that define the exact information needed for each of 10 exchange types. The IDM is now ready for distribution as a draft for balloting to representatives of the precast concrete industry and of architectural and engineering firms who work with the industry.

The research proposal for this project contemplated progress toward development of the first module of the national BIM standard, for the domain of architectural precast concrete. However, at the time that the project was funded, the procedures for defining a national BIM standard had not yet been established by the NBIMS committee. In fact, the interim results of this research project contributed significantly to formulation of those procedures (through the participation of the first author) by virtue of this being the first practical attempt to develop an NBIMS for any domain. The procedures prescribe two activities that could not be carried out within the scope of this project: extension of the IFC schema as needed for the domain, and industry review of the IDM prior to development of the Model View Definitions. For this reason, the project scope was limited to development of the IDM in a form ready for review.

With the recent publication of the formal procedures for definition of NBIMS, the remaining major steps needed to complete this work as an NBIMS standard and to move it into use, can be defined. They are:

a) Form an interest group comprised of Precast/Prestressed Concrete Institute and possibly Architectural Precast Association leadership to review, approve and promote the implementation of the Architectural Precast IDM.
b) Based on the completed analysis, identify the extensions required of the IFC schema to support the exchanges contemplated in the IDM. The results will be recorded in an Exchange Requirements Model (ERM). This work will extend the scope of the IFC to support surface mixes, reveals, embeds and other aspects of architectural precast addressed in the IDM but not covered in the current IFC release. Other extensions to address all of precast concrete can also be developed.
c) Specification of the IFC construct extensions to the International Alliance for Interoperability (IAI), in the form of an IAI Model View Definition (MVD). Its adoption would lead to incorporation of the precast specific objects into the IFC schema. The resulting Model View and Implementation Specification would be among the first NBIMS module to be implemented in the United States. The MVD would identify the testing regime associated with the use cases that would lead to certification of the software implementation of the use cases.

d) Meet with BIM software developers to promote the implementation of the MVD.
e) Participate in the building SMART review and validation process to see that the use cases defined in the IDM, ERM and MVD have been properly implemented.

This work requires participation of an industry steering group, primarily for review and approval of each formal document. The second step also requires approval from the broader construction industry, under terms of the IFC approval process. However, once the first step has been completed and the second step has submitted a proposed IFC module to the IAI, preparation of the final two parts of the NBIMS guide can begin:

- A software vendor's guide to implementing translators based on the ERM and reported in the MVD.
- A modeler's guide, which may have specific recommendations for each BIM software that has prepared IFC translators. This task should be the responsibility of the software company.

A summary statement of need for further research is included as an appendix to this report. The statement defines the specific work plan for undertaking these steps for the full domain of precast concrete.

Short Authors' Biographies

Charles Eastman is a Professor in both Architecture and Computing and is Director of the College of Architecture Ph.D. program at Georgia Tech. Professor Eastman has served as the IT Advisor for the CIMsteel building modeling project sponsored by the American Institute of Steel Construction. He led the technical advising team for the Precast Concrete Software Consortium, which developed an industry-wide specification for a parametric building modeling system for precast concrete. His group in the Design Computing Lab has developed IFC interfaces for software companies and he is a member of the IFC Technical Advisory Committee. He currently has projects with the Construction Specifications Institute and GSA. He is an author of the "BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors" together with Paul Teicholz, Rafael Sacks and Kathleen Liston.

Rafael Sacks is an Associate Professor in the Structural Engineering and Construction Management Unit, part of the Faculty of Civil and Environmental Engineering at Technion – Israel Institute of Technology. He has researched and developed information technologies for structural engineering and construction since graduating from MIT in 1985. He has developed detailing and other software plug-ins for CAD systems. He founded and heads the Building Information Modeling lab at the Technion's National Institute for Building Research and is co-author (with Charles Eastman, Paul Teicholz and Kathleen Liston) of the "BIM Handbook".

INTRODUCTION

After almost three decades of international gestation, integrated three-dimensional modeling is being adopted as the base construction information by major architectural and engineering firms in the United States (Eastman et al. 2008). At a minimum, these programs facilitate the construction of a virtual digital building that contains a clear and unambiguous geometric description of the architectural design intent, guarantees that all documents, including drawings, are spatially consistent and eliminates most spatial conflicts. These new systems have adopted the term Building Information Modeling (BIM), to characterize their new functionality.

The NIBS Facilities Information Council (FIC) defines building information modeling (BIM) as “a computable representation of the physical and functional characteristics of a facility and its related project/lifecycle information using open industry standards to inform decision making for realizing better value” (NIBS 2007). BIM enables data to be organized and used/reused during the facility lifecycle to document transactions, identify data requirements specific to disciplines and inform business decisions to improve value. However, productive use of BIM requires exchange of data between disciplines, or ‘interoperability’.

The move to 3D modeling of buildings at the construction level is moving ahead within various sectors of the construction industry in parallel with those in architecture. While each of the building industry sectors is supported by particular software applications, the exchange and interoperability between sectors is an important aspect of improving processes and workflows.

The design community is in transition, adopting and learning to effectively utilize the new generation of parametric 3D modeling tools developed for production use. These include Revit from Autodesk, ArchiCAD from Graphisoft, Bentley Architecture and Digital Project from Dassault and Gehry Technologies. The consistency of a single 3D digitally readable model, with associated data regarding functional, material and product information, leads to major changes and potential productivity benefits across broad parts of the construction industry. The involvement by architectural firms is significant. The AIA Committee on Technology in Architectural practice has established a BIM Award competition, seeking to recognize those firms that are using this technology most innovatively. The Association of General Contractors (AGC) has published a set of BIM guidelines for its members (AGC 2006), who seek to leverage BIM to improve the management of construction: through increased support for prefabrication, error-free detailing for production and installation onsite, and better management. Government agencies, such as the GSA, have mandated the use of BIM by their service providers (GSA 2007).

In the domain of precast concrete fabrication, there are two software programs available for production detailing and preparation of drawings (Sacks et al. 2005). They are focused exclusively on leveraging the three-dimensional parametric design approach to integrate all aspects of the design, fabrication, and erection of precast concrete structures. These are Tekla Structures and Structureworks. Both the BIM programs and the solutions developed for the precast industry are based on the assembly of discrete parametric objects in three-dimensional space. Prior to this research project, there was little effort to realize, test and evaluate the interoperability of these tools and the three-dimensional data they generate.

Currently most architectural practices and precast concrete companies are hesitant to adopt fully BIM supported information exchanges, using advanced three-dimensional software solutions directly for their design collaborations, in the absence of unbiased and credible demonstrations of their feasibility and value (Sacks 2004). In that architectural models are almost never made available to fabricators, precast companies must laboriously create the 3D models internally by interpreting the two-dimensional plans provided by designers.

Although there is gathering evidence that even this inherently inefficient process provides distinct advantages over a traditional two-dimensional process, direct migration of the architectural model into the precast concrete programs will allow the delivery of a building to be far more rapid, flexible, efficient, and economical (Sacks et al. 2005). Thus this research sought to document this process and develop a standard that could be used by software developers to create more useful and uniform software in the future.

The Facilities Information Council (FIC) of NIBS is coordinating development of national BIM standards (or 'NBIMS'). A BIM standard is needed for any construction business domain to guide all involved in ensuring that two conditions for interoperability are achieved:

a) that the models created by each discipline are composed of meaningful information structures that can be translated into a neutral file format conformant with the IFC schema (IAI 2007a, IAI 2007b), and
b) that each vendor writes translators that use the same subset of IFC objects in the same way.

The overall procedure for development, implementation and deployment of a BIM standard is shown in Fig. 1. The first steps are to coordinate formation of an industry task group, to elicit the domain knowledge of both the product and process aspects of the exchange requirements, to formally model the business processes, and to prepare an Information Delivery Manual (IDM) for industry review. The following steps (shown as the 'construct' step in the figure) are technical in nature, focusing on information and software engineering: development of model view definitions (product model schema views) and software implementations. This includes both the formal process to incorporate new IFC definitions in the internationally recognized IFC schema as well as implementations of software translators by BIM vendors. The final tasks prepare guides for deployment and follow early adopters' experiences to refine the BIM standard.

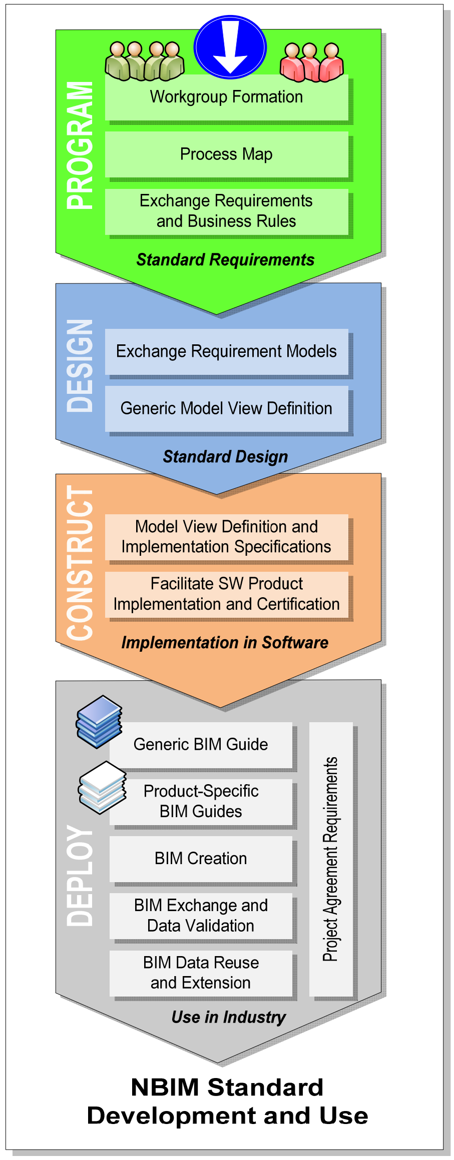

Fig. 1. NBIM Standard Development and Use

This research report has four segments. This document provides an overview, and makes reference to the three major parts:

- **Part A**: describes the **Rosewood experiment**, in which a building was modeled and exchanged using BIM tools concurrently with its actual design and fabrication detailing of its precast parts using standard 2D CAD tools.
- **Part B**: describes the information exchange **benchmark tests**, in which a small but complex building model was tested for modeling, IFC export, IFC import and

exchange between four architectural BIM tools and two precast fabrication detailing tools.

- **Part C**: the **Architectural Precast Information Delivery Manual,** which defines the information exchanges needed for precast architectural façade pieces.

GOALS AND OBJECTIVES

The goal of this research was to complete the first stage of development for one of the first NBIMS Standard under the auspices of the National Institute of Building Sciences. This was achieved by pursuing two experiments to elicit the information needed and by then developing an Information Delivery Manual (IDM). The goals and objectives for each of these three activities are detailed below.

The first experiment (called the “Rosewood Experiment” because the Rosewood Building in Dallas, Texas, served as a test bed) aimed to examine and document an example specific workflow scenario between building sectors – the exchange of data between architects and precast concrete fabricators. This pass-off has traditionally occurred in the format of the contract documents (CDs) provided to the general contractor by the architect and passed on to the precast fabricator. An early task of the fabricator is to generate from the CDs a new set of drawings of the precast assembly, typically called Precast Assembly Drawings, which will later be used to coordinate the detailing of each of the precast pieces and the development of piece drawings for actual production. Later these detail piece drawings are passed back to the contractor and architect to verify design intent and for construction coordination between different building systems.

The move to 3D modeling potentially reduces that task immensely, allowing generation of the Precast Assembly Model in hours rather than days or weeks. The experiment tested and documented the integration and exchange of a 3D building model between architect and precast fabricator. It addressed the information exchanged in different exchange tasks. It also assessed, from the perspective of the precast fabricator, the time and dollars associated with working in this new technology-enhanced process in relation to processes relying on drawing-based exchanges.

The second experiment involved tests of exchanges of building model data between four leading commercial architectural BIM software tools and two commercial precast fabrication BIM tools. A small structure, comprising a wide variety of precast, steel and CIP pieces with complex geometries was used as a benchmark model to test the exchanges. The cooperation of the vendors of all four architectural BIM tools was sought and obtained – each received the benchmark model definition. The goal was to establish the state-of-the-art in exchanging building model information between the applications and to identify the shortcomings, in order to inform development of an Information Delivery Manual (IDM) for the domain.

The IDM that was developed is the basic building block for the architectural precast national BIM standard (NBIMS). The goal was to develop the IDM to the point at which it could be distributed to industry professionals for comment and review, as part of the formal NBIMS balloting process.

PART A: Rosewood 3D Modeling Experiment

The full report of this work is presented in the attached document "Part A Rosewood Experiment - Goals, Methods, Execution and Results". The following is an executive summary.

In this study, the collaborative process of architectural façade design and precast detailing for fabrication was examined in a unique experimental setup in which a fully 3D BIM enabled process was performed in parallel with the standard 2D CAD process. The subject of the experiment was the Rosewood building – a 16 story office building composed of cast in place concrete and precast architectural concrete facades in Dallas, Texas (see Fig. 2). It was designed and detailed using traditional 2D CAD tools by the architect, HKS (Dallas), and the precaster, Arkansas Precast of Jacksonville Arkansas.

HKS later prepared a full 3D model of the structure and the façade elements, using Revit Building 9.1 BIM software. The model included slabs, columns, beams and walls for the structure and mass elements for the precast concrete façades. A Technion graduate civil engineering student modeled the precast concrete facades using Tekla Structures v13 BIM software while in residence at High Concrete Structures plant in Denver, Pennsylvania.

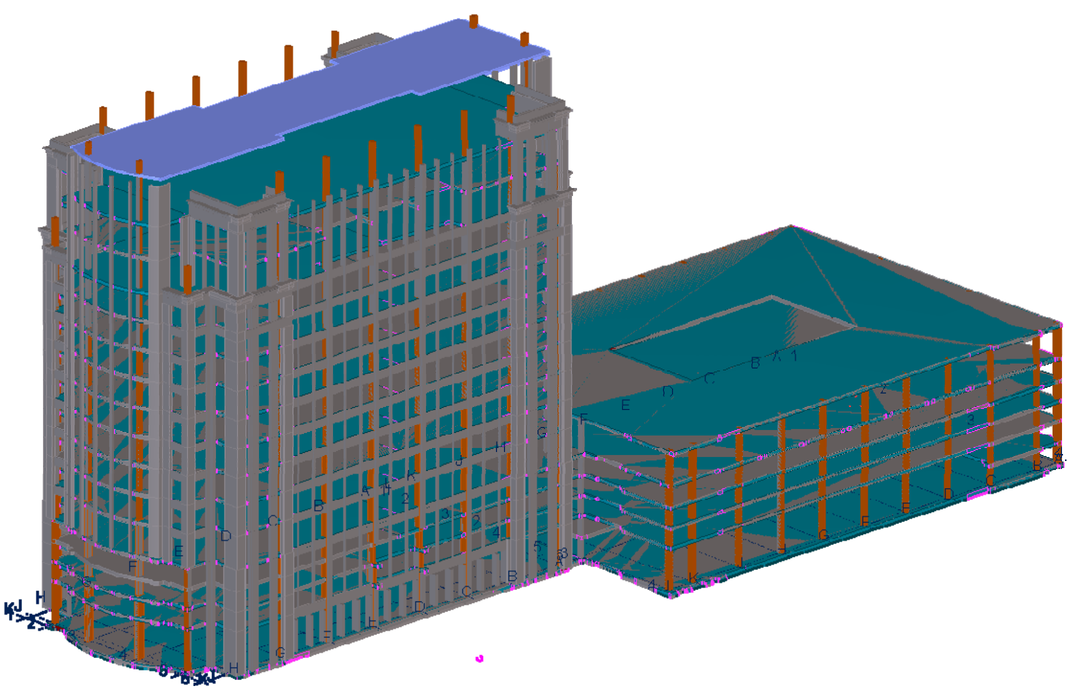

Fig. 2: Rosewood Building

The goals established for the experiment were:

- to explore best practice for the use of 3D BIM tools in collaboration between architects and precast façade fabricators, and to highlight shortcomings of the procedures and software available.
- to record the processes and productivity achieved in parallel 2D and 3D workflows for the same project, identifying the productivity, the benefits and the problems encountered in each of the workflows.
- to identify appropriate workflows and the information exchanges needed to support them.

Method

A complete 3D model of all of the precast façades of the building was built using Tekla Structures. The model was prepared to a level of detail that allows output of general arrangement drawings and shop drawings of the geometry only for all of the pieces. The ‘raw material’ for the modeling was provided in the form of IFC models provided by HKS. IFC files of the entire building were provided at three points in time with increasing detail, to simulate the natural progression of information development in design. Where necessary, the actual precast shop drawings and connections were consulted. Numerous full general arrangement and erection drawings were prepared.

Ten precast pieces were modeled in full with complete production details; all of the remaining pieces were modeled at the level of detailed exterior geometry only. Four full production-ready shop drawings that include the geometry, embeds and rebars were prepared. Material take-off data was extracted for four pieces in a format compatible with High Concrete's purchasing and production scheduling software. Full precast piece reports were prepared with piece name, position, length, volume, weight and other attributes for production and erection scheduling.

Results

Workflows: During the experiment different workflows of the modeling and communications using the BIM tools between the precast engineering staff and the architect's staff were recorded. The modeling wasinitiated using the architect's model, as would be expected in a normal process. The precaster, Arkansas Precast, modified the architect’s layout and detailing, as would be expected from the Design-Bid-Build process. We also anticipated how this workflow would change in a Design-Build or teaming arrangement. Some important differences to the current 2D workflow and collaboration were found for both processes modeled.

In the 2D workflow, the tools do not facilitate careful consideration of the context for each piece, and changes through a piece's extruded length can be overlooked.
In contrast, in the 3D workflow, the tools demand a more detailed approach to engineering the façade pieces as soon as modeling begins, because the context for

each piece within the building, with all of its local peculiarities, becomes clearly evident. Thus users identify local solutions and provide a richer, more specific design at the early stage. This requires more thought and effort than required using typical sections and pieces, which is the case when using the 2D tools at this stage. Alternatively, 3D modeling can have different results depending on the context of the project collaboration:

- If there is close collaboration, then design issues are brought to the attention of the team early and this avoids rework later in the detailed design phase.
- If the collaboration is not close, then the architectural design may still be changed as the design is detailed, with the result that most of the pieces may have to be remodeled later. In this case, greater time invested up front may be wasted and the re-work of rebuilding the models for scratch is imposed.

Another important difference observed between 2D and 3D workflows concerns the ways in which design alternatives can be represented. In 2D, two alternative cross-sections for a spandrel, for example, can be given by simply drawing the two alternatives adjacent to the spandrel plan view. However, existing 3D modeling software requires that a single 'reality' exist, and so alternatives must be represented by saving separate model files. This is a limitation at the conceptual design stage for most BIM software, where a precast fabricator often needs to communicate multiple alternatives to an architect for evaluation. Functionality is needed in 3D modeling software to allow local saving of alternative sets of data and the ability to toggle between them when evaluating candidate designs.

Information Exchange: The experience gained and the information elicited through the course of this experiment supported articulation of current information exchanges and prospective new ones, identifying the use cases, data exchanges and the corresponding sets of data that need to be transferred using BIM software. The results of this analysis are reported in Part C of this report, which is a draft Information Delivery Manual (IDM) for the domain of architectural precast facades. The IDM is intended to form the basis for a BIM Standard for architectural precast concrete facades that can be formally incorporated in the National BIM Standard.

The main limitations observed throughout this experiment were that the BIM software applications did not enable full exploitation of the capabilities of the IFC exchange schema. This means that the model data was degraded somewhat through each step – export and import – in both directions. The degree of degradation was such that relatively little more than the basic geometry of the structural components, and only the geometry of the precast façade pieces were transmitted. For example, the lack of a specific precast façade object in Revit Building meant that no such object can appear in an IFC export file. However, by the same token, no specific precast façade object exists in the IFC schema (as of the IFC 2x3 version). On the precast import side, Tekla Structures v13.0 only allowed import of the IFC file as reference objects. The limitations are detailed in Part A, see especially Section 6.

Productivity: The experiment demonstrated the viability of designing and detailing of precast façade pieces completely with existing BIM software. All of the information needed for design coordination, fabrication and erection could be generated using BIM tools. No specific limitations were encountered.

During the experiment, 3D modeling working hours were carefully logged. At the same time, the 2D design team logged their working hours. The level of detail recorded allowed comparison at different common points in the processes. The result was an overall productivity gain for precast detailing that was estimated at 58%.

PART B: Benchmark Data Exchange Tests

The full report of this work is presented in the attached document “Part B Data Interoperability Benchmark Test, Between Architect and Precast Fabricator”. The following is the executive summary of that document.

Many of the potential benefits of Building Information Modeling (BIM) can only be realized if both the modeling tools and the exchange technology between different users are robust and perform at high integrity. This report describes a set of experimental tests used to assess the current capabilities of BIM design and fabrication tools to support advanced practice in the area of architectural precast design and fabrication. It assesses the modeling capabilities of the tools, the effectiveness of expert users to utilize the tools, and most importantly, the exchange capabilities between the tools.

A small but complex benchmark building design (shown in Fig. 3) was developed and assigned to in-house modelers from each of four prominent BIM architectural tool developers (Revit, Bentley, ArchiCAD, Digital project). Each of the models they prepared was then exported into an IFC file and assessed. The four models were then each imported into the two main precast detailing tools (Structureworks and Tekla Structures). Detailed examination identified the errors at each step, in modeling, in exporting and importing. The exchanges were assessed regarding the geometry exchanged, the properties and the grouping of geometry into pieces.

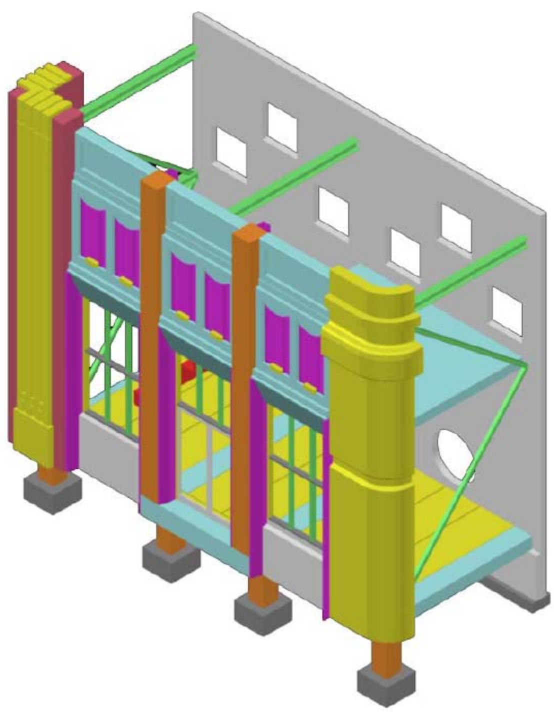

Fig. 3: Benchmark Building

A broad spectrum of capabilities and limitations was shown. In most cases, almost all of the geometry was transmitted, with local specific errors that could be corrected. However, in many cases, the piece count of the model changed. Importantly, all of the exchanges in this example allowed only static, non-editable geometry exchange; editing on the receiving application required re-building of the pieces. There was also a wide variety of mappings between internal model objects and the IFC objects use to represent them. The wide disparity in the ways in which valid IFC files can be exported for the same building model, with users applying different modeling methods and objects, strongly underlines the need for BIM standards. The standards in terms of IDM and MVD, are only part of the complete solution. The complete solution requires definition of which objects in the BIM tools are to be used for architectural precast exchange, what IFC objects should be used for those building elements, and how they should be related to one another. The Part C document of this report, the Information Delivery Manual (IDM) for precast architectural facades, is a first step in defining the needed conventions for reliable standard exchanges of architectural precast concrete.

All four BIM tools have IFC export functions, and three of the four have IFC import functions. Of the two fabrication modeling tools tested, only Tekla Structures has IFC import and export functions. Where IFCs could not be used, DXF/DWG and SAT/STP file formats were tested, although these can export geometry only, with no object data. The only exchange that could not be made was that between ArchiCAD and Structureworks, due to the absence of any common file format.

Among the tests of IFC import into Tekla Structures, which were performed using files exported from all four of the BIM tools of Group A, a careful visual and data inspection identified discrepancies in the type or geometry of all objects. The results of this inspection showed that of the 52 distinct features examined, Revit's IFC file correctly represented 50 features (or 96%), Bentley's 41 (79%), ArchiCAD's 31 (60%) and Digital Project's 11 (21%).

Where SAT or DWG formats were used, both resulted in varied errors. However, one surprising result was discovered: in three of the exporting programs that supported SAT, the export application supplied geometry that when imported, was directly editable in the receiving application. This allowed errors to be fixed quickly and work could directly continue using the imported geometry, without rebuilding.

PART C: Information Delivery Manual

The information delivery manual is provided in the attached document “Part C: Use Cases and Information Exchanges for the NBIMS: Architectural Precast Domain”.

This document defines the data exchange requirements and workflow scenarios for exchanges between an architect and precast fabrication contractor for two primary construction contracting arrangements: Design-Bid-Build (DBB) and Design-Build (DB). The Design-Build scenario also supports, we believe, other types of teaming and collaboration-based project delivery methods.

The draft IDM for architectural precast extends to include exchanges between precast fabricator and structural engineer of record and between precast fabricator and general contractor, as these are important parts of a complete process for this building elements.

Part C provides important input for codifying this exchange scenario for the Facilities Information Council and its development of a national BIM standard. It is the most detailed example developed to date, to the authors’ knowledge.

CONCLUSIONS

From a precast concrete construction perspective, the ideal world would be one in which an architect and a precast fabricator (and the engineer of record and general contractor, who are also directly involved in precast concrete construction) are able to exchange building information model data between their applications in a seamless fashion. This goal remains elusive; although a building product model schema (IFC) is now available, standards are still needed to define how each discipline should prepare its models for exchange, how software vendors should map their proprietary objects to IFC objects, and which IFC objects are needed for each of the specific business exchanges. These are the aspects that will be defined in the national BIM standards.

BIM tools are developing rapidly and their benefits are becoming clearer. However, their need to incorporate and reflect the expertise and practices in the broad range of building systems points out the scale and depth of this transition. This research, funded by the Charles Pankow Foundation, initiated the pioneering development of one of the first BIM standards; the precast concrete domain was selected to serve as an example. The two experiments carried out here illuminate many of the issues and complexities of effective interoperability, and enabled development of an Information Delivery Manual (IDM) for architectural precast.

The productivity benefits that were measured in the Rosewood experiment for the precast fabricator are in the order of 58% (this exceeds results of 38% to 41% obtained in earlier research projects (Sacks etal. 2003; Sacks et al. 2005) .This result is considered more reliable than earlier work due to the large scale of the experiment.. However, the Rosewood experiment and the Benchmark tests, also pursued in this research project, have confirmed that the level of interoperability between BIM tools for this domain is still very low. Much work has been identified to improve it. These studies, together with the development work in elaboration of the Architectural Precast Information Delivery Manual, have clearly shown that development of BIM standards is an essential step in raising the value of the information exchanges contemplated.

Although exchanges using formats other than IFC were also investigated (DWG, SAT and STEP), they served primarily to highlight the possibilities of exchanging geometry for any case in which an IFC exchange is unavailable. This was relevant for the architectural precast domain because one of the precast concrete detailing BIM tools, Structureworks, does not yet have IFC capability. The exchange using SAT files proved to be accurate and resulted in editable geometry, but (predictably) it could not deliver semantically meaningful building objects or any of their properties. Geometry imported to Structureworks had to be grouped into solid objects before it could be related to as precast façade pieces and detailed. Return direction exchanges were not attempted, although by the nature of the file format, it would necessarily degrade the building information back to geometry alone.

The IFC exchanges experienced in both the Rosewood and the Benchmark work revealed that the barriers to effective IFC exchange are clearly resolvable. The barriers are based on non-uniform use of the BIM tool, non-uniform mappings to IFC objects, variation in the ways geometry was represented in the tests, and objects missing from the IFC for domain-specific concepts. These barriers are described in more detail below.

Non-uniform use of the BIM tool. Modelers have multiple ways to model a building artifact that has not been specified through documentation or specific commands in the BIM design tool. As a result, the element will be created in various ways by the sender and cannot be interpreted by the received in an exchange. For example, in one instance of the benchmark model concrete footings were modified as mass elements and so were not exported as IfcFootings. In the Rosewood study, some façade panels were also modeled as mass elements, where modeling them as wall or curtain wall objects would have been more accurate. There is not yet any regular convention for naming or otherwise identifying precast elements. These can be problems with any communication, but in BIM exchanges, they render the data useless for anything other than visual inspection or transfer of geometry only. This limitation can be resolved with clear BIM tool documentation, along with extensions to carry needed attributes and naming conventions.

Non-uniform mappings between internal native objects and IFC schema objects. Each software company has defined its own mapping between its native objects and the IFC schema objects within its export and import translators. Although all of the four architectural BIM tools and the one precast/structural engineering BIM tool that were tested for IFC exchanges have been subjected to both internal and external conformance testing, the conformance testing did not address precast concrete. There is a wide discrepancy in the contents and values generated in the IFC files that were exported and imported. This stems from the absence of any clear guidance to implementers of the translation functions for mapping between their own internal data objects to IFC objects.

Variations in representations of geometry. Developers of IFC translators are also unrestricted in their choice of appropriate geometric representations from those supported (B-Rep, swept solids, CSG). Indeed, the degree of flexibility of the IFC object schema can be considered a weakness in that it does not force conformance. Dumb geometry can be translated with high fidelity, but it is generally not editable. In most cases of successful geometry tasnaltion, B-rep geometry was used However, a BIM standard must relate to the geometry level as well as the semantic level. In many cases, extruded profiles in the form of swept solids provide editable exchanges fro BIM tools exchanges. Using the SAT exchanges as a guide, it appears that profile cross-sections defined separately from the building element instances in which they are used would allow the base objects in architectural BIM to be transferred to precast BIM tools in a directly editable mode. Details and features based on Boolean operations can be added to provide architectural details. However, this requires changes to be specified for implementation by the BIM tool vendors in their IFC export and import translators

Domain-specific objects missing from the IFC 2x3 schema. Detailing of the Architectural Precast Information Delivery Manual revealed a number of gaps between the information items that must be transferred in various exchanges and the availability of appropriate classes of IFC objects to represent them. Some examples are: a generic *IfcPrecastFacade* object, which is needed to support schematic design and panelization; and an *IfcPrecastFacadePanel*, which would represent the individual pieces of a façade. Multiple additional classes may be needed to model other features (face mix, surface embeds) within the panels that are defined by the architect or precast contractor and shared with other parties to the building process.

The Architectural Precast Information Delivery Manual that was derived in this project provides initial specification of the exchange scenarios for the domain of architectural precast concrete. As such, it is an important building block toward the development of a national BIM standard by the Facilities Information Council of the National Institute of Building Sciences. A BIM standard would provide solutions to the first three problems cited above, once software vendors implement the appropriate translation functions in compliance with the standard. The fourth issue requires a precast-specific extension of the IFC model schema. Fig. 4 shows the ‘pyramid’ of needs for interoperability. The Information Delivery Manual provides the contents highlighted with dashed lines in the figure.

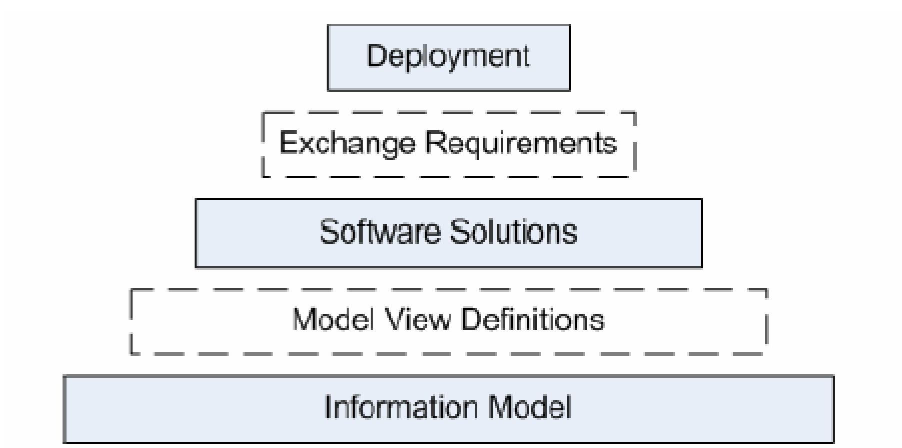

Fig. 4: IM/MVD Interoperability Frame

New workflows. The lessons learned from the Rosewood experiment provided a good understanding of the changed workflows for architectural precast design and detailing that are needed to gain maximum benefit from BIM tools. The key finding is that in the 3D workflow, the process strongly benefits from a more detailed approach to engineering the façade pieces, once a façade concept is selected, because the context for each piece within the building, with all of its local peculiarities, becomes clearly evident. Thus users identify local solutions and provide a richer, more specific design at the early stage. This requires more thought and effort (expertise) than required using typical sections and pieces, which is the case when using the 2D tools at this stage. However, it leads to higher quality designs through more detailed consideration of alternatives, and drastically reduces the effort required for production detailing and preparation of shop drawings.

It is not expected that architects will have the detailed expertise to manage the often plant-specific issues of precast concrete fabrication. These potential benefits are most directly realized by early involvement of the precast fabricator in the design process.

Limitations: This study has multiple limitations:

1. The study was based on a single example of exchanges, using only the traditional Design-Bid-Build delivery method. Multiple examples are needed, especially to deal with architectural precast with different features.
2. While we made an initial effort to define collaboration-based workflows, example workflows are needed to validate and refine Design-Build and similar increasingly important types of business models.
3. This study and IDM has been directed toward exchanges between architect and precast fabricator. However, this type of product – architectural precast – has wider interactions. They include the range of analysis associated with sustainability issues – energy, lighting – and also various production activities within the precast fabricator shop. These include materials handling, shop plant scheduling, advance ordering systems and accounting, rebar bending and reinforcing mesh patterning, plus others. These will be addressed in later IDMs.
4. This process took the development of a national BIM standard to the level of IDM – defining the functional needs for exchanges. The next step is to define the Model View Definitions (MVD) and to document these fully for IFC translator implementation. Many of the technical issues for the MVD implementation have been defined, for example in the Level 3 IDM specifications. However, additional work is called for, to first propose needed extensions required to the IFC schema in order to better support representation of architectural precast objects. These extensions and the documentation would be required prior to full implementation.
5. Implementation involves both strong involvement and support by the expected users of this system, in order to build the commitment to implement the translators by the software companies.

Each of these limitations identifies future steps to be addressed to complete and extend the work initiated in this project. The next practical steps toward deployment of an NBIMS for precast concrete are to:

a) Form an interest group comprised of Precast/Prestressed Concrete Institute and possibly Architectural Precast Association leadership to review, approve and promote the implementation of the Architectural Precast IDM.
b) Based on the completed analysis, identify the extensions required of the IFC schema to support the exchanges contemplated in the IDM. The results will be

recorded in an Exchange Requirements Model (ERM). This work will extend the scope of the IFC to support surface mixes, reveals, embeds and other aspects of architectural precast addressed in the IDM but not covered in the current IFC release. Other extensions to address all of precast concrete can also be developed.

c) Specification of the IFC construct extensions to the International Alliance for Interoperability (IAI), in the form of an IAI Model View Definition (MVD). Its adoption would lead to incorporation of the precast specific objects into the IFC schema. The resulting Model View and Implementation Specification would be among the first NBIMS module to be implemented in the United States. The MVD would identify the testing regime associated with the use cases that would lead to certification of the software implementation of the use cases.
d) Meet with BIM software developers to promote the implementation of the MVD.
e) Participate in the building SMART review and validation process to see that the use cases defined in the IDM, ERM and MVD have been properly implemented.

The resulting Model View and Implementation Specification would be one of the first NBIMS module to be implemented in the United States. This standard would allow software vendors to design and implement tools that would allow effective and reliable interoperability of data and provide for uniform input and output of data specific to business exchanges between disciplines identified here.

This work will require participation of an industry steering group, primarily for review and approval of each formal document. The second step also requires approval from the broader construction industry, under terms of the IFC approval process. However, once the first step has been completed and the second step has submitted a proposed IFC module to the IAI, preparation of the final two parts of the NBIMS guide can begin:

- A software vendor’s guide to implementing translators based on the ERM and the MVD.
- A modeler’s guide, which may have specific recommendations for each BIM software that had prepared IFC translators.

In conclusion, this project has achieved two major advances toward development of NBIMS. It has developed the first IDM for a domain, and it has also been instrumental in informing the development of a detailed guide that other NBIMS efforts can use as template and model for future initiatives. Appendix A provides a summary needs statement for the additional research needed to extend this project and complete an NBIMS for precast concrete, which would be the first of its kind.

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Publications

The Georgia Tech–Technion team has submitted three journal papers describing the work accomplished to date. One conference paper has also been submitted.

Journal Papers

Kaner, I., Sacks, R., Eastman, C.M., and Jeong, Y-S., (2008). "The Rosewood Experiment – Building Information Modeling and Interoperability for Architectural Precast" submitted to the special issue on Interoperability in *Automation in Construction.*

Jeong, Y-S., Eastman, C.M., Sacks, R., Kaner, I., (2008). "Benchmark Tests of IFC Exchanges for Precast Concrete" in preparation for *Computer-Aided Design (CAD)*.

Eastman, C.M., Sacks, R., Kaner, I., Jeong, Y-S., (2008). "Development of an Information Delivery Manual – a step toward a National BIM Standard" submitted to the *ASCE Journal of Computing in Civil Engineering*.

Conference Paper

Sacks, R., Eastman, C.M., Kaner, I., and Jeong, Y-S., (2008). "R&D of BIM Exchange Standards for IFCs: A Case Study of Architectural Precast Facades" submitted to the International Conference on Computing in Civil and Building Engineering, Tsinghua University, Beijing, China.

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APPENDIX A

Needs Statement:

BUILDING INFORMATION MODELING STANDARDS FOR ALL PRECAST CONCRETE

The precast concrete fabrication industry has recently begun to use parametric 3D modeling tools for fabrication-level modeling of precast products. This new technology is called Building Information Modeling (BIM). The architectural, structural design, general contracting and other AEC communities are also quickly adopting BIM technology for production use. Each uses specific BIM tools tailored to their profession or functional need. The development of robust and smooth interoperability between such electronic tools requires the definition of exchange standards and their implementation in relevant BIM applications, so as to guarantee that the data exchanges are effective and efficient. Standards of this kind have two components: a **building product data model**, which defines the object-oriented structure of all information needed to describe buildings (the IFC model is the basic building product data model) and a set of **model view definitions**, which define what information will/must be exchanged in each of the different stages of any given workflow process.

The research described in this report encompassed initial specification of an Information Delivery Manual and corollary work needed as a first step toward a BIM standard for workflows dealing with architectural precast data exchange. This needs statement describes the work needed to extend and complete this initial work, by developing the model view definitions (MVDs) needed and formalizing them in a national BIM standard (NBIMS) for architectural precast and to extend the basic effort to address all common forms of precast concrete construction. To complete the standard it will be necessary to follow the NBIMS process defined in Chapter Five of the National BIM Standard, Volume 1.

The following precast products should be included: stemmed deck members, flat deck members, beams, columns, load bearing walls and spandrels, piles, and architectural facades. A necessary component of this task (as partially established in the initial research) is to identify and specify objects and relationships missing from the current IFC model and represent them in a form to be implemented in the next release of the IFC. These would enable BIM software vendors to write the export and import routines needed for their products to support interoperability for all types of precast products.

This effort will require the following specific activities, following the procedures outlined in Section 5 of Volume 1 of the national BIM Standard:

- establishment of a coordinating committee of the Research and Development or other committee of the Precast/Prestressed Concrete Institute (PCI);
- extension of the IFC schema to properly represent precast pieces and behavior;
- definition of IFC Views for the defined workflows;

- development of a testing and validation process, and coordinating with precast and other related software companies on their implementations.

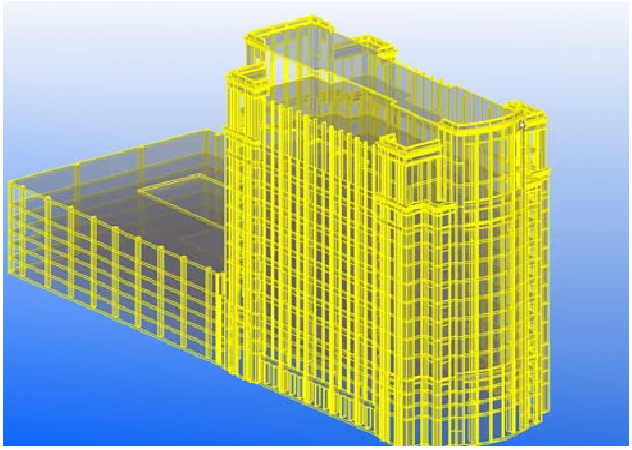
The immediate deliverable will be a national BIM standard for all precast concrete. It will support this segment of the precast industry, including the businesses it works with, and the software vendors it works with. The standard will support development of a new set of debugged and reliable translators supporting data exchange of precast concrete data with other relevant applications. These exchanges will make available new productivity and collaboration processes that are not possible today. The completed work will also generate explicit guides and documentation for other AEC industry segments to undertake similar NBIMS standard activities. These will serve as examples for all other parties in AEC about the process that may follow to develop BIM Standards in other areas.

The Precast/Prestressed Concrete Institute will need to support the research, as will the National Institute of Building Sciences (NIBS) as the organization supporting the National BIM standard effort.

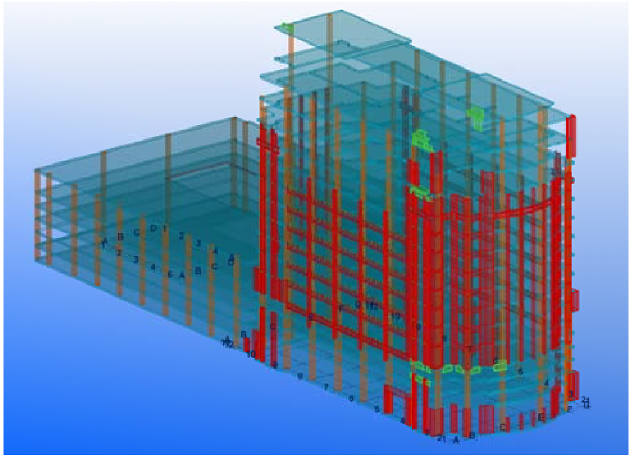
Part A

Rosewood Experiment

Goals, Methods, Execution and Results



Revit IFC Model



Tekla Model

Contents

List of Figures

List of Tables

1 Background

The experiment described in this document was a central part of a research project designed to explore the current and potential capabilities for exchanging building information models between an architect and a precast company for precast architectural facades. It served both as a platform for knowledge elicitation of the design and detailing process and the information exchanges that are required. The project was funded by the Charles Pankow Foundation in line with its aim to further innovations in building design and construction, so as to provide the public with buildings of improved quality, efficiency and value. The project encompassed several companies and organizations, and was supervised by FIATECH and NIBS. Georgia Tech and Technion were the research coordinators and undertook the experimental work described in this document with the assistance of HKS Dallas and Arkansas Precast.

The overall research report had three major segments. This document (Part A) describes an experiment in which a building was modeled and exchanged using BIM tools concurrently with its actual design and fabrication detailing of its precast parts using standard 2D CAD tools. The second document (Part B) describes an information exchange benchmark experiment, and the last document (Part C) defines the information exchanges needed for precast architectural façade pieces.

The experiment described here had a number of specific goals:

- The first goal was to explore best possible practice for the use of 3D BIM tools in collaboration between architects and precast façade fabricators, and to highlight shortcomings of the procedures and software available (Winter 2007). The 3D process adopted is detailed in Chapter 3 of this report.

- The second goal was to record the processes and productivity achieved in parallel 2D and 3D workflows for the same project, identifying the productivity, the benefits and the problems encountered in each of the workflows. The 2D process is reported in Chapter 4, and detailed comparisons, including productivity estimates, are provided in Chapter 6.
- The final goal was to identify appropriate workflows and the information exchanges needed to support them. These are reported in Chapter 5.

The experience gained and the information elicited through the course of this experiment supported definition of the use cases, data exchanges and the corresponding sets of data that need to be transferred using BIM software. The results of this analysis are reported in a separate document, Part C, which is a draft Information Delivery Manual (IDM) for this domain. The IDM is intended to form the basis for a BIM Standard for architectural precast concrete facades that can eventually be formally incorporated in the National BIM Standard.

Acknowledgment

The authors are greatly indebted to a number of people and organizations whose support and assistance was vital to the execution of this experiment. They include Davis Chauviere and Kelly Garcia at HKS in Dallas, Dave Bosch, Bill Whary and Karen Laptas at High Concrete in Denver, PA, Russ Vines and Mark Ramm at Arkansas Precast, and Charles Pool at Tekla, Atlanta.

2 Goals, method and procedure

The experiment was conducted using the design process for the precast façade panels of the Rosewood project, a 16 story (35,000 sq.ft.) mixed retail and office building in downtown Dallas, Texas, as a research 'workbench'. Fig. 1 shows a rendered view of the buildings. The project was designed by HKS, a leading architectural firm; HKS provided the Rosewood project information both in 2D and 3D files and data. Arkansas Precast, an architectural precast fabricator, was selected by the owner to design and deliver the architectural façades of the building. At the time of the experiment, Arkansas Precast worked exclusively with 2D CAD tools, and had not yet adopted 3D parametric software. In order to compare the production and productivity values of BIM, High Concrete Structures, also a precast fabricator company, supported the 3D BIM experiment; High's 3D modelers and engineers mentored a Technion graduate student at their offices through the modeling process. In fact, all of these firms played the roles that collaborating teams play in construction practice.

Fig. 1 - A rendered image of the Rosewood Building

Fig. 2 provides an overview of the control and experimental activities. The first comparison that could be drawn was between the alternate architect-precast fabricator collaboration workflows, schematically shown by the two bi-directional arrows labeled #1 and #2 in Fig. 2. The second comparison made was between the productivity experienced by the precast fabricator using 2D CAD and the experiment team using 3D parametric modeling; this comparison is labeled #3 in Fig. 2.

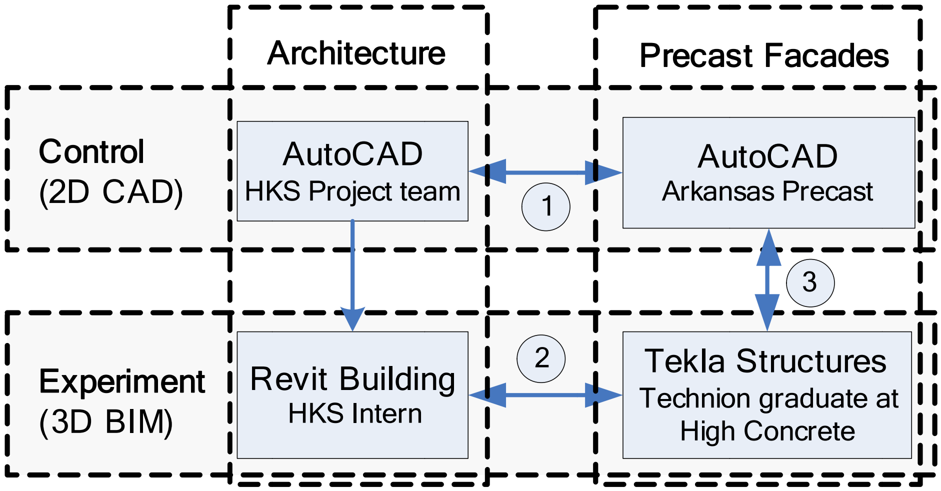


Fig. 2. Experiment activities and the comparative analyses they afforded.

2.1 Goals

The goals defined for the Rosewood experiment were to:

- Identify the collaboration workflows that are currently in use using conventional CAD systems (labeled #1 in Fig. 2).
- Identify the new collaboration workflows that will be used with 3D BIM tools (labeled #2 in Fig. 2).
- Identify the object level exchange capabilities that are available today, allowing smooth workflows and minimal replication, within the exchanges of #2, using leading commercial software. For this modeling exercise, Revit Building was selected by the architect and Tekla Structures was selected for precast fabrication to be compatible with High Concrete's practices).
- Identify the new IFC objects that appear to be needed in order to enable effective workflow collaboration between the parties involved in design of architectural precast facades.

- To collect productivity data for comparison between the different types of design processes (between 2D CAD vs 3D BIM - labeled #3 in Fig. 2.) Both qualitative and quantitative comparisons were required. Productivity data is measured in terms of hours worked on the project.

An additional aim was to evaluate the status and capabilities of the IFC product data model for the purposes of the workflows being examined. The fine details of each information exchange were recorded at the level of information items using the GT-PPM process maps. These form the basis for the development of the information exchanges that were developed and are reported in Part C of this report.

2.2 3D Modeling Experimental Method

In order to achieve these goals the research team proposed the following steps:

- To compile, using Tekla Structures software, a complete 3D model of all of the precast façades of the building to a level of detail that allows output of general arrangement drawings and shop drawings of the geometry (only) for all of the pieces.
- To produce at least four full production ready shop drawings that include the geometry, embeds and rebars.
- To extract material take-off data for the four pieces in a format compatible with High Concrete's purchasing and production scheduling software.
- To produce at least four full general arrangement and erection drawings for the project.

- To produce full precast piece reports that include: piece name, position, length, volume, weight and other attributes for production and erection scheduling.
- To integrate production and erection phasing (schedule) information within the 3D model and visualize the processes.

Most of these were completed in full – details are provided in section 3 below.

2.3 Collaboration process workflow

In order to understand the collaboration workflows, the project participants were asked to record all of the activities and information communication events. These included review iterations among High, HKS and the structural engineer. A web site was prepared for logging this activity (see Fig. 3).

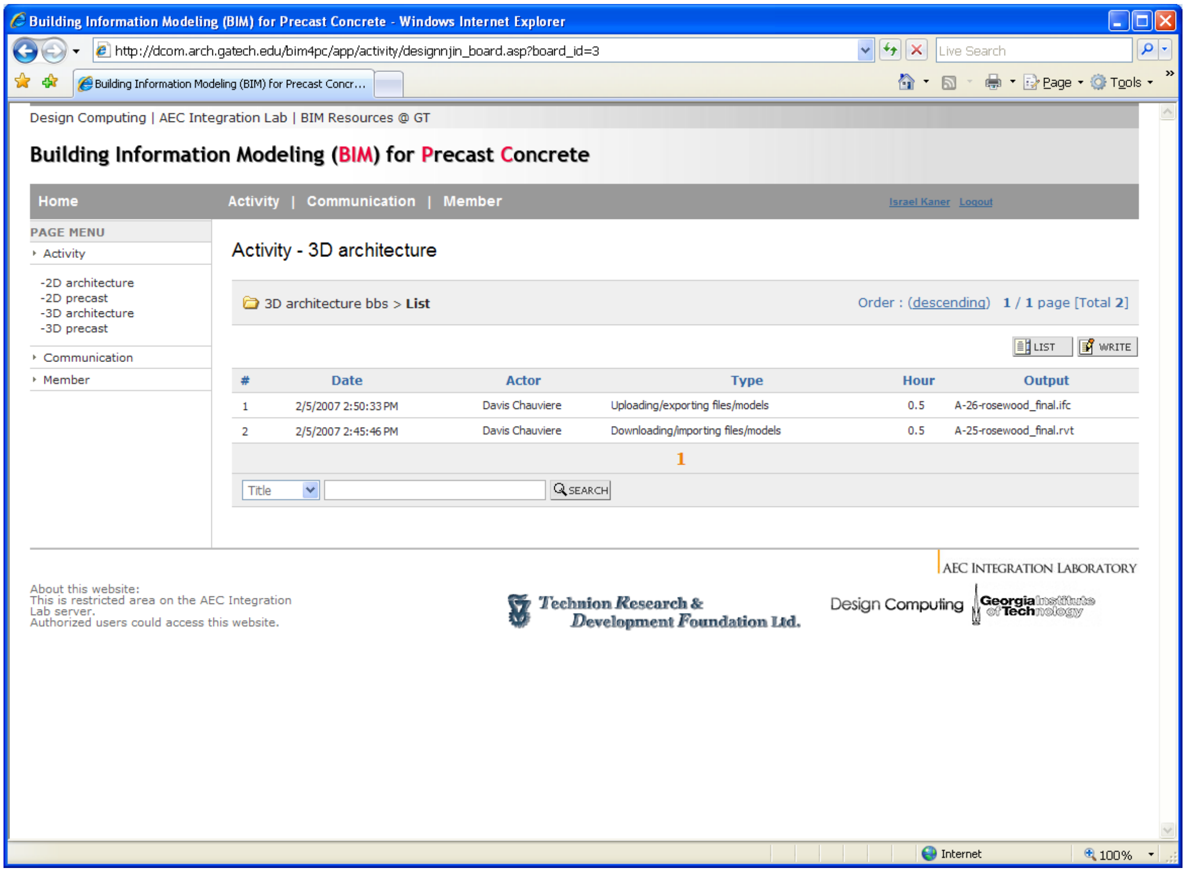


Fig. 3. Web pages for recording workflow log.

In practice, little of this information was recorded during real-time, and instead data was collected retrospectively. Details are provided in Chapter 5.

The process workflow was modeled using GT-PPM (Lee 2007, Lee et al. 2006). The process was broken down into detailed steps, which were defined by the process context. Each typical cycle of RFIs and reviews was modeled in a process model page. One of the goals of the process mapping was to identify bottlenecks and/or procedures which do not fully exploit the BIM capabilities of the modeling systems and the data exchanges between them.

Building on the lessons learned, an alternative workflow was also developed. Both the original and proposed workflows are described and discussed in Chapter 6.

2.4 Modeling Procedure

The Rosewood building is a 16 story office building composed of a cast-in-place concrete structure (columns and flat slabs) and precast architectural concrete facades. The building was designed by HKS Dallas, using standard 2D CAD practice. The precast façade pieces were detailed and fabricated by Arkansas Precast, also using standard 2D CAD practice. To parallel the standard 2D practice, the experiment pursued 3D modeling of the building using BIM tools. HKS prepared the architectural model using Revit Building v9.1, and the precast facades were modeled by the academic research team using Tekla Sturtcures v13.0, with support from High Concrete Structures.

In the first step of the experiment, HKS prepared a 3D model of the structure. The model included slabs, columns, beams and walls for the structure and concrete mass elements[1] to represent the architects' initial proposals for the precast

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[1] In REVIT, all components of a building are modeled using software 'objects'. The software has predefined objects for doors, windows, walls, etc. but not for precast façade panels. 'Mass elements' are generic objects in REVIT that can be used to model any building geometry for which no internal pre-defined object is available. Revit, like other BIM tools, also supports the definition of custom parametric objects that, with careful pre-engineering of functionality, could have represented the precast objects.

concrete façades. All of the architectural modeling of the building was done by Ms. Kelly Garcia, an intern in the Dallas offices of HKS. Ms. Garcia was not part of the actual HKS internal Rosewood project team; she imported all of the 2D drawings into REVIT as reference layers and built the model from the drawings (plans, sections and elevations). Her model accurately reflected the 3D geometry as defined in the drawings that were released for bidding. In reality, after Arkansas Precast was awarded the job and design development was pursued with the input of its engineers, the shapes and extents of the precast pieces were changed and the architectural drawings were updated accordingly. The 3D architectural model, however, was not updated to reflect current status as transferred to the precast fabricator for production design. Once the initial model was complete, it was exported in three formats: IFC 2x2, SAT and 3D DWG (these three formats were also explored in depth in the benchmark study reported in Part B).

The 3D modeling experiment of the precast facades was performed at High Concrete by Mr. Israel Kaner, a structural engineer and Technion graduate student, with the assistance of High Concrete staff, during February-March 2007. Mr. Kaner had just over one year of prior experience operating Tekla Structures in various projects, both in practice and in academic research.

The IFC file exported from Revit was imported into Tekla, where it could be represented as a background reference file against which the structure could be rebuilt. Rebuilding was necessary because, while the full shape representation could be accurately imported, it was not in a data structure that Tekla could edit. During the experimental process of designing and detailing the precast pieces using BIM, collaboration with the architects was carried out using RFI's and other communications. Certain aspects of the design also required consultation with the actual precast fabricators, Arkansas Precast Corp (APC) engineers.

During the time of execution of the experiment, most of the architectural panels were also redesigned by APC. The parallel processes provided a unique opportunity for close examination of the differences between the two different approaches to designing and detailing precast facades: 2D CAD vs. 3D BIM.

3 3D Precast Modeling

This section explains the overall precast modeling process preformed using Tekla Structures software. Throughout the process, it became apparent that a variety of problems are to be expected from inconsistent and/or inaccurate use of the 3D BIM software. A rethinking of the standard process is needed in order to take advantage of BIM tools. The experimental process is described in the first person, from the perspective of the precast modeler.

3.1 General Issues

Using the 3D IFC file, we could quickly understand the building's proportions, geometry and the relationships between its facades and floors. However, we learned that the architectural model was quite different from the actual building geometry at the detailed level, because of differences necessitated by engineering considerations. The details must respond to precast capabilities in terms of the panelization, loads, forces and material strengths and most important the capabilities of the precast plant. These are best addressed by the precast fabricator.

At first we believed that the architectural IFC export model file had numerous errors, but we later determined that these were caused by problems within the native Revit model. For example: the 15th floor was mistakenly modeled in Revit as two slabs, one slab overlapping the other, which resulted in the broken slab object visible in the IFC file as shown in Fig. 4. The two red lines that can be seen in the Revit plan view shown in Fig. 5 reveal the presence of the two slabs that were modeled in error.

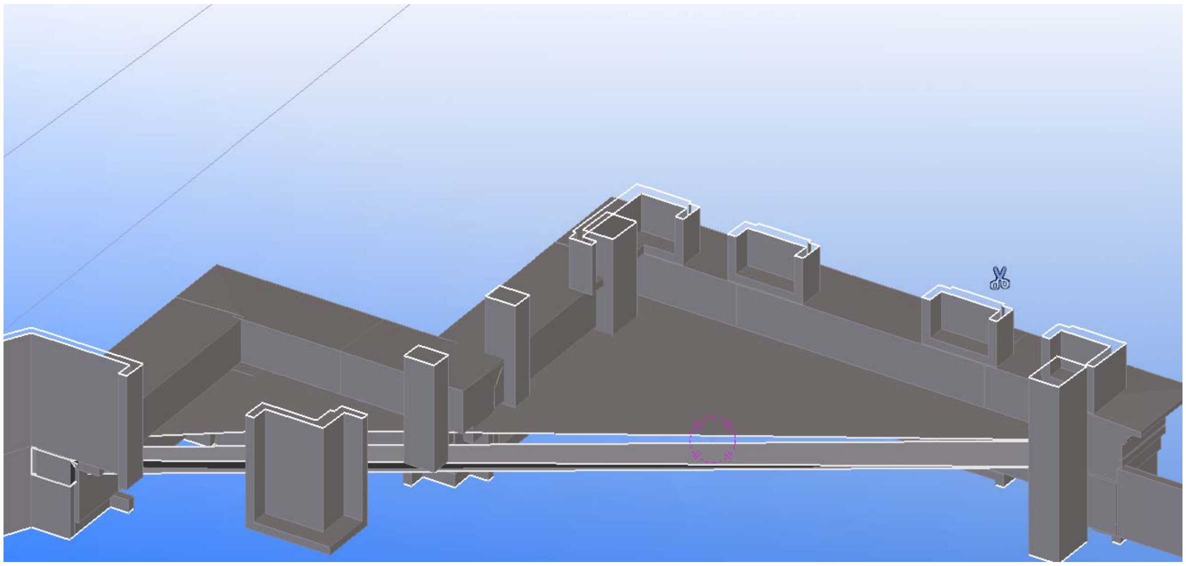


Fig. 4 IFC import failure in Tekla as a result of incorrect modeling in Revit.

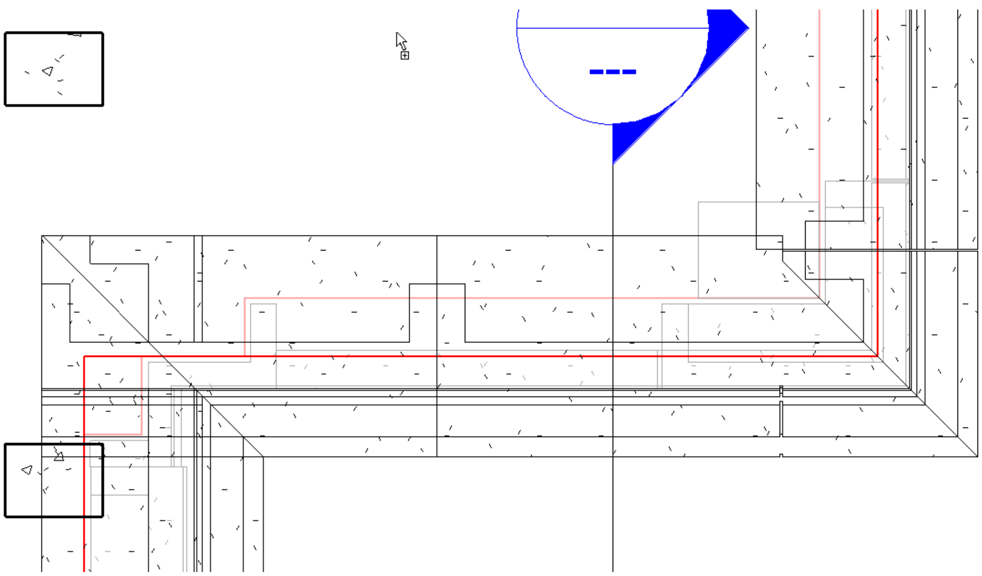


Fig. 5. Two overlapping slabs in Revit

3.2 Design Intent Issues

At the start of the collaboration, we found that the set of 2D bid drawings and the Revit model left a number of issues unclear. In this section we describe the main topics that were either undecided or not communicated in the model. These were communicated as an initial set of RFIs.

Column supports: How were the precast facade column covers to be supported? Should they be self-bearing (i.e. supported from bottom to top) or they can the structural columns carry the self weight of the column covers through their height? Perhaps they should be attached to structural columns only for lateral loads? They could also bear on the slabs rather than directly on the columns.

Limestone: How is the limestone attached? For example, in the detail on sheet No. A7.10, Section 04 (reproduced Fig. 6) how is the limestone attached while the facades are being poured? Perhaps they could be installed later on site? How should the limestone be anchored?

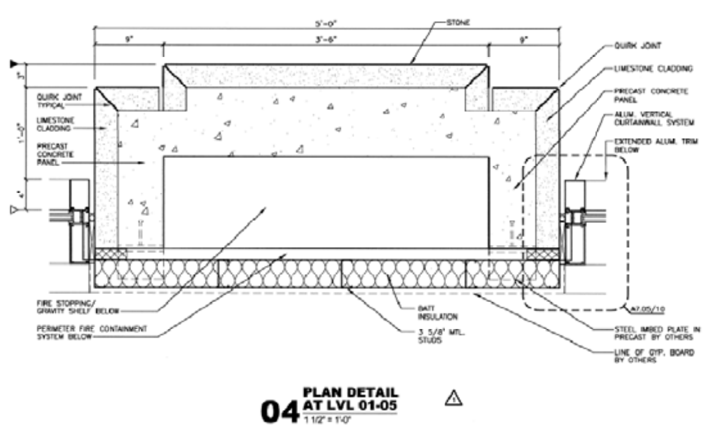


Fig. 6. Column Cover with limestone

Panelization: What were the weight-limits, imposed by the tower crane lifting capacity, that restrict the size of the precast elements?

Joints: What was the architect's intent regarding vertical and horizontal joint placement and sizing? The Revit model showed the precast façade with horizontal joints at every level except for the first level of lobby. Should the panelization be as in the model, or does the intent allow generation of false joints (reveals) in the model?

Erection: In what sequence were the facades to be erected onsite, following vertical or horizontal staging?

Fire shelf: There are fire shelves shown in the Revit model both at the bottom and at the top of each component, as shown in Fig. 7. Were they required on each level on both sides of the precast panels? Were the shelves required at every floor?

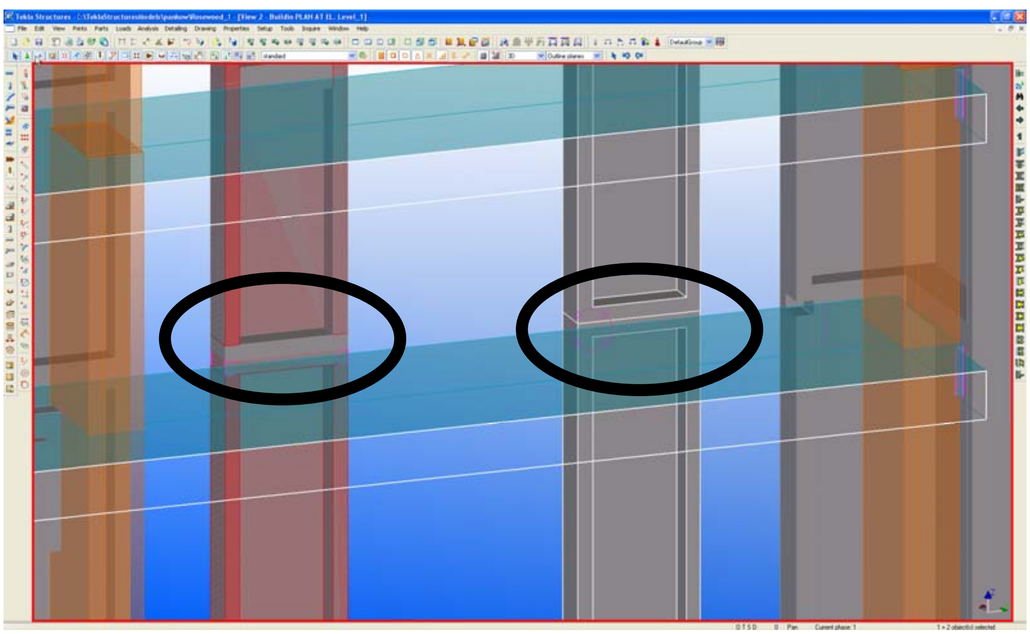


Fig. 7. Example of fire shelf detail.

Modeling: There were two slabs modeled at the 14th level? Which one was the correct one? Why are the slab thicknesses in Revit listed as ‘12" generic slabs’ and in reality they 21" thick?

These issues were resolved one-by-one through the RFI process.

3.3 Experiment timeline and working hours

The overall time line for the experiment is shown in

Table 1 (detailed time records for modeling of several pieces will be described later in this report). Table 2 shows the total numbers of hours for each phase of the modeling activities. 350 hours of modeling were recorded. This modeling time included all the steps of the modeling workflow that are described below.

3.4 Modeling experiment workflow overview

Because the experimental modeler had limited experience of designing architectural precast facades, he started by studying the design practice workflow based on the existing 2D experience. After this there was a need to learn how the architectural precast façades are connected to the main building and what reinforcement was used in each panel. During the first week most of the modeler’s work was devoted to this learning experience. The following weeks were spent on modeling and drawing production, in the steps detailed below. This list provides an overview; each major task is described in the following section in more detail.

Table 1. Time line of the experiment

Date/Period	Activity	Notes
Sept 2006	Preliminary IFC file exchange tests using the 'Ballroom' model	Results were not satisfactory
Oct 2006	Meetings at HKS (Dallas) and Orientation for experiment at High Concrete (Denver PA)	
Jan 2007	Received IFC files exported from Revit model from HKS	Model did not represent the final building design
Feb 12-16	Start of modeling at High Concrete	
Feb 19-23	Model Details	
Feb 26-March 2	Model Connections	Based on Arkansas Precast 2D drawings
March 5-8	Model Reinforcement	
March 12-16	Plans & shop tickets	Meetings at Tekla offices (Atlanta, GA) and at Arkansas Precast (Jacksonville, AR)
March 19-23	Modeling of additional parts	
April	Experiment report & results	

Table 2. Detailed work table and times

Stage	Time (hours)
Importing model	10
Learning 2D drawings	20
Modeling the building's concrete superstructure	20
Sketching cross sections	40
Creating columns covers and panels	51
Modeling details & embeds	50
Modeling connections	42
Modeling recesses and details	22
Modeling reinforcement	20
Preparing templates for drawings	22
Generating E-drawings, plans	21
Generating shop tickets	31

Import IFC model: The IFC file was imported using the import option of the Tekla Structures software, which displays the IFC model as reference geometry. Several problems were found during the first import; several pieces were overlapped and caused glitches in rendering mode.

Studying the 2D drawings and similar projects: This was done both by learning the 2D drawings that were released by HKS and Arkansas precast, as well as U.S. detailing practice found in the PCI manual of Architectural Precast Concrete (PCI 2004).

Modeling the superstructure: Using the IFC Reference file imported in to the Tekla Structures model, the main objects (the 21" thick slabs and the structural columns) were all modeled.

Sketch piece cross-sections: Using dimensions taken in part from the IFC file (measured on-screen) and in part from the final DWG files from Arkansas Precast, more than 30 cross sections were created for this project. Definition of the sketch profiles are a necessary part of defining the editable cross-sections in Tekla Structures. An example is shown in Fig. 8. Note that they had to be generated from scratch, not copied from the IFC file. Some of them were spandrels and others were columns and column covers. Examples can be seen in Fig. 8 and Fig. 19.

Model column covers and spandrels (main parts): The main parts were created by using the column and panel tools within Tekla Structures.

Submit geometry for architect review: Using the IFC format export tool in Tekla Structures, the model was exported to an IFC file and sent to the Architect for approval.

Create details and embeds: Using the basic embeds for this kind of job, we modeled more than 20 pieces of steel embeds. Fig. 10 shows examples.

Model and apply connections: Tekla Structures has the ability to create parametric connections from the embeds and other steel hardware, in order to connect the main parts of facades and the structural superstructure.

Model recesses and apply details and finishes: Most of the architectural precast facades have multiple different finishes and recesses. At this stage we made the recesses using the detail tool. The details, which are mostly the result of Boolean operations (cuts and reveals), give the desired architectural look.

Model reinforcement: The final stage of the modeling is the modeling of the reinforcement. Using the reinforcement tools in Tekla Structures we added rebars and mesh reinforcement. We used the detail tool to make parametric rebars that could adjust automatically to the main part in which they were embedded (such as column covers and spandrels).

Prepare templates for drawings: Once the modeling of the projects is complete the final mission was to prepare the 2D drawings. In order to make it efficient we had to prepare the templates for each kind of drawing, by using different classifiers (Tekla Structures Automatic Filters), automatic dimensions and labels. Preparation of the templates included a template for the rebar detailing and for automatic counting of the embeds. Another type is the BOM reports that are most of the time in table format. The example can be seen on Fig. 20

Generate elevation drawings and plans: The following information appears on the elevation drawings: the erection and connection labels, dimensions and panelization of the architectural precast façade. On the plan drawing the embed layout in the cast-in-place slabs and how the different kinds of connections relate to them are shown.

Generate shop tickets, BOMs: Shop tickets are the drawings that the precast plant uses to manufacture the individual precast pieces. These drawing have all the dimensions, cast in precast embeds and lifting anchors, and all of the reveal and recess information. They also include reinforcement layout and finishes.

Submittal: The final phase of the work was to submit the drawings for the approval of the architect and structural engineer and after this forward the design to production.

3.5 Detailed steps: columns cover example

In the following paragraphs we describe the first of two detailed scenarios that were done as part of the modeling process using Tekla Structures Software.

Step 1: Cross-section sketch

We created a fully parametric cross section that could serve most of the typical column covers. Most of the parameters were hidden from the user, but the main dimensions were shown to the user for manipulation to represent all of the individual profiles that could arise. In the Rosewood project the designers varied only one parameter of the column cover, namely the depth of the column cover. This parameter is labeled ‘h1’ in Fig. 8.

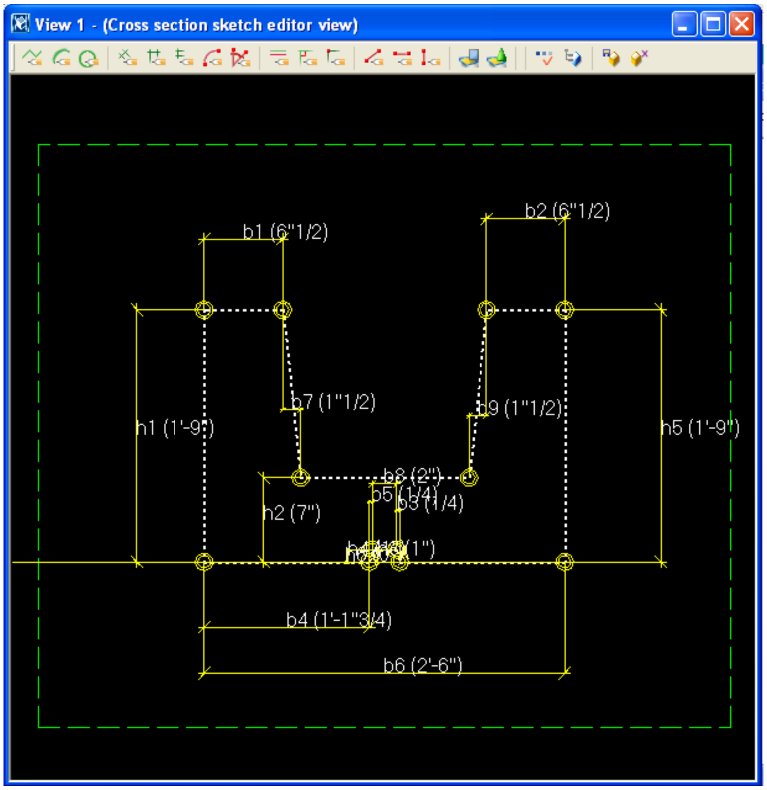


Fig. 8. Column cover crossection sketch

Step 2: Modeling the column cover

After completing the cross section of the column covers, we created the column covers in the model. The correct position was set based on the drawings obtained from Arkansas precast. The column covers were made to extend over a height span of two full floors, as shown in Fig. 9.

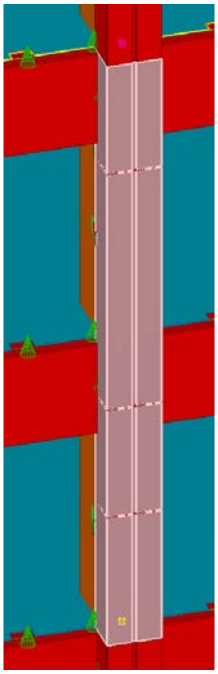
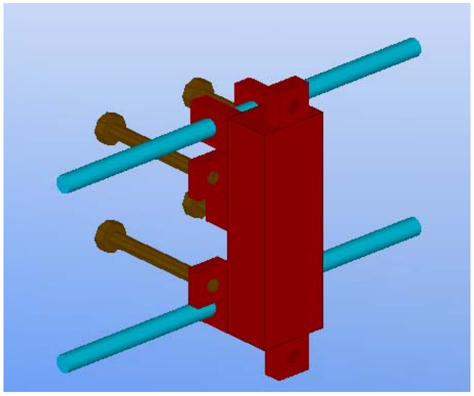


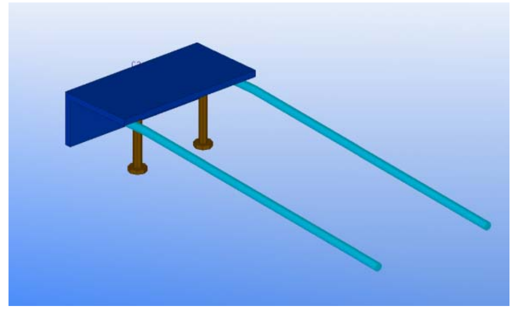
Fig. 9. Typical column cover, extending over two floors with reveals representing false joints within the column cover's length.

Step 3: Creating embeds & steel details

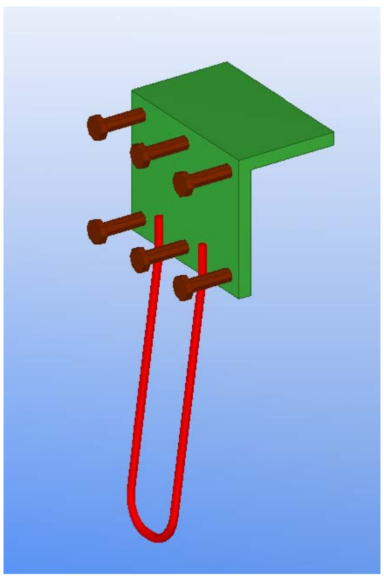
At this stage of the modeling we needed to create a custom component library which was then used as a resource for modeling the connections, the embeds in the cast-in-place concrete slabs and columns, and the embeds cast into the precast facades. Most of these embeds were standard details that precast factories commonly use. Examples of the embeds are shown below (**Fig. 10**).



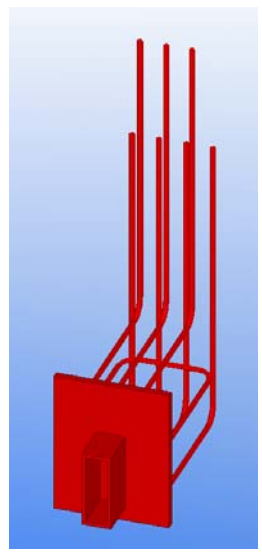
a) Insert Embed



b) Cast-in-place embed



c) Cast in precast embed



d) Column connection embed

Fig. 10. Different precast facade panel embeds.

Step 4: Connections

At this point the typical embeds were used to create the column cover standard connections using the parametric ‘custom connections’ feature of the modeling software. In the column cover situation there were two basic connections – the tie back connection for the lateral forces (see back side view in Fig. 11) and a gravity load connection (see Fig. 12). Fig. 13 shows a column cover, spanning two stories, with a tie-back connection applied near the top and a gravity connection applied near its base.

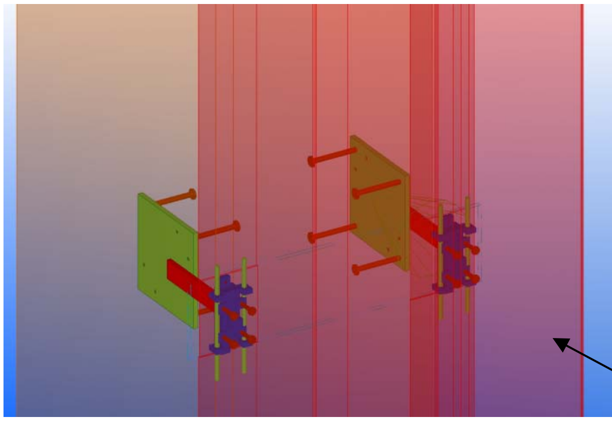


Fig. 11. Tie back connection to resist lateral forces.

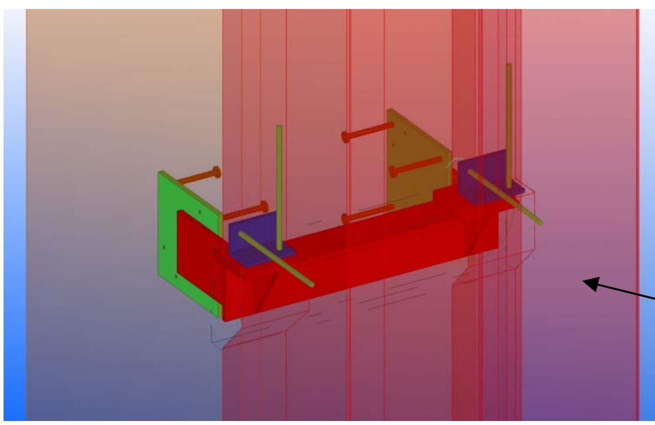


Fig. 12. Gravity load bearing connection.

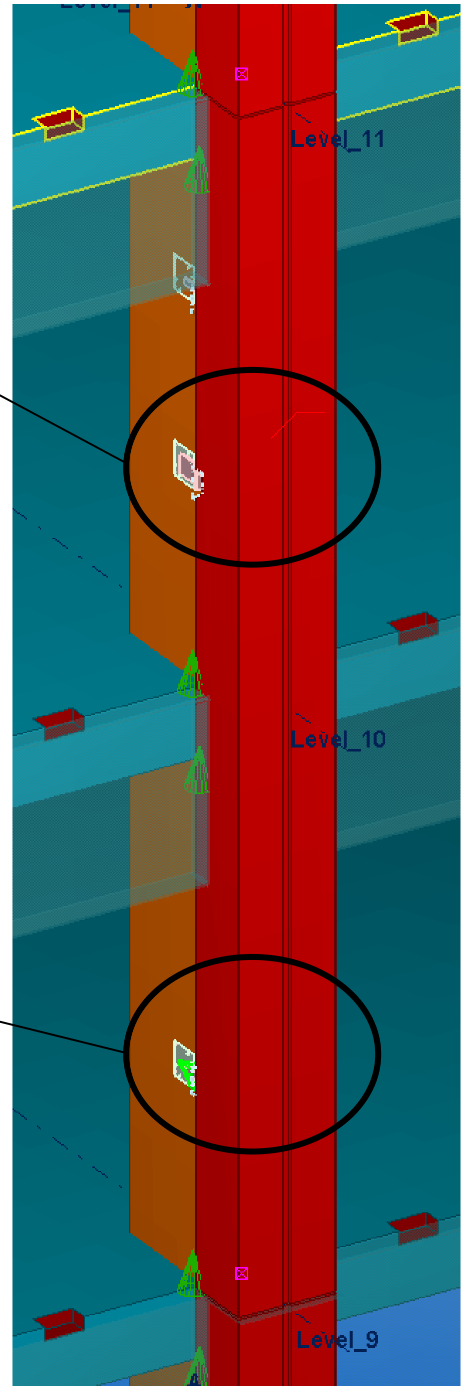


Fig. 13. Connection of the column covers to column

Step 5: Reinforcement

Generally, the reinforcement in the architectural precast façade panels is simple bent mesh and straight reinforcement rebars, so that application of the reinforcement to the column cover was straightforward. All of the reinforcement was bound to the top of the column cover, so that all of the reinforcement adjusted automatically according to the height of the column cover. In this way the same basic column cover part could be re-used to model multiple column covers of different lengths. The reinforcement is shown in Fig. 14.

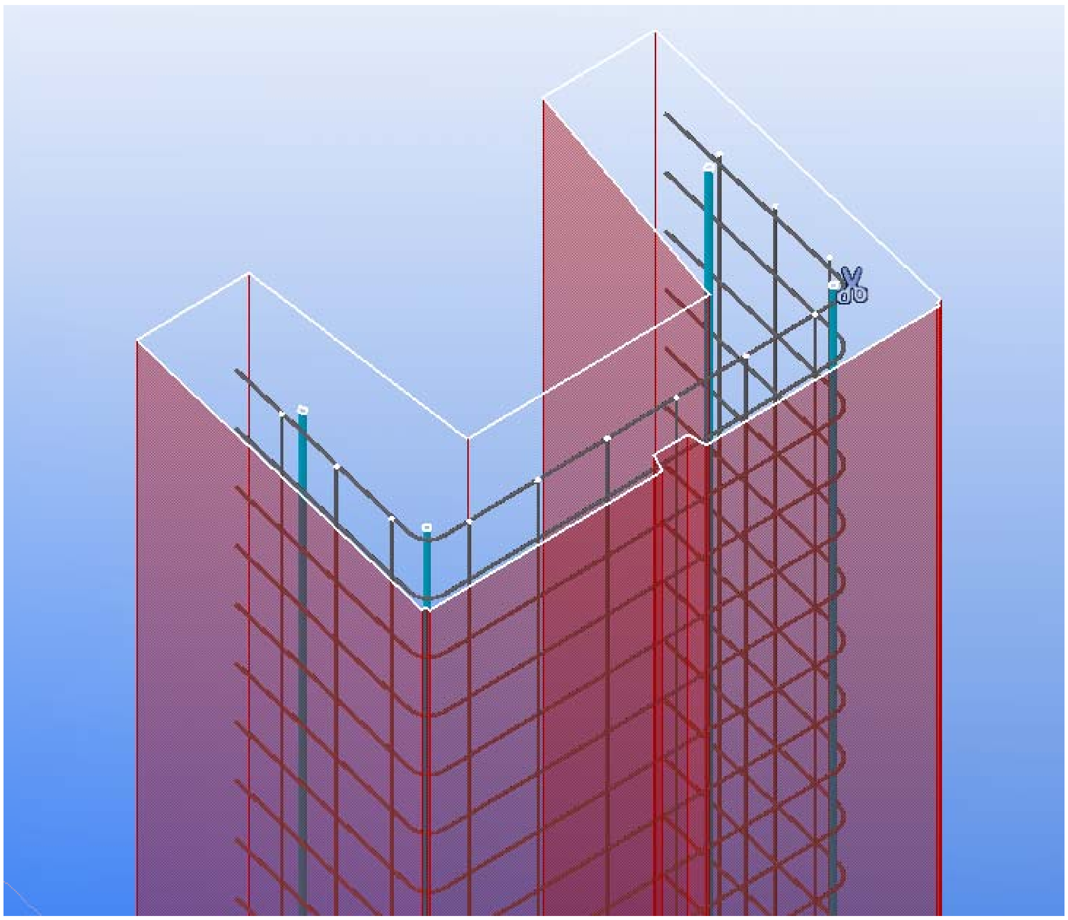


Fig. 14. Reinforcement of column cover.

Step 6: Recesses and reveals

The next step was to model the architectural recesses (shown in Fig. 15) and the fire shelves between the floors (shown in Fig. 16). The fire shelves were added to the basic column cover part cast unit as detailed concrete objects. They were modeled parametrically and bound to the top of the column cover, so that they could be applied easily to all of the different column covers (the main difference between the columns covers was their length) that are needed in the project. Note that, unlike the original architectural model, fire shelves were only placed at the top level of the column covers and at their mid-height, and not at their bottoms; the vertical position of the covers was set so that the fires shelves would be located correctly vis-à-vis the slabs.

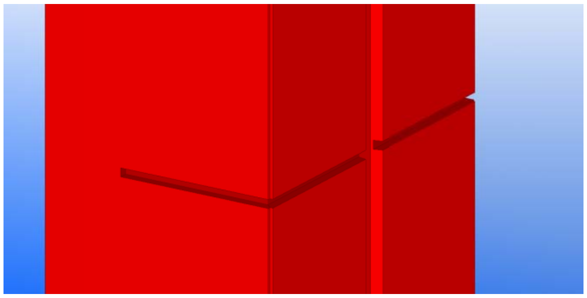


Fig. 15. Architectural reveals

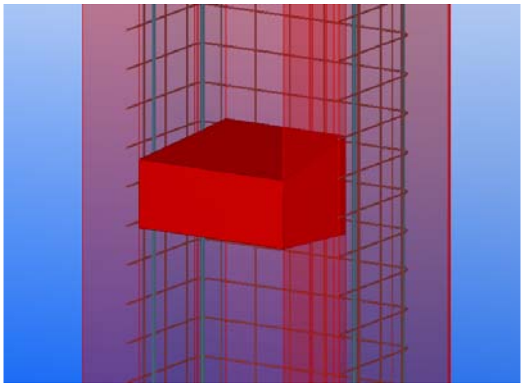


Fig. 16. Fire shelf

Step 7: Shop tickets

The ‘shop ticket’ piece production drawings include all the information needed to produce them in the plant. The information includes all dimensions, embeds, reinforcement layout and specific finishes for the piece. The drawing also reports the volume and weight properties of the piece. An example can be seen below in Fig. 17. The following figures show larger scale images of the top view (Fig. 18), a cross-section (Fig. 19), the BOM list (Fig. 20) and the drawing label (Fig. 21).

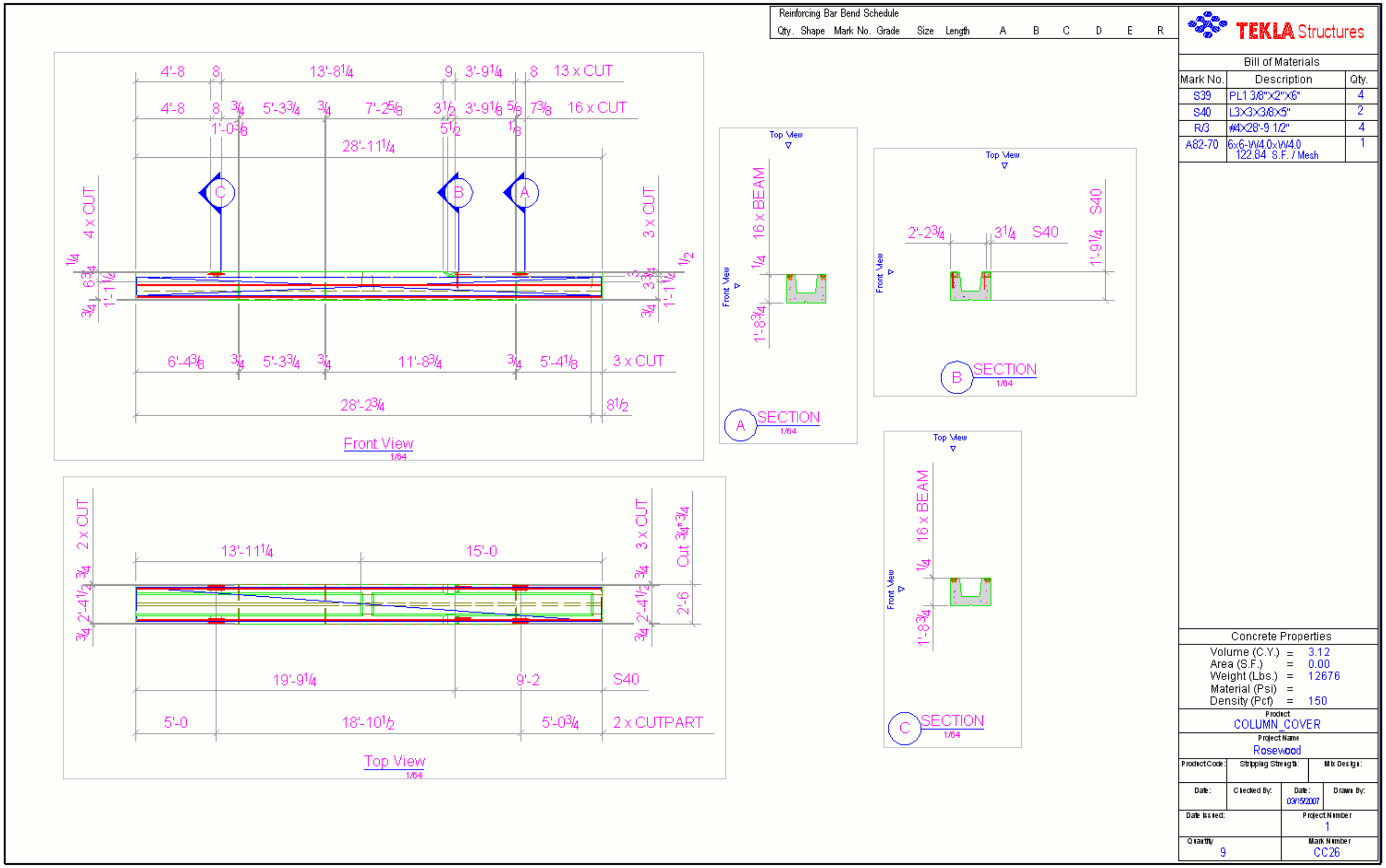


Fig. 17. column shop ticket

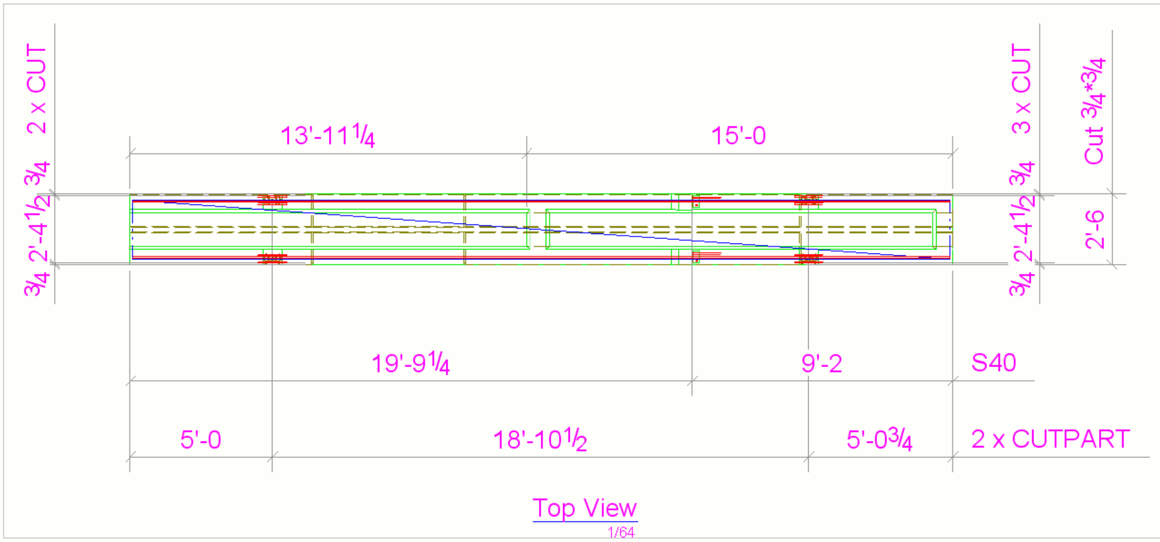


Fig. 18. Column cover top view

Fig. 19. Column cover crossection

TEKLA Structures		
Bill of Materials		
Mark No.	Description	Qty.
S39	PL1 3/8"X2"X6"	4
S40	L3X3X3/8X5"	2
R/3	#4X28'-9 1/2"	4
A82-70	6x6-W4.0xW4.0 122.84 S.F. / Mesh	1

Fig. 20. Shop ticket BOM

Concrete Properties			
Volume (C.Y.) = 3.12 Area (S.F.) = 0.00 Weight (Lbs.) = 12676 Material (Psi) = Density (Pcf) = 150			
Product COLUMN_COVER			
Project Name Rosewood			
Product Code:	Stripping Strength:		Mix Design:
Date:	Checked By:	Date: 03/15/2007	Drawn By:
Date Issued:		Project Number 1	
Quantity 9		Mark Number CC26	

Fig. 21. Shop ticket label

3.6 Detailed steps: spandrel example

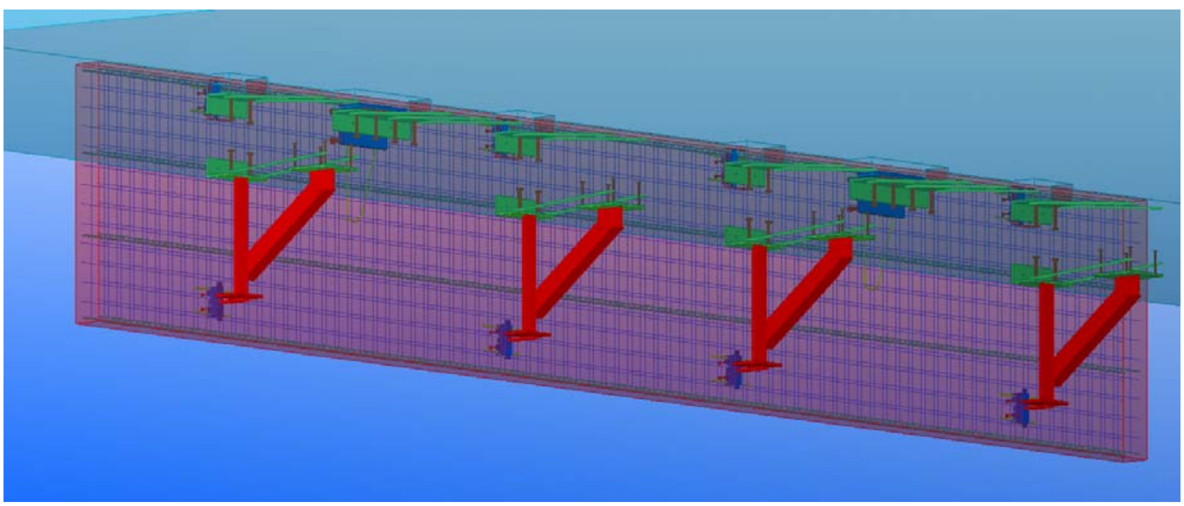


Fig. 22. Fully modelled spandrel, back view with transparent slab.

Step 1: Cross section sketch

As before, the first step is to sketch the cross section to build the parametric model.

For this spandrel, which has a very simple cross section, there were only two parametric variables: the width and the height (Fig. 23). Other spandrels in the building had more complex geometries, including curved ledges and reveals.

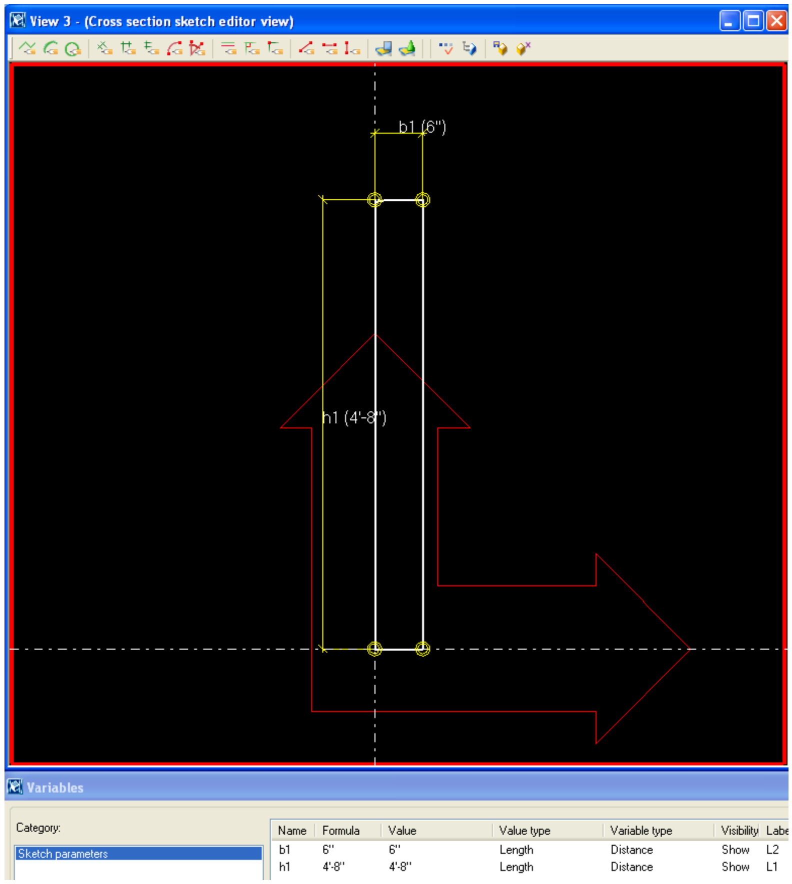
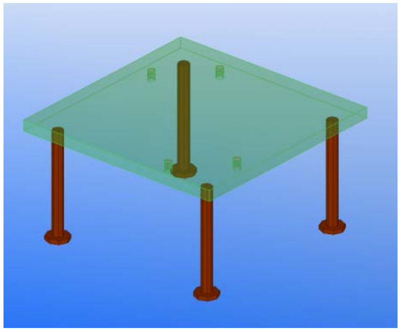


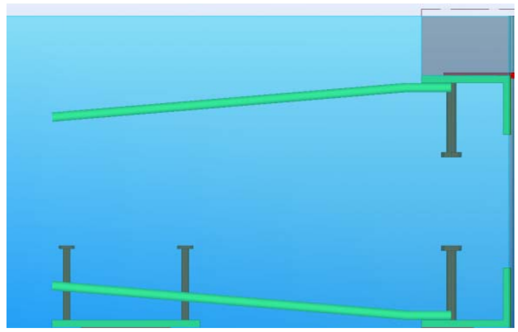
Fig. 23. Spandrel parametric crossection

Step 2: Model embedded details

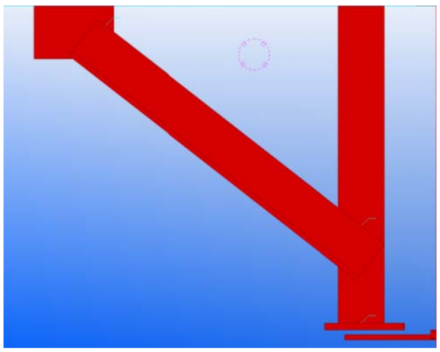
There are several different embeds in the spandrels: cast-in-place, cast in precast and loose hardware, as can be seen in Fig. 24a). All the cast-in embeds were modeled in the standard details and applied through connections or directly to parts, while loose hardware was created in the main model. Careful attention was paid to these aspects of association in order to ensure that the embeds would be reported in the correct bills of material according to their fabrication context. After creation of the embeds, the connections could be modeled.



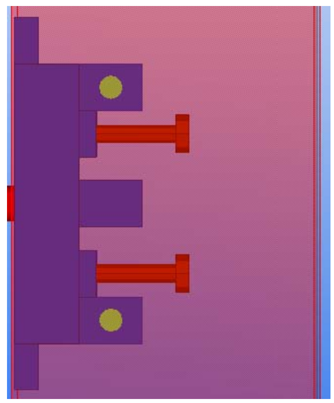
a) Cast-in-place plate with studs



b) Cast-in-place embeds



c) Loose steel hardware



d) Insert embed

Fig. 24. Embed details for the spandrel.

Step 3: Connections

The spandrels (Fig. 25) have two different connections: lateral forces connections (Fig. 26) and gravity forces connection (Fig. 27). After creating these two basic parametric connection types, both had to be applied numerous times to each spandrel. For this purpose, a ‘super’ custom connection was made (shown in Fig. 25), which applied two gravity and four lateral connections kind of connections simultaneously to each spandrel-slab instance. All of the simple connections were bound to the center of the spandrel, so that when the length of the panel is changed, the connections are always placed symmetrically around the center of gravity of the panel, with spacing values that can be changed using the predefined parameters.

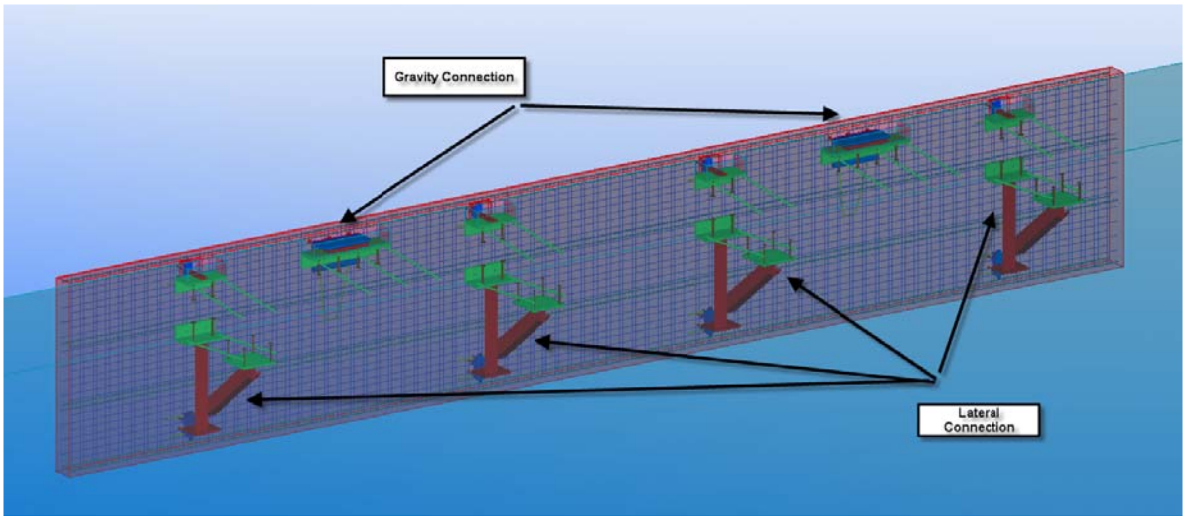


Fig. 25. Spandrel 'super' connection including two gravity and four lateral connections.

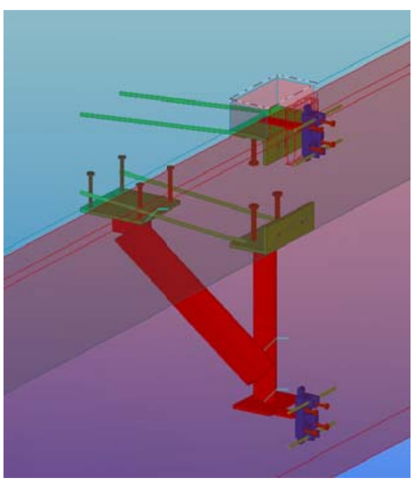


Fig. 26. Spandrel lateral connection

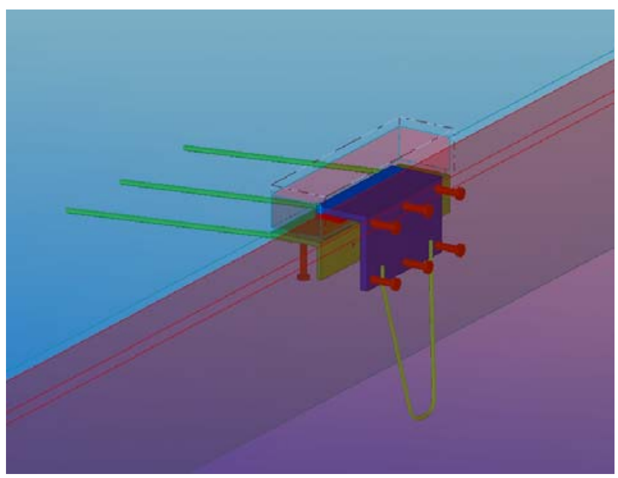


Fig. 27. Spandrel gravity connection

Step 4: Reinforcement

As stated above, the reinforcement in the architectural precast façade panels is generally only a simple mesh and some straight rebars. Nevertheless we were able to model a parametric rebar detail (shown in Fig. 28) for the spandrels that could adjust the rebars and mesh to the size of the spandrel fully automatically. This detail made modeling spandrels of different sizes very efficient.

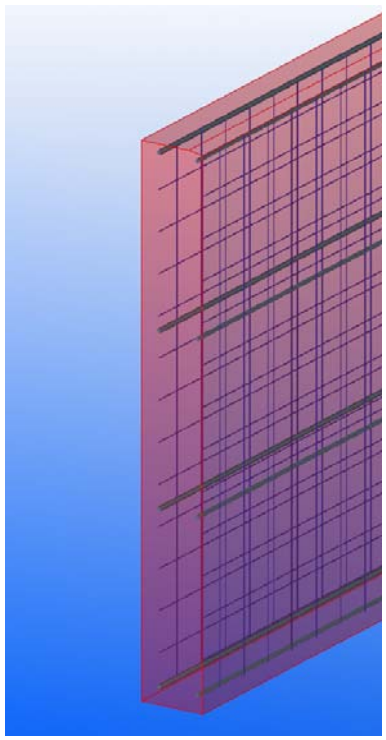


Fig. 28. Spandrel rebar detail

Step 5: Drawings

This step is identical to that described above for the column cover. An example of the spandrel shop ticket can be seen in Fig. 29 below. In this case too, enlargements of areas of interest of the shop ticket drawing are shown below: they include the front view (Fig. 30), a cross-section (Fig. 31), the BOM list (Fig. 32) and the drawing label (Fig. 33).

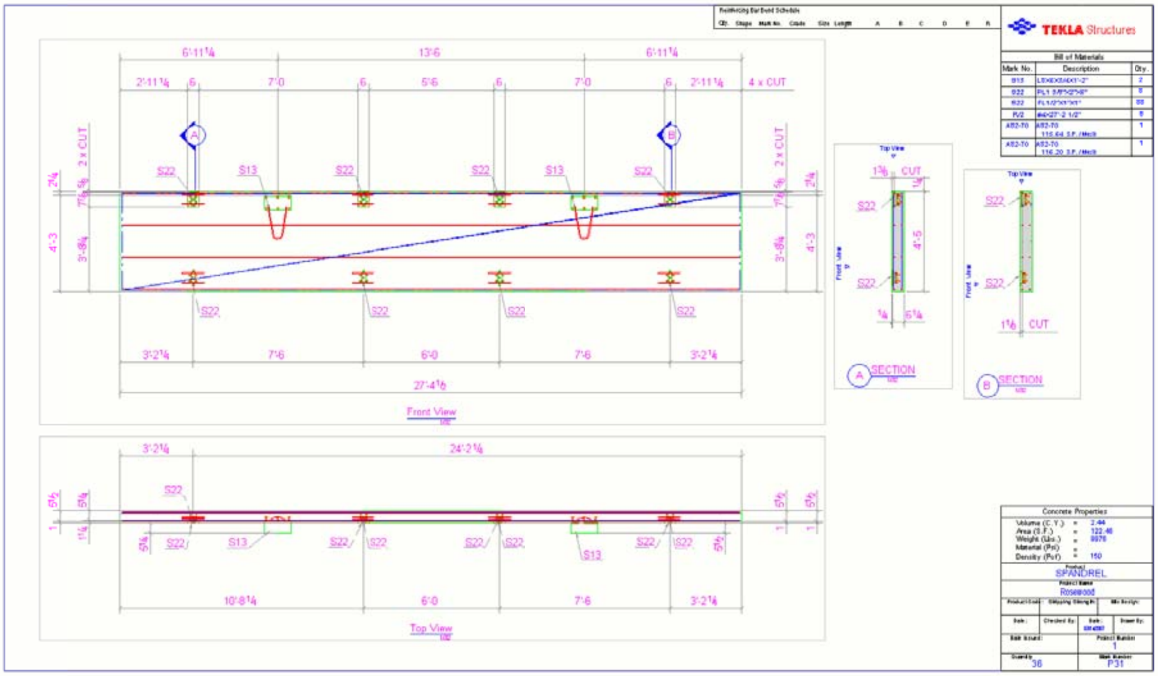


Fig. 29. Spandrel shop ticket drawing

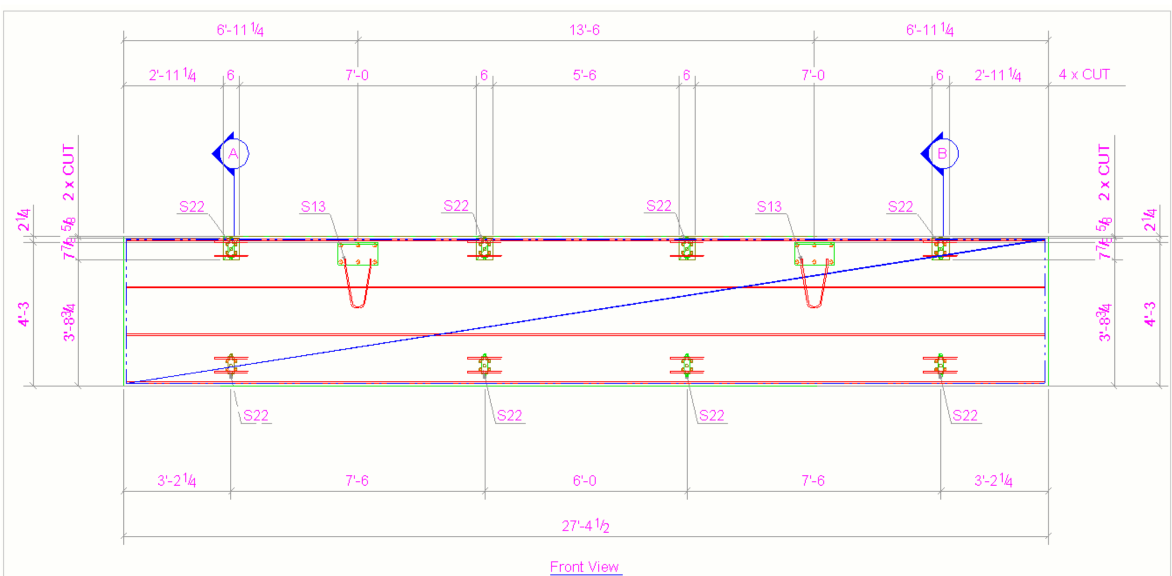


Fig. 30. Spandrel shop ticket front view

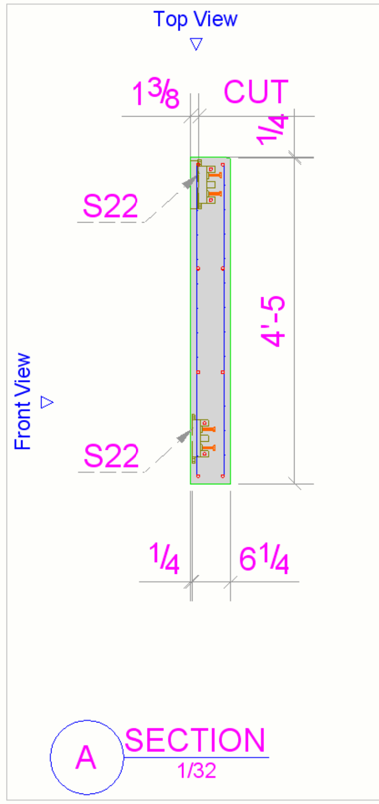


Fig. 31. Spandrel cross section

TEKLA Structures

Bill of Materials		
Mark No.	Description	Qty.
S13	L8X6X3/4X1'-2"	2
S22	PL1 3/8"X2"X6"	8
R/2	#4X27'-2 1/2"	8
A82-70	A82-70 115.64 S.F. / Mesh	1
A82-70	A82-70 116.20 S.F. / Mesh	1

Fig. 32. Spandrel shop ticket

BOM

Concrete Properties		
Volume (C.Y.)	=	2.44
Area (S.F.)	=	122.46
Weight (Lbs.)	=	9976
Material (Psi)	=	
Density (Pcf)	=	150

Product SPANDREL			
Project Name Rosewood			
Product Code:	Stripping Strength:		Mix Design:
Date:	Checked By:	Date: 03/14/2007	Drawn By:
Date Issued:		Project Number 1	
Quantity 36		Mark Number P31	

Fig. 33. Spandrel shop ticket label

3.7 Lessons Learned

3.7.1 Software and modeling

The success in fully modeling the architectural precast aspects of this project showed that the software used[2] is mature for all aspects of the process. It proved possible to fully model the geometry of the precast facades and the necessary details of the supporting structure. We also succeeded in detailing complete facade pieces, such as column covers and spandrels, including all the necessary reinforcement and embeds. For all the pieces modeled, the connections were fully detailed; this was done with full exploitation of the parametric abilities of the BIM software, which enabled modeling of different pieces using the same connections. The result was that the work was quick and highly efficient.

The use of parametric connections not only improved speed and productivity, but also gave us the ability to control the detailing work to avoid the possibility of errors. This meant that quality control was embedded in the design process itself; the significance of accurate modeling is that the waste of identifying errors in design reviews or only after pieces are being erected in the field are eliminated.

3.7.2 Collaboration and interoperability

We were able to import the Revit derived IFC model into Tekla with good results. Two important lessons were learned: first, that the architectural model is by its nature different to the precast engineering model in significant ways, and second,

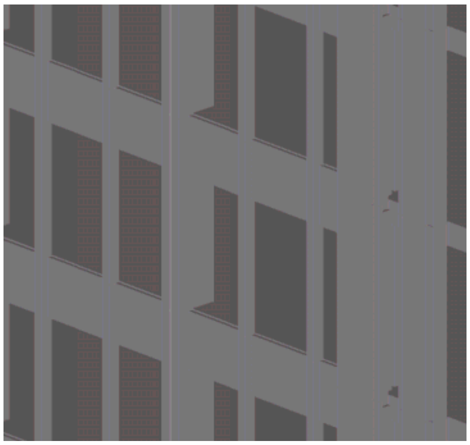
[2] Tekla Structures version 13.0

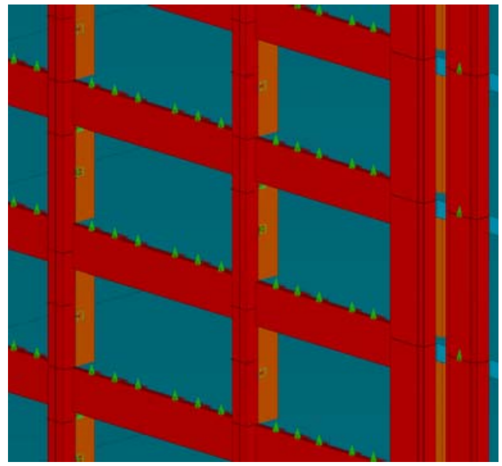
that there is much to be improved in technical aspects of the IFC exchange functionality.

The differences between the architectural and precast engineering models reflect the different ways in which each profession relates to the information, primarily reflecting different levels of detail and focus. The differences observed were:

- The mullions between window panels were canceled during the project. See Fig. 34.
- The fire shelves between floors are cast monolithically with the column covers. The architect's model showed only conceptual design, with a 'half' fire shelf at the bottom and top of each cover. The precast design had quite different geometry, as can be seen in Fig. 35.
- Column covers were one floor high in the architectural model, but extended over two floors in the precast model. Two architectural model objects relate to one precast model object. See Fig. 36.
- The engineer's precast spandrels covered the full width of each building bay; the architect's model had three panels, one between each original mullion. In this case three architectural model objects relate to one precast model object. See Fig. 37.

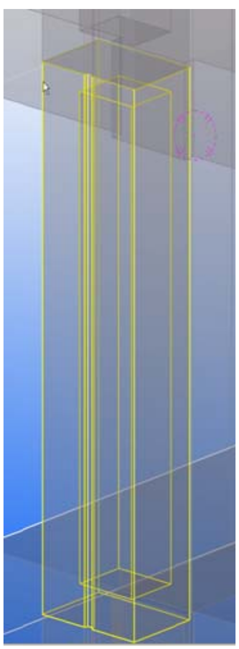
The principle behind the latter two differences is that the precast fabricator is concerned with productivity in fabrication and erection, thus preferring solutions that require fewer individual precast pieces. The architectural modeler was apparently not aware of this aspect, preferring to minimize modeling work by creating a typical floor arrangement that could be easily duplicated to model the full building.

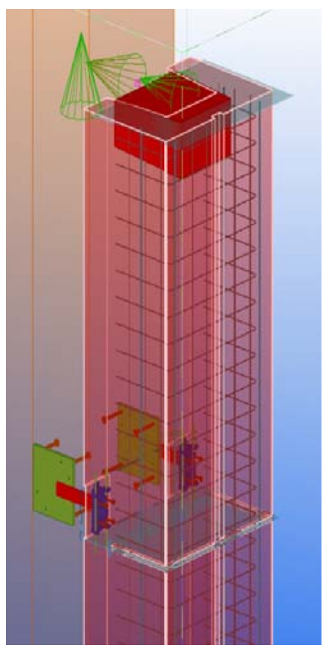


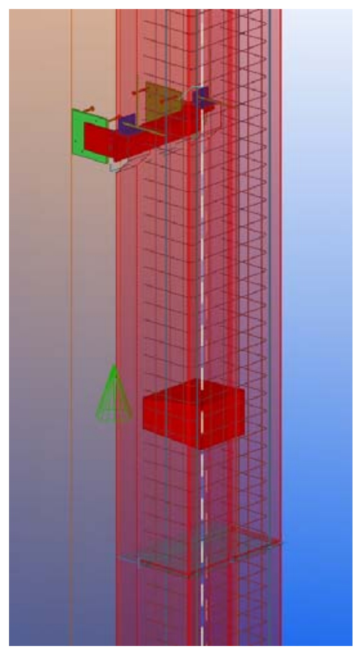


Revit model with mullions **b) Tekla model without mullions**

Fig. 34. Architectural and precast models, with and without mullions.







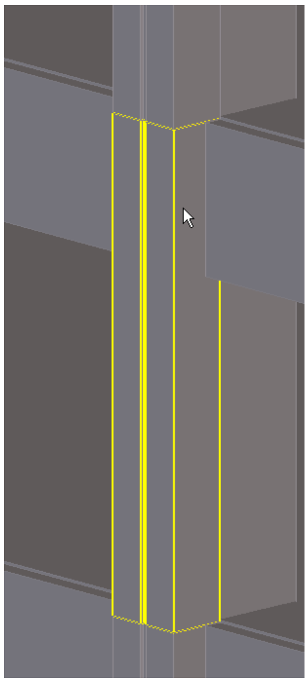
a) Revit model showing fire shelves at the top and bottom

b) Tekla model showing a fire shelf at the top of the column cover

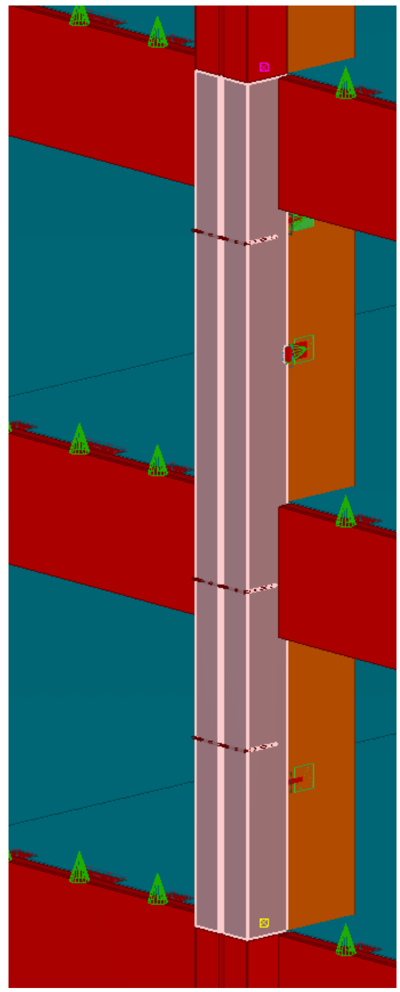
c) Tekla model showing a fire shelf in the middle of the two-story column

of the column cover **cover**

Fig. 35. Three views of a typical column cover, showing different conceptions and models of the fire shelves between the architectural and preacst engineering models.

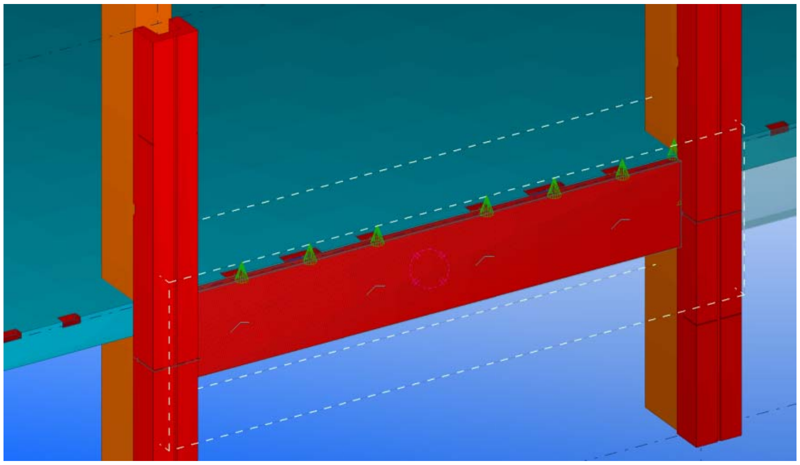


a) Revit model with a single story high column cover.

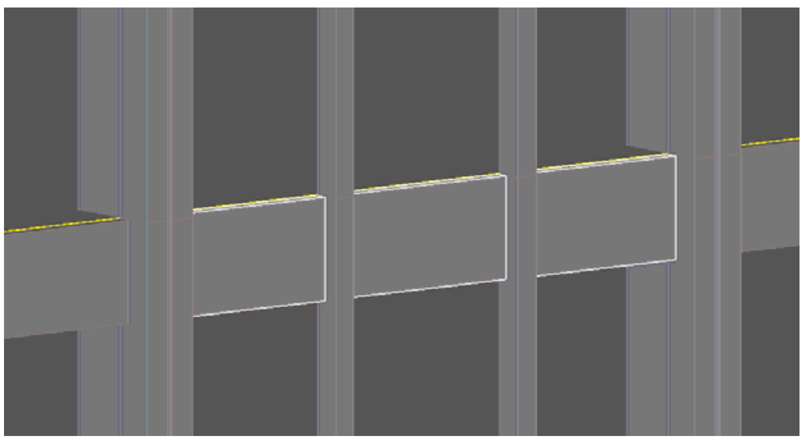


b) Tekla model with a two story high column cover.

Fig. 36. Architectural and precast models, with column covers of different heights.



a) Tekla model showing a full bay wide spandrel.



b) Revit model with three separate spandrel panels.

Fig. 37. Different architectural and engineering model objects for a spandrel

The technical problems encountered in performing the IFC exchanges were the following:

- No grid lines were imported.
- Many of the objects imported were ‘proxy’ objects, i.e. not specific IFC building objects, but simply ‘blobs’ of concrete. Only the columns, slabs and

beams were imported as logical objects. The reason behind this is that the Revit modeler used 'mass element' objects to model the spandrels, and mass elements are exported by Revit into IFC as proxy objects.

- In the other direction, the Tekla IFC output translator was unable to export the connections and their component parts.

3.7.3 Suggested BIM practice workflow

The following steps lay out a viable workflow for the precast modeling aspect of this type of project, based on the lessons learned from review of the modeling activities performed within the experiment (collaboration activities are shown in italics):

1. Import IFC model.
2. Model the superstructure, resolving any inconsistencies.
3. *Submit superstructure model to confirm accuracy and intent*.
4. Sketch piece cross-sections for any pieces unavailable in the company custom component library.
5. Model column covers and spandrels (main parts).
6. *Submit building geometry for architect's review*.
7. Model any details and embeds unavailable in the company custom component library.
8. Apply connections; model any connections unavailable in the company custom component library.
9. Model recesses and apply details.

10. Model reinforcement.
11. Prepare any drawing templates unavailable in the company custom component library.
12. Generate e-drawings, plans.
13. *Submit for review*
14. Generate shop tickets, BOMs
15. *Final submittal*

4 2D Drafting work

The real precast facades for the Rosewood project, as explained above, were designed and fabricated by Arkansas Precast. Toward the end of the experiment, we visited the engineer and the drafter who were designing the project in Jacksonville, Arkansas. In this section we describe their every day experience designing different precast facades, within the context of the Rosewood project. On the basis of the workflows observed, and earlier process models compiled within the precast industry (Sacks et al. 2004), a process flow map of precast architectural façade pieces was compiled (see section 0 on page 64).

4.1 2D workflow

Arkansas Precast's work on the project started in November 2006, and by the middle of March 2007, it was approximately 60% complete. At this point in time, the status of their progress was equivalent to the status achieved in the 3D BIM experiment.

The actual 2D project followed these steps:

1. Obtaining architectural drawings of the project.
2. Preparation of new drawings (their standard approach is not to use the drawings obtained from the architects as external references, in order to avoid any errors present in the architectural drawings). As a result, they draw everything in the project from scratch according to their interpretation of the architects' plans and sections.

2.1. Establish building grids

2.2. Draw slab footprints

2.3. Draw building sections

3. Preparation of elevations and deciding on panelization
4. Design of connections – this design work was done by an Arkansas structural engineer, according to the different panel weights and cross sections.
5. First submittal: story 6 to 14 – this submittal to the architects consisted only of sections, plans and connections.
6. Drawing cast-in-place embed sheets – after approval of the first submittal, Arkansas Precast released cast-in-place embeds plans and elevations that included names, locations and different embed numbers and details.
7. Preparation of an Excel sheet defining cast-in-place hardware. This is done in at this early stage – before preparing shop tickets – in order to get exact quantities so that the right quantities of embeds can be ordered for delivery to the construction site (these embeds must be cast into the structural frame by the general contractor before precast pieces are delivered).
8. Prepare shop tickets - produce all the shop ticket drawings, including all of the geometry dimensions, reinforcement layouts, etc. This stage also includes preparation of :

   8.1. Hardware drawings

   8.2. Excel sheet schedules of embedded hardware for plant fabrication

   8.3. Excel sheet schedules of loose hardware for erection
9. Submittal of the final design to the architect for approval

10. Corrections to the shop drawings as needed and handover to production.

4.2 Collaboration issues

The collaboration between architects and precast contractor used several channels:

- Live meetings: there were several face-to-face meetings.
- Exchange of drawings. The Arkansas drafter did not use any of the drawings as electronic files; he plotted out the drawings and reproduced all of the drawings from scratch. This was in fact a good decision because in this way Arkansas precast had fewer dimensional errors.
- Phone conferences – there was almost no contact by phone, except for a small number of calls regarding conflicting geometry in architectural drawings.
- Emails – was used for sending the drawings.
- Fax –was used for sending some sketches of different designs.

4.3 Detailed work cases

In the internal workflow (between the two bold horizontal lines in Fig. 54) the design job was split between two persons: an engineer, who was responsible for the project as a whole and for the engineering design of the connections, and a drafter who worked with the engineer. The following sub-sections describe the different kinds of AutoCAD drawings produced.

4.3.1 Connections

Several examples of connections can be seen in Fig. 38 thorough

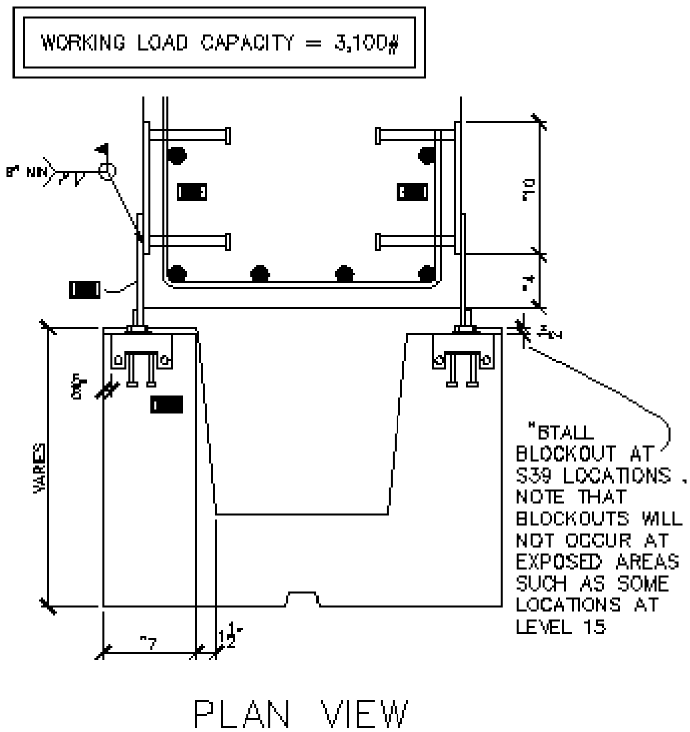


Fig. 42 below. They show different sections of a variety of connections (the same connections were also modeled in the 3D BIM experimental work).

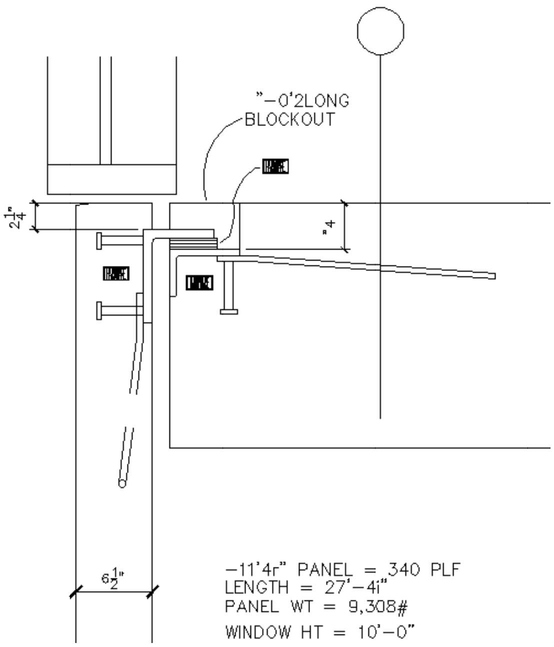


Fig. 38. Spandrel to floor gravity connection

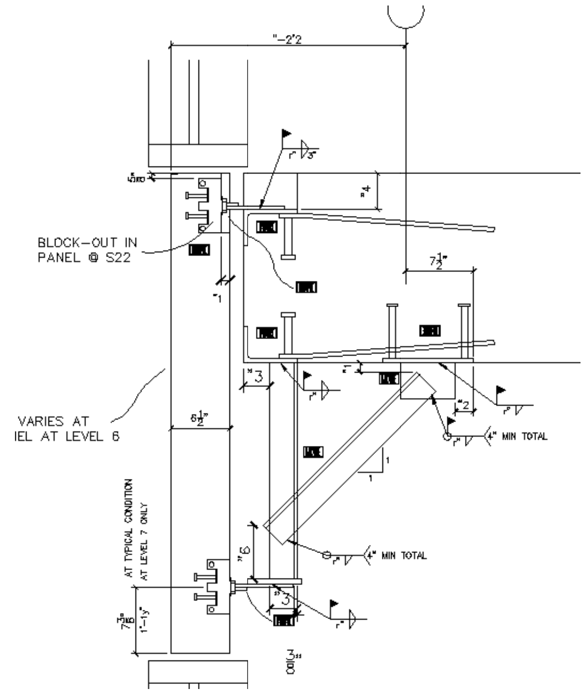


Fig. 39. Spandrel to floor lateral connection

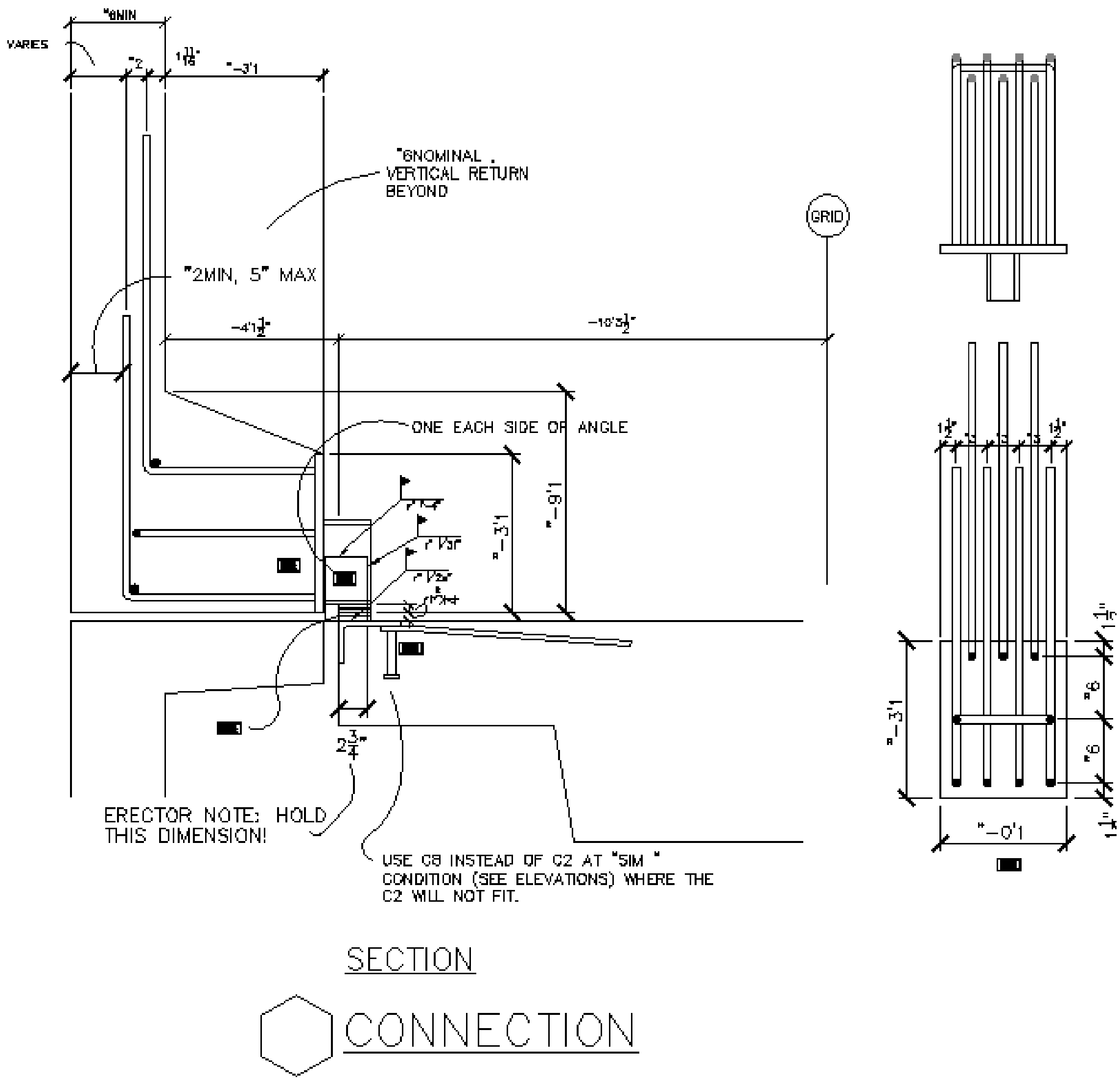


Fig. 40. Heavy column cover connection (lateral and gravity)

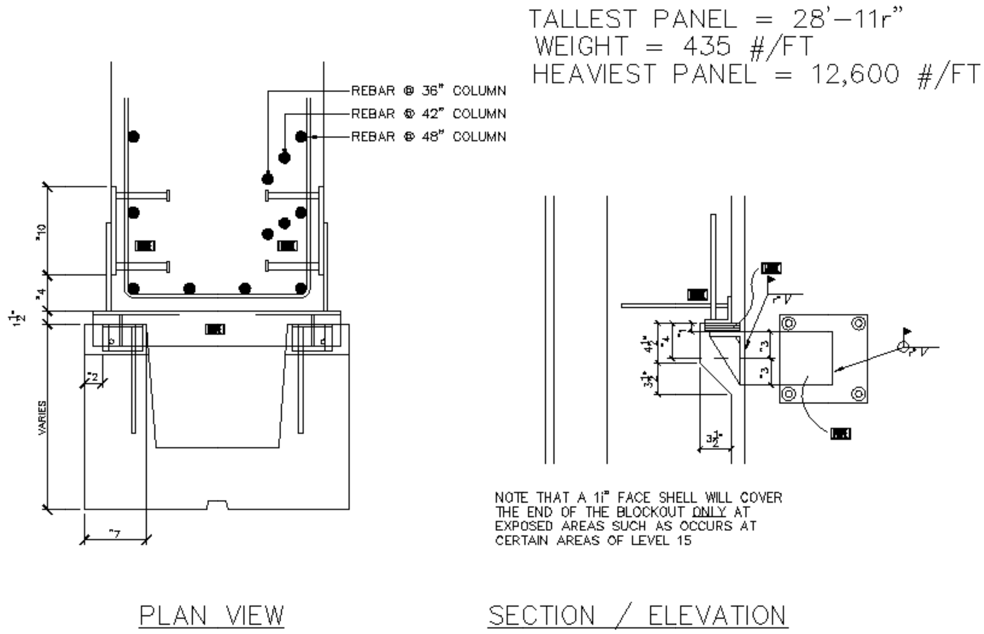


Fig. 41. Column cover gravity connection

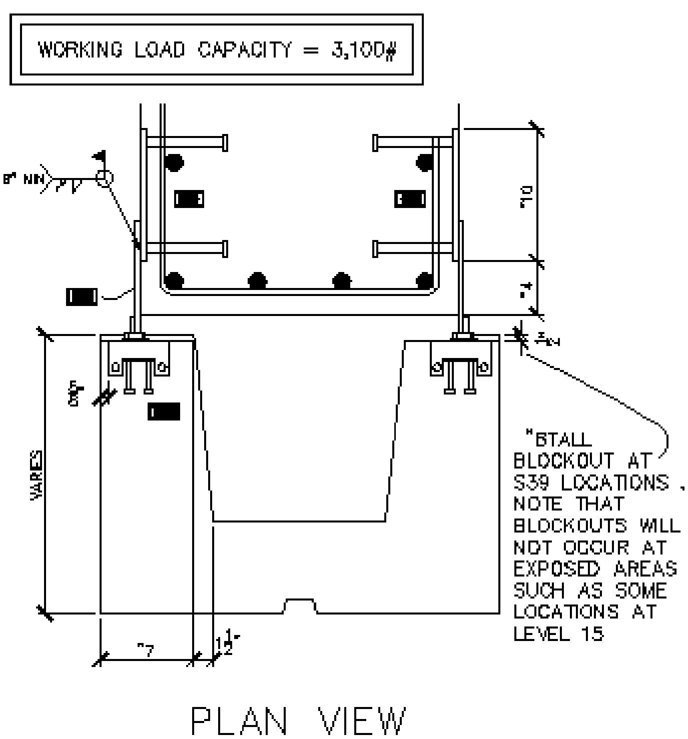


Fig. 42. Column cover lateral connection

4.3.2 Elevation drawings

The elevation drawings shown in Fig. 43 were made in order to show the panelization of each façade of the building.

4.3.3 Cast-in-place embed plan

In this project, as is typical for most of the projects in this field, the reinforced cast-in-place structure was begun before the precast facades were designed. Therefore, it was critical to prepare the cast-in embeds drawings at an early stage of the design in order to enable the general contractor to ensure that all the embeds are in fact cast in during the time the concrete structure is built.

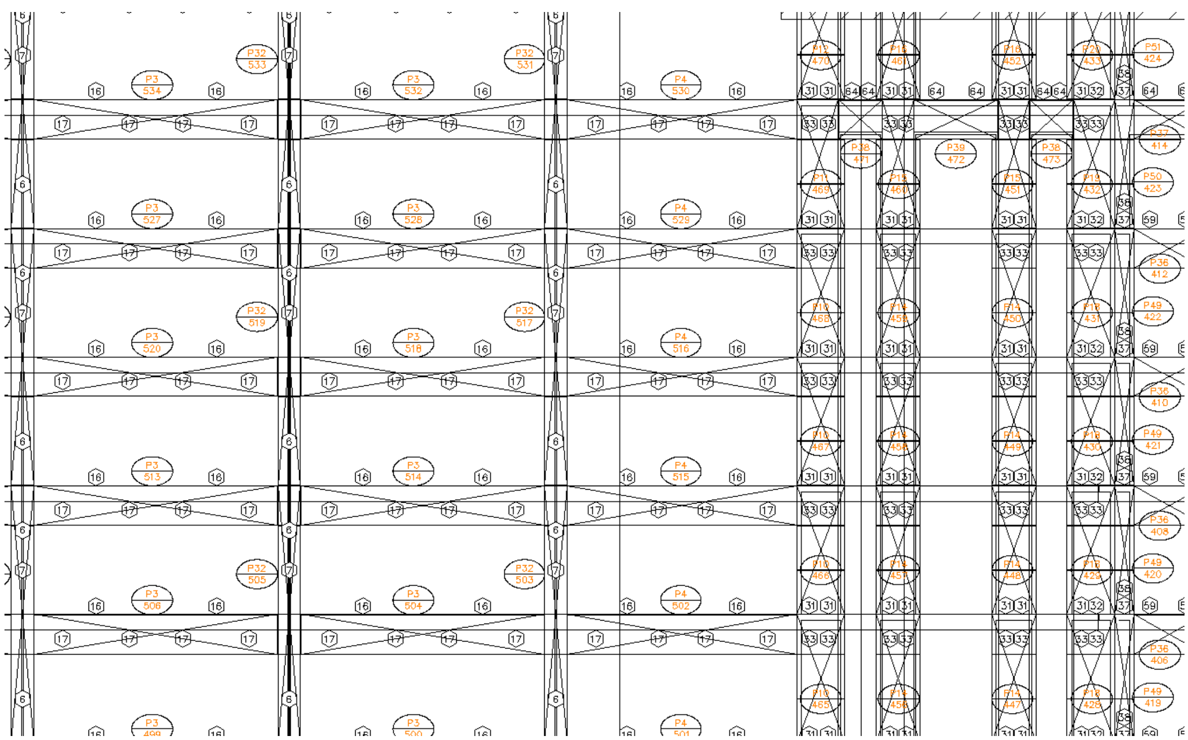


Fig. 43. Partial elevetion drawing

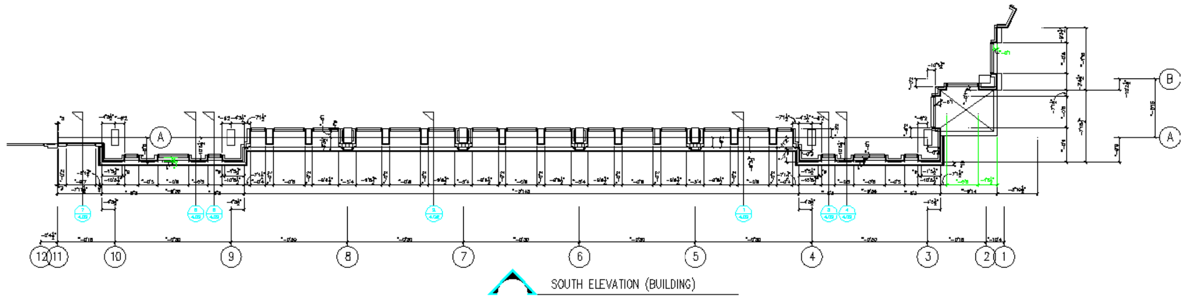


Fig. 44. Elevation typical cross section

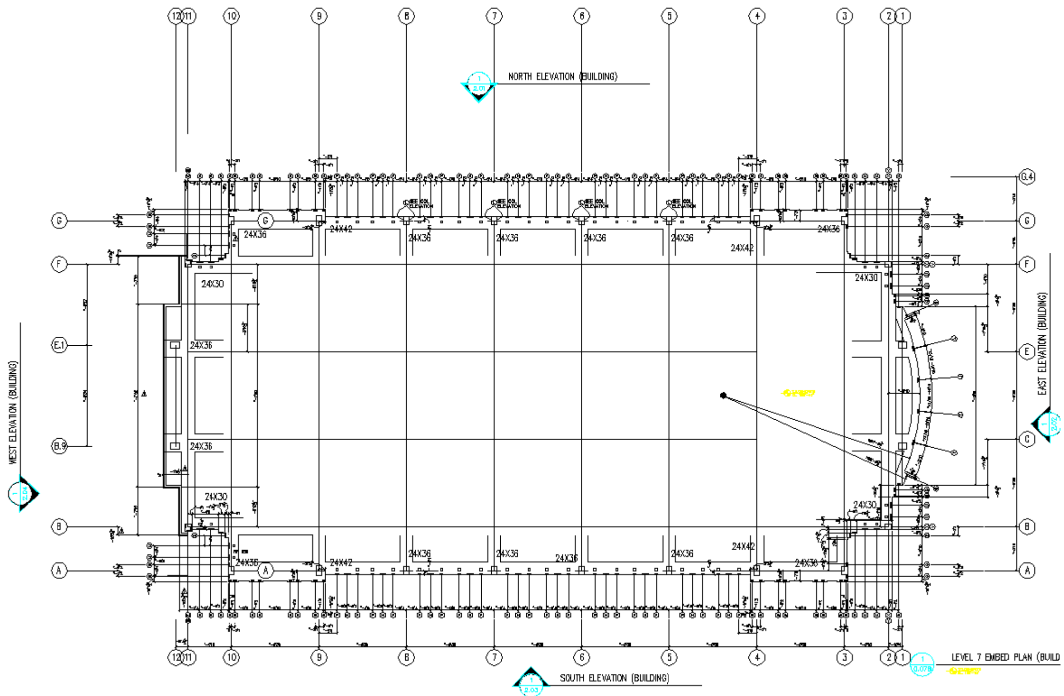


Fig. 45. Cast-in-place embed plan

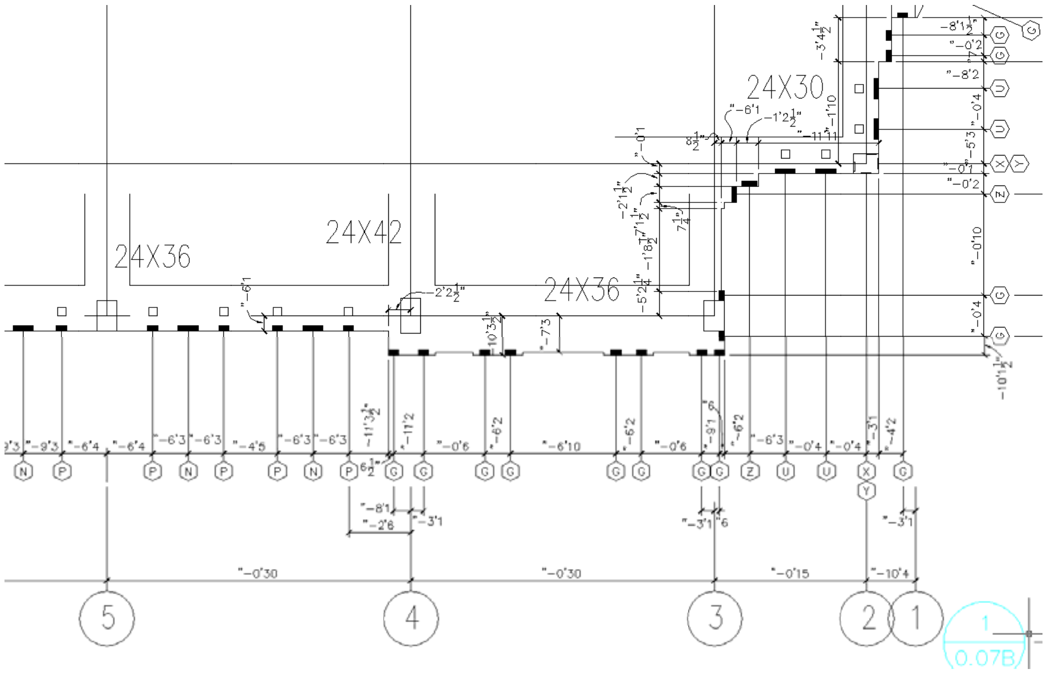


Fig. 46. Enlarged view of the same cast-in-place embed plan

4.3.4 Column cover shop ticket

Piece detail drawings of the kind shown in Fig. 47 (which shows a column cover piece) are made for the production team in the plant. They show the overall dimensions of the pieces, all the joints and recesses, the embeds (Fig. 48) and the reinforcement (Fig. 49).

4.3.5 Spandrel Shop ticket

The same data that was described for column covers exists also in a spandrel shop ticket (see Fig. 50 to Fig. 52).

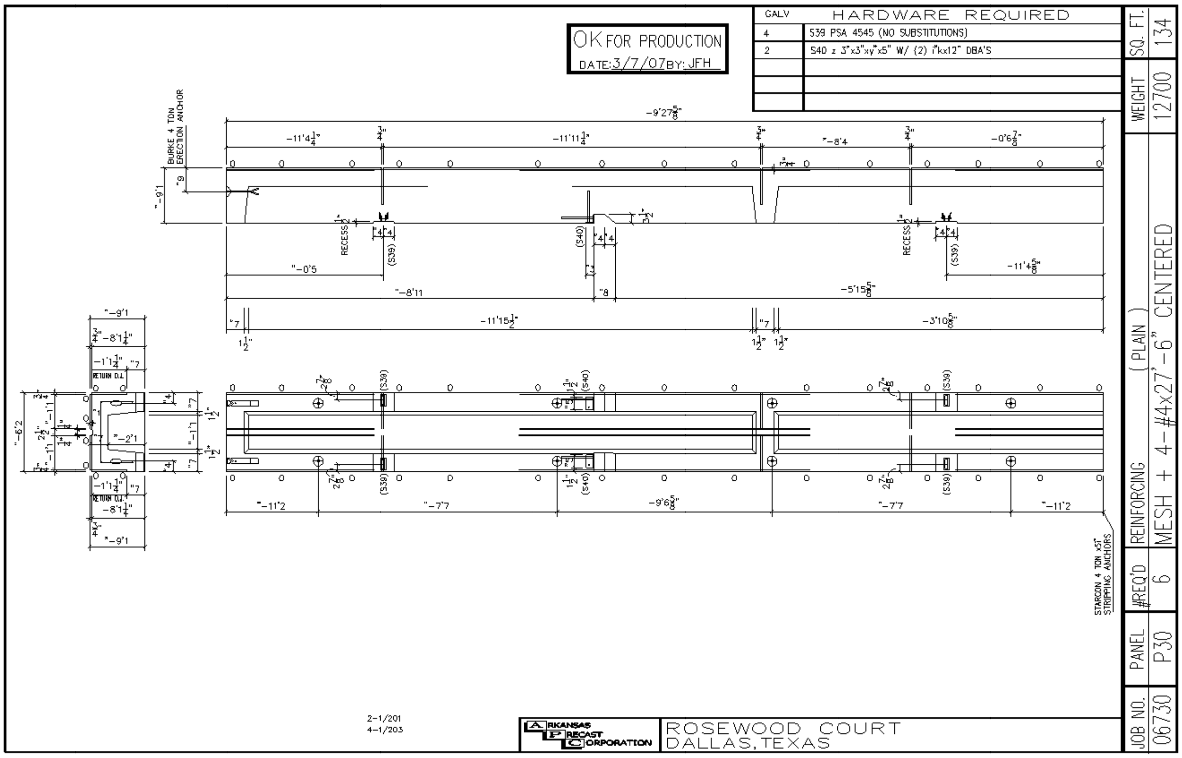


Fig. 47. Column cover shop ticket

GALV	HARDWARE REQUIRED
4	S39 PSA 4545 (NO SUBSTITUTIONS)
2	S40 z 3"x3"xy"x5" W/ (2) i"kx12" DBA'S

Fig. 48. Shop ticket Hardware BOM

JOB NO.	PANEL	#REQ'D	REINFORCING (PLAIN)	WEIGHT	SQ. FT.
06730	P30	6	MESH + 4-#4x27'-6" CENTERED	12700	134

Fig. 49. Shop ticket reinforcement

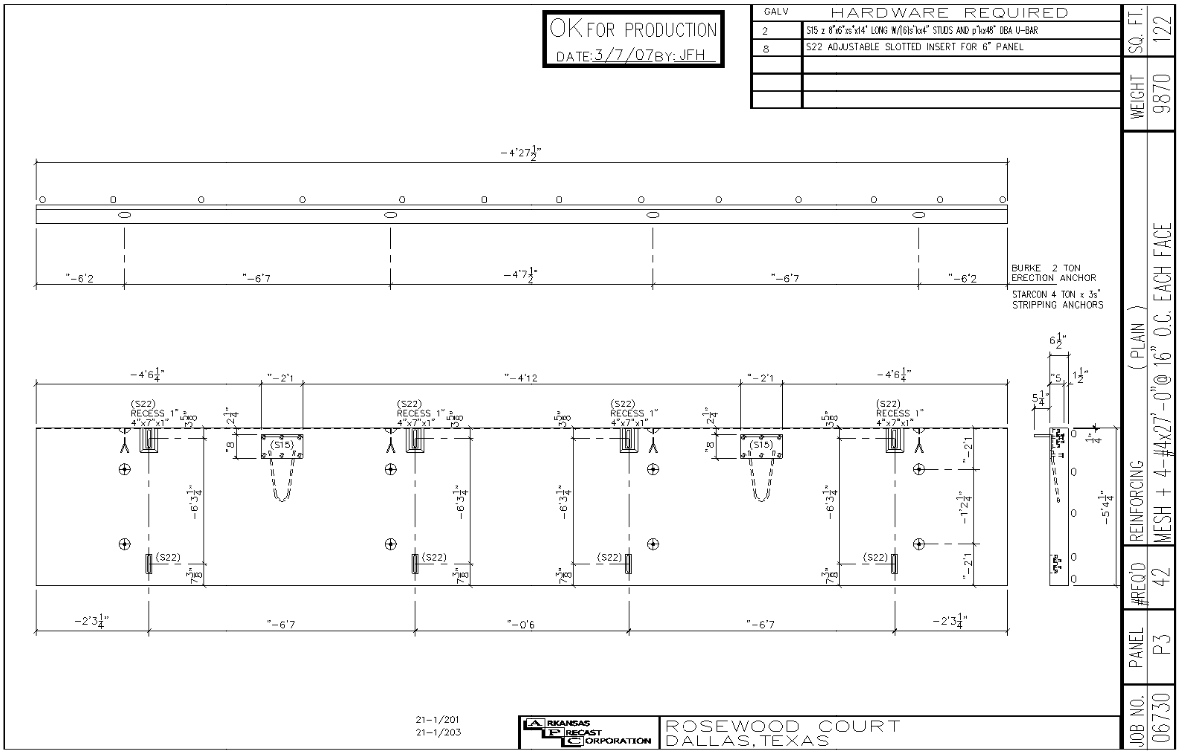


Fig. 50. Spandrel shop ticket

GALV	HARDWARE REQUIRED
2	S15 z 8"x6"xs"x14" LONG W/(6)s"kx4" STUDS AND p"kx48" DBA U-BAR
8	S22 ADJUSTABLE SLOTTED INSERT FOR 6" PANEL

Fig. 51. Shop ticket Hardware BOM

JOB NO.	PANEL	#REQ'D	REINFORCING (PLAIN)	WEIGHT	SQ. FT.
06730	P3	42	MESH + 4-#4x27'-0"@ 16" O.C. EACH FACE	9870	122

Fig. 52. Shop ticket reinforcement layout

5 Architectural Precast Workflows

During the extended period of the experiment, the current 2D practice workflow was observed and a process map was compiled. The map, shown in Fig. 54, was based on observation of the practices in the two precast companies and the architectural practice, as well as on interviews of the principal actors. In the light of this map, the experience gained in the extensive 3D modeling experiment and the authors' knowledge of BIM, a process map of a candidate typical 3D modeling based workflow was then compiled. These processes are the subject of this section.

5.1 2D CAD workflow map

The 2D workflows observed were summarized in an information flow process map using the GT-PPM tool. The workflow map was compiled using three sources of information:

a) In earlier research (Sacks et al. 2004), precast company representatives mapped the workflows common in their organizations from project acquisition to erection. However, although 13 companies participated, only two of those mapped workflows for architectural facades. Of these, only one related to information exchange with architects, although it was not very informative. A local view of the relevant process is shown in Fig. 53;
b) Observation of practice at High Concrete and at Arkansas Precast during the course of the experiment;

c) Detailed interviews with company personnel at both companies.

(Note: insufficient information was provided through the research project website to support this activity).

The 2D workflow was mapped using GT-PPM (Lee et al. 2007). The resulting information flow map is shown in Fig. 54. Special attention was paid to determining and classifying the exchanges between architect and precast fabricator; the process map shows the interface between them as a solid horizontal line. The information flow arrows that cross the interface line in the figure are the exchanges that are the subject of the proposed future National BIM Standard. The figure also shows the interface between the precast fabricator and the engineer of record, although this was of secondary importance in terms of the scope of the research.

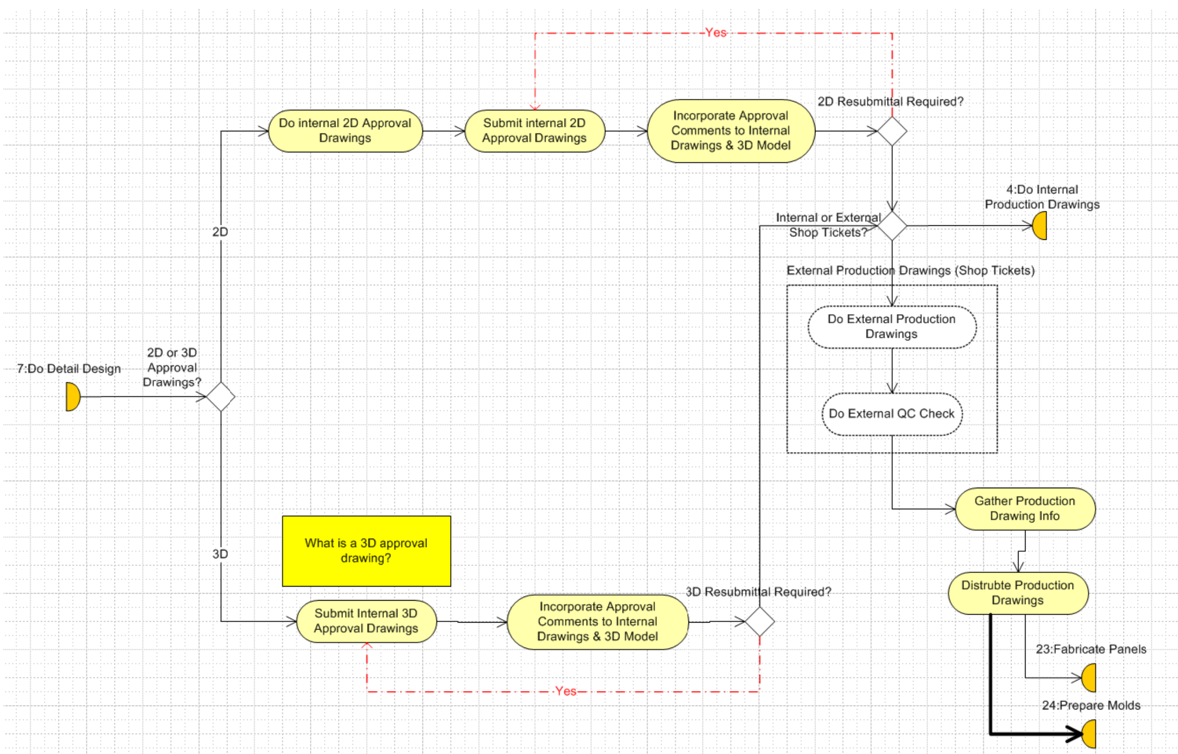


Fig. 53. A view of a section of CTI process model

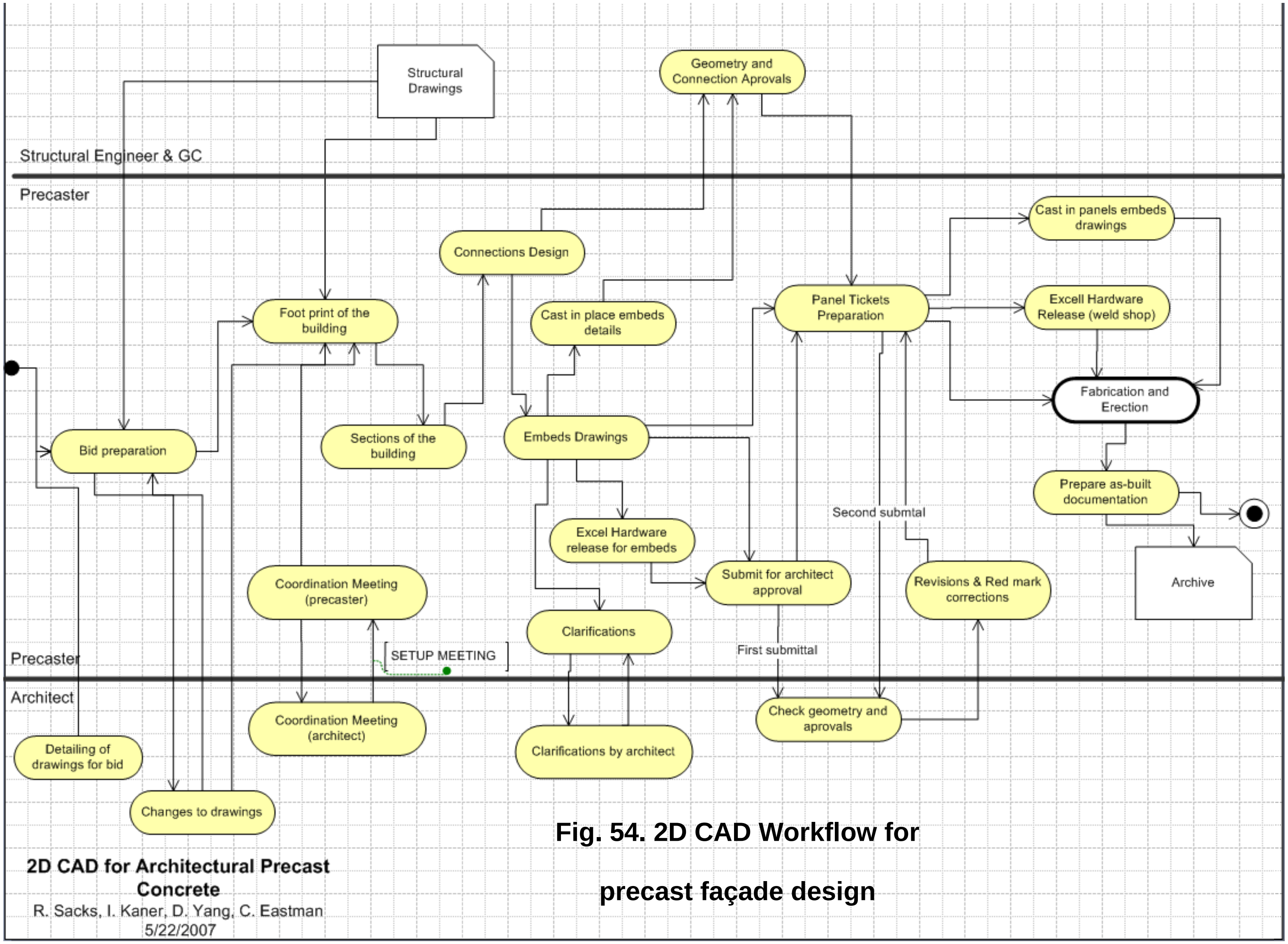


Fig. 54. 2D CAD Workflow for precast façade design

5.2 3D Schematic Workflow

The experience gained in the course of performing the experiment enabled preparation of a generic candidate workflow suitable for 3D modeling based exchanges. The workflow is shown in Fig. 55. Using this workflow as a basis, a set of information exchange definitions was proposed. These exchange definitions are the subject of Part C of this report.

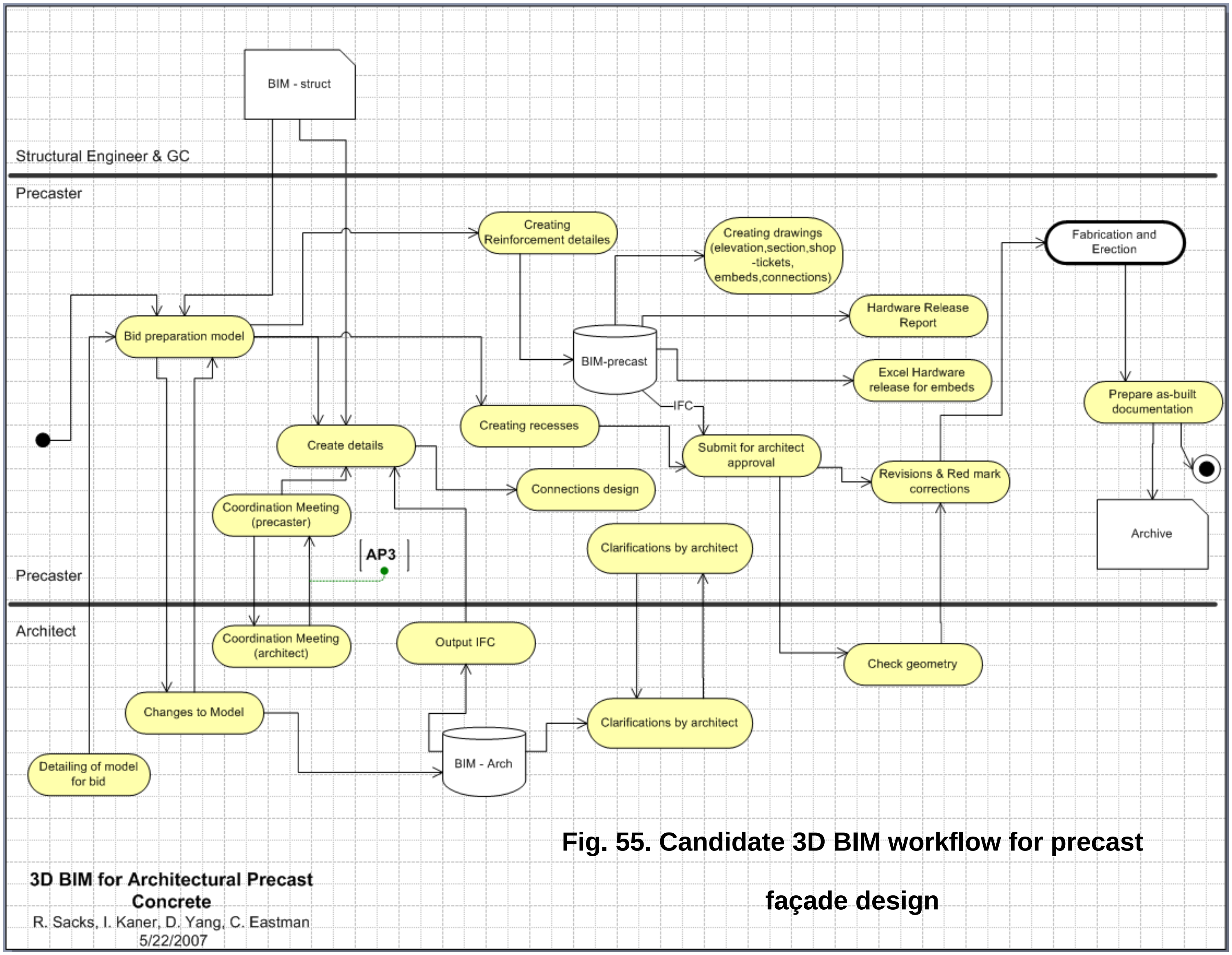


Fig. 55. Candidate 3D BIM workflow for precast façade design

6 Summary and Conclusions

6.1 3D Modeling

The experiment demonstrated the viability of designing and detailing of precast façade pieces completely with existing BIM software. All of the information needed for design coordination, fabrication and erection could be generated using BIM tools. No specific limitations were encountered.

The experiment provided a clear understanding of the appropriate workflows for 3D modeling. As described in 3Chapter 5, the workflow is considerably different from the existing 2D CAD workflow.

6.2 IFC Exchange Capability Status

The main limitations observed throughout this experiment were that the BIM software applications did not enable full exploitation of the capabilities of the IFC exchange schema. This meant that the model data was degraded though each step – export and import – in both directions. The degree of degradation was such that relatively little more than the basic geometry of the structural components, and only the geometry of the precast façade pieces were transmitted.

For example, the lack of a specific precast façade object in Revit Building meant that no such object could appear in an IFC export file. However, by the same token, no specific precast façade object exists in the IFC schema (as of the IFC 2x3 version). On the precast import side, Tekla Structures v13.0 only allowed import of the IFC file as reference objects.

These conclusions underline the importance of a common domain-specific BIM exchange schema for this (or any) specific domain. The schema is primarily needed as a guide for software companies, so that they can develop their tools in two important ways:

a) incorporate all of the basic building element objects that are needed in their native model schemas;
b) ensure that their IFC import and export translators incorporate all of the necessary objects and their relationships between the objects.

6.3 Workflow Comparisons

In 2D drafting of the precast façade pieces, the workflow has two basic phases:

- **Preliminary, conceptual design**: here, it is sufficient to draft typical cross-sections for the spandrels and column covers and elevations that show the positions of the pieces proposed on the building.
- **Detailed design**. All of the piece drawings, including detailed cross-sections, are essentially redrawn **from scratch**. This is because it is only at this stage that the precast designer must account for the finer details addressing the architectural design, as well as production and erection.

In the 2D workflow, the tools do not facilitate careful consideration of the context for each piece, and changes through a piece's extruded length can be overlooked.

In contrast, in the 3D workflow, the tools demand a more detailed approach to engineering the façade pieces as soon as modeling begins, because the context for each piece within the building, with all of its local peculiarities, becomes clearly evident. Thus users identify local solutions and provide a richer, more specific design at the early stage. This requires more thought and effort than required using typical sections and pieces, which is the case when using the 2D tools at this stage. Alternatively, 3D modeling can have different results depending on the context of the project collaboration:

- If there is close collaboration, then design issues are brought to the attention of the team early and this avoids rework later in the detailed design phase.
- If the collaboration is not close, then the architectural design may still be changed as the design is detailed, with the result that most of the pieces may have to be remodeled later. In this case, greater time invested up front may be wasted and the re-work of rebuilding the models for scratch is imposed.

In this report, chapter 6 presented a candidate 3D workflow. This workflow assumed that both the architect and the precast fabricator are performing 3D modeling in close collaboration.

Another important difference observed between 2D and 3D workflows concerns the ways in which design alternatives can be represented. In 2D, two alternative cross-sections for a spandrel, for example, can be given by simply drawing the two alternatives adjacent to the spandrel plan view. However, existing 3D modeling software requires that a single ‘reality’ exist, and so alternatives must be represented by saving separate whole model files. This is an important limitation at the conceptual design stage, where a precast fabricator often needs to communicate multiple alternatives to an architect for evaluation. Functionality is needed in 3D modeling software to allow local saving of alternative sets of data and the ability to toggle between them when evaluating candidate designs.

6.4 Productivity Findings

Not only did the experiment enable evaluation of the status of the BIM technology and synthesis of possible BIM workflows, it also provided an opportunity to collect valuable data concerning engineering productivity. This was an important goald of the research because, as stated in the research proposal, in the absence of any productivity gain, BIM technology will not be adopted.

During the experiment, 3D modeling working hours were carefully logged and productivity was calculated (see Table 3). At the same time, the 2D design team logged their working hours. The level of detail recorded allowed comparison at different common points in the processes.

Table 3. Labor hours for 2D CAD and 3D BIM, architect and precast fabricator.

Profession	Activity	2D CAD (hours)	3D BIM (hours)	Productivity Gain (%)
Precast fabricator	Drafting	830	350	58%
	Design	440	?	?

The work hours reported by Arkansas precast were validated by comparing them with a benchmark of productivity reported in the PCI Journal (Sacks et al. 2005). The Rosewood project has 35,000 sq.ft., which fits the classification as a medium-sized project. The benchmark figure for medium-sized architectural projects is 37.5 hr/1000sq.ft. Computing the expected number of hours for engineering and drafting yields an expected 1,312 hours; the labor hours reported by Arkansas Precast were: 830 + 440 = 1,270 hours.

7 References

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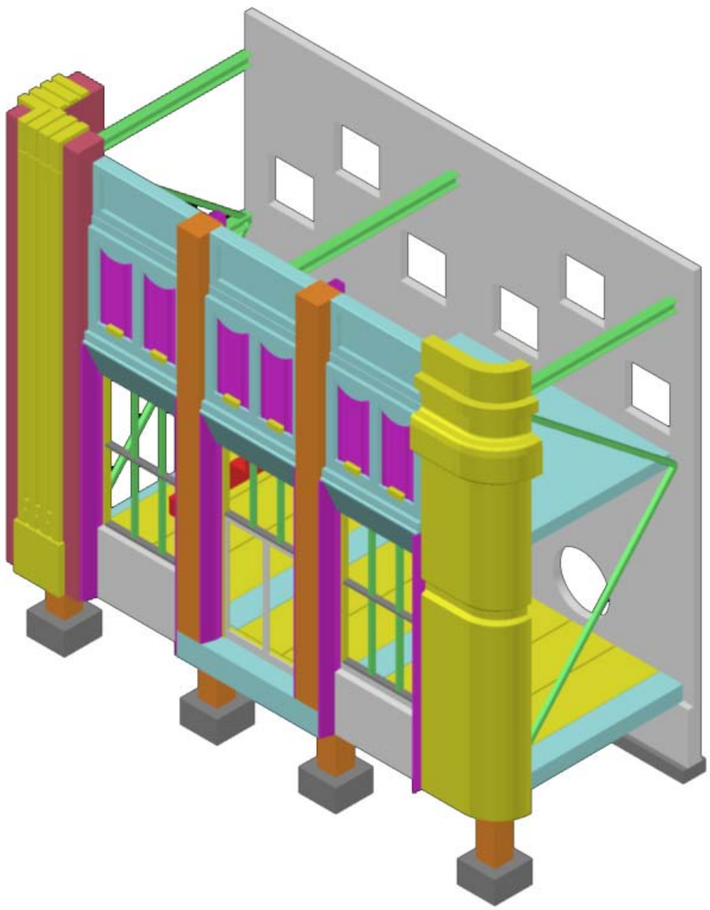
Part B

Data Interoperability Benchmark Test

Between Architect and Precast Fabricator



Yeon-Suk Jeong, Charles Eastman, Rafael Sacks, Israel Kaner

Table of Contents

Tables

Figures

Executive Summary

Many of the potential benefits of Building Information Modeling (BIM) can only be realized if both the modeling tools and the exchange technology between different users are robust and perform at high integrity. This report describes a set of experimental tests used to assess the current capabilities of BIM design and fabrication tools to support advanced practice in the area of architectural precast design and fabrication. It assesses the modeling capabilities of the tools, the effectiveness of expert users to utilize the tools, and most importantly, the exchange capabilities between the tools.

A small but complex benchmark building design was developed and assigned to in-house modelers from each of four prominent BIM architectural tool developers (Revit, Bentley, ArchiCAD, Digital project). Each of the models they prepared was then exported into an IFC file and assessed. The four models were then each imported into the two main precast detailing tools (Structureworks and Tekla Structures). Detailed examination identified the errors at each step, in modeling, in exporting and importing. The exchanges were assessed regarding the geometry exchanged, the properties and the grouping of geometry into pieces.

A broad spectrum of capabilities was shown. In many cases, their piece count changed. All of the exchanges in this example allowed only static, non-editable geometry exchange. Editing on the receiving application required re-building of the pieces. There was also a wide variety of mappings between internal model objects and the IFC objects use to represent them. The wide disparity between the ways in which valid IFC files can be exported for the same building model strongly underlines the need for BIM standards that define which IFC objects should be used for which building elements, and how they should be related to one another, in each domain. The Part C document of this report, the Information Delivery Manual (IDM) for precast architectural facades, is a first step in this direction for the domain studied in this research.

All four BIM tools have IFC export functions, and three of the four have IFC import functions. Of the two fabrication modeling tools tested, only Tekla Structures has IFC import and export functions. Where IFCs could not be used, SAT/STP file formats were tested, although these can export geometry only, with no object data. The only exchange that could not be made was that between ArchiCAD and Structureworks, due to the absence of any common file format.

Where SAT or DWG formats were used, both resulted in varied errors. However, one surprising result was discovered: in three of the exporting programs that supported SAT, the export application supplied geometry that when imported, was directly editable in the receiving application. This allowed errors to be fixed quickly and work could directly continue using the imported geometry, without rebuilding.

Acknowledgment

The authors are greatly indebted to a number of people and organizations whose support and assistance was vital to the execution of this series of benchmarking tests. They include Frank Wang at Tekla, Atlanta; Jennifer Huber and Jason Lien at Structureworks, Denver; John Sullivan at Autodesk; Angi Izzi at Design Integrations (ArchiCAD); Rob Riley at Bentley; Dennis Shelden at Gehry Technology;

1. Introduction

This document describes a series of tests designed to test the efficacy of exchange of building models between the leading building information modeling (BIM) tools. A small but complex sample structure was specifically designed to test the capabilities of the tools in modeling and exchanging data.

The experiments described in this document were performed within the framework of a research project designed to explore the current and potential capabilities for exchanging building information models between an architect and a precast company for precast architectural facades. The experiments aimed primarily to determine the state-of-the-art of building model exchanges using the translators that conform to the Industry Foundation Classes building product model schema. However, its scope was extended to test for best modeling practice within each BIM tool because this was identified as a prerequisite for effective data exchange between tools. Alternative file formats available for model transfer were also tested, but these are limited to transferring geometry only.

The project was funded by the Charles Pankow Foundation in line with its aim to further innovations in building design and construction, so as to provide the public with buildings of improved quality, efficiency and value. The project encompassed several companies and organizations, and was supervised by FIATECH and NIBS. Georgia Tech and Technion were the research coordinators and undertook the experimental work described in this document with the assistance of representatives of the following software companies: Autodesk, Bentley, Digital Project, Graphisoft, Structureworks and Tekla.

The overall research report has three major segments. This document (Part B) details the benchmark tests described above. The first document in the series (Part A) reported on an experiment in which a building was modeled and exchanged using BIM tools concurrently with its actual design and fabrication detailing of its precast parts using standard 2D CAD tools. The last document (Part C) defines the information exchanges needed for precast architectural façade pieces.

1.1 Background

Current construction practice includes a range of behaviors that are becoming widely recognized as dysfunctional:

- Architectural firms produce construction documentation with little knowledge about how the components of the building will actually be fabricated and erected.
- In the traditional procurement process or design-bid-build, fabrication input to the design generally comes after the architectural contract drawings are complete
- Fabricators regularly regenerate (usually from scratch) the detailed documentation required for fabrication and erection, resulting in much duplicated work.
- All of these steps are carried out using electronic drafting, relying almost 100% on the skill of the drafter/designer to interpret how the building systems will fit together,

interpreting all related drawings. Like the earlier process of drafting on paper, computer-aided drafting is intrinsically prone to human error; as a result, significant errors and change orders occur on all large projects (Gallaher et al. 2004).

- These same issues apply to bills of material, quantity take-offs and other information extracted from the drawings. These also are error-prone.

Building Information Modeling (BIM) technology potentially addresses many of these issues (Eastman et al. 2008). It applies to all fields within the construction industry: architectural design, structural, energy and other types of engineering, construction, maintenance, facility management and energy over the whole life-cycle (see Figure 1). It transforms the paradigm of the construction industry from 2D-based drawing information systems to 3D-based object information systems, from documentation that is only readable by humans to new representations that are machine readable. These 3D-based systems facilitate the construction of a virtual digital building that contains a clear and unambiguous geometric description of the building. Being a single model, all drawings from the model are guaranteed to be consistent. Report extraction for bills of material can be automated. Routines for detailing, such as connection design, rebar and tension cable layout has also been automated.

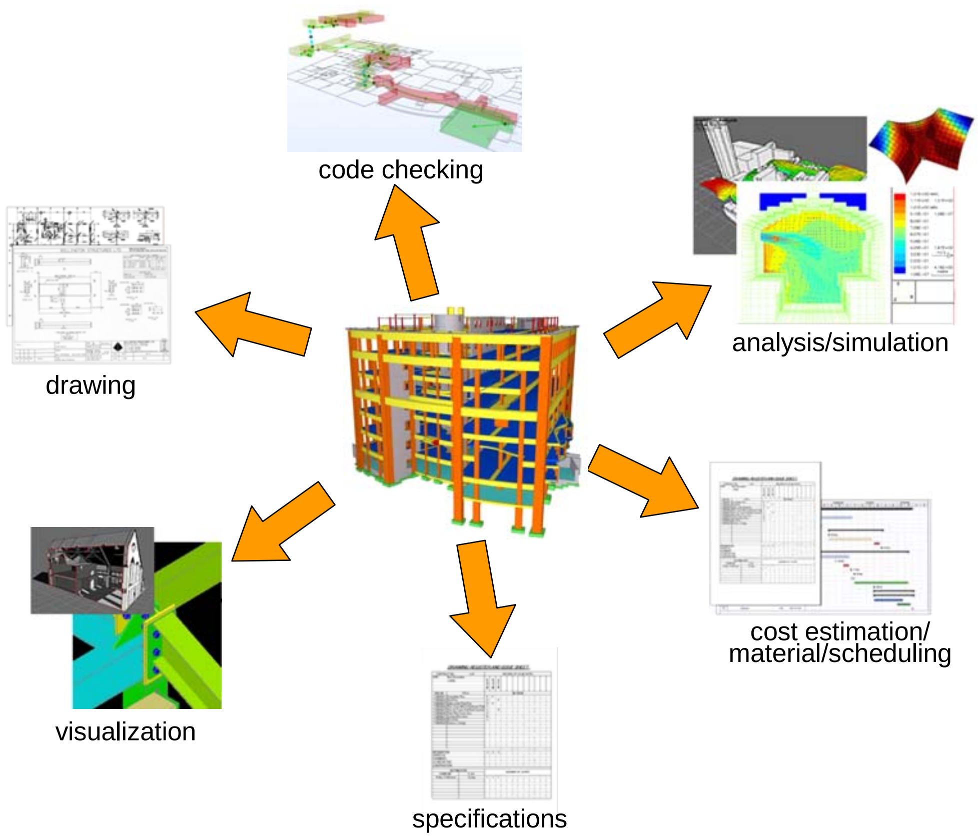


Figure 1 Application of BIM approach

BIM tools first allow collaboration between users to be greatly enhanced through better visual understanding of the building artifact. However, collaboration is greatly enhanced if the partners can share their models not only for viewing, but for direct analysis, editing and development. In order for collaboration to be fully effective, the data exchanged and shared needs to include both geometric shape data and building element and assembly property data. It needs to address design intent, fabrication and other production details, and the interface between systems, such as connections and pass-throughs. These are all potentially available, with proper use of BIM technology.

BIM tools are also different from existing CAD systems because end-users can model 3D geometric shapes using parametric solid modeling and can exchange complex building information using an industry standard product model - Industry Foundation Classes (IFCs). BIM tools have allowed the construction industry, especially engineering fields, to apply 3D modeling techniques to fabrication. For example, this technology has been used for steel structures starting ten years ago (Watson and Crowley 1997). Recently the same BIM technologies are used to structural engineering, fabrication and construction stage of precast concrete structures (Sacks et al., 2004).

Earlier geometric exchange formats, such as DWG/DXF, SAT, IGES, etc. allow the (often imperfect) exchange of most geometric shape data. Data loss and corruption is still common, requiring manual correction. The Industry Foundation Classes (IFC) is the only data modeling format that includes geometry, object structure (topology) and material and performance attributes. Thus it provides the basis for next generation exchange and collaboration. Because of its fairly recent adoption by software companies, IFC translators too have current limitations and implementation errors, which are still being worked out.

Currently, the design community is in the transition, adopting and learning to effectively utilize this new generation of parametric 3D modeling tools. The tools include both those targeted for architectural design, such as Revit from Autodesk, ArchiCAD from Graphisoft, Bentley Architecture and Digital Project from Gehry Technologies. They also include specialized tools for fabricators, such as Tekla Structures, Structureworks, CADDuct and CADpipe, and other tools embedding system specific design rules and capabilities.

An additional difficulty is that the technology itself is not mature, yet has embedded complex practices and layout rules of different building systems. The result is that professional designers (who have an inherent understanding of how different building systems should relate to one another) are sometimes surprised, usually in less commonly encountered design contexts, where the software proposes design solutions that are not feasible or sub optimal. These have to be sorted out and fixed through collaboration between practitioners and the software companies.

A consistent 3D model, with associated data regarding functional, material and product information, has the potential to significantly reduce construction time and costs, reduce errors, enhance fabricator productivity and improve building performance. The benefits are accrued by all of the various members of the design/construction/fabrication community. However, realization of these capabilities is only possible if the modeling and exchange works effectively. This experiment was designed to assess the capacity of data communication between two kinds of BIM tools by using a so-called ‘benchmark’ test model. The benchmark test model includes complex geometric shapes – typical of architectural precast, several kinds of materials and design members. Some problems and limitations of data communication based on several data formats are examined through this experiment.

1.2 IFC Status

This section briefly describes the current development and progress in IFC compliant applications. The version mentioned throughout this report is restricted to IFC 2X3 which was published in February 2006. Several applications have just passed the IAI (International Alliance for Interoperability) IFC2X3 certification in late May 2007. Certifications are issued in two steps: a basic test for applications which are at the starting phase to develop IFC interface and the second step for more advance IFC capability. Each certification phase has particular scope and requirement that were defined by the ISG (Implementer Support Group) committee. Basically, each version certification focuses only on a set of entities and not the whole IFC2X3 schema.

The IFC schema defines the overall scope of information that potentially can be exchanged on buildings over the life-cycle. In each ISG meetings, series vendor-agreements were made to narrow the overall implementation work. Agreements were made on version basis and not overruling the official schema. Available agreements are now published at the ISG websites (see http://www.iai.fhm.edu/). Vendors can implement beyond endorsed agreements to gain advanced IFC exchange capability. For instance, Solibri supports reading B-Spline curve which is agreed not to be implemented among most vendors in IFC2X3.

2. Goals and Outline

2.1. Goals of Experiment

The goal of this benchmarking experiment was to establish the state-of-the-art in modeling and exchange of building information model data between existing software packages. Developing a sound understanding of the various technologies is essential in identifying how they can be exploited to develop effective collaborative workflows. The experiment examined alternative formats of bi-directional communication between BIM authoring tools prevalent in the architectural domain (Group A tools) and those prevalent in the domains of structural engineering and precast concrete (Group B tools), as shown in Table 1. The medium of communication considered between the two groups was file exchange – use of model servers was not explored. The benchmark tests mainly focused on IFC format files, but two other data formats were tested - DWG and SAT format files.

The experiment examined both modeling methods and exchange capabilities between four major architectural BIM tools and two precast BIM tools, using a benchmarking example. The major focus was to check interoperability of 3D geometric shape, member properties and organization of member parts, topological relations between the parts, etc.

However, these capabilities are dependent upon several inter-connected issues:

- the capabilities of each BIM design tool in terms of modeling complex building components such as architectural precast;
- the skill and practices of the modeler, to effectively use the software available to best use;
- the quality of the translators for output and input that write and the read the model data in the heterogeneous applications.

The IFC and SAT file formats were used as main file formats for assessing data interoperability between Group A for architectural domain BIM tools and Group B for structural engineering/precast concrete domain. The data exchange and validity is partially dependent upon the modeling practices of the user, so these are considered here. Since façade panels of precast concrete parts are often composed with complex geometric shapes, data loss and corruption can occur during data transfer between architect and precast fabricator. Thus, we compared import results of the geometric shape with the original benchmark test model. The benchmark test model has some complex geometric shape and various architectural and structural members.

One of the major goals was to check whether data exported from BIM tools of Group A can be modified or edited with ease in the BIM tools of Group B. In addition, we checked transfer of data exported from Group B and imported back into Group A tools as a round-trip test. This test is very important for collaboration work between architect and precast fabricator. In general, products designed by an architect are transferred to a precast fabricator for fabrication. However, the architect cannot provide complete fabriaciton details, and so the process relies on the precast fabricator receiving the information accurately and interpreting the architect's design intent correctly. The process is collaborative, and must consider structural design, fabrication and construction constraints. Thus, results of this interactive design modification should be transferred without data loss and corruption.

Table 1. BIM Tools included in the benchmark tests

Group A Architectural BIM tools	Group B Precast concrete BIM tools
Revit Building v9.1 ArchiCAD v10.0 Digital Project v1 R3 Bentley Architecture v8	Tekla Structures v13 Structureworks

The experiment explored the following aspects of BIM data exchanges:

1) The modeling capabilities of the software in both domains. The benchmark model contains most of the object types common in building structures – cast-in-place reinforced concrete members (footings, columns and slabs), steel members (columns, beams and bracing), and precast concrete members (beams, hollow-core slabs and architectural façade panels). While the structural members have straightforward geometries, the façade panels contain more complex geometry.
2) The export capabilities of each of the software tools. Exported files were examined for geometric accuracy and semantic content.
3) The import capabilities of each of the software tools. Any actions needed to 'convert' the imported model to a native form to enable the workflow were documented.
4) Comparison between different versions of model geometry and data, using either third-party comparison utilities or within the authoring applications.

2.2. Experiment Method and Process

As stated above and shown in Table 1, the two groups of software tools are architectural design group and precast fabrication group. Three types of data formats were used for testing data communication: IFC, DWG, SAT (or STP) file formats.

Figure 2 shows Group A on the left and the Group B tools on the right. The benchmark structure was modeled in each of the tools in Group A and then exported to each of the three file format types considered (IFC, DWG, and SAT or STP), with one exception: ArchiCAD did not export an SAT file. In the diagram of Figure 2, continuous, square dot and dash lines with arrows represent the import and export functions of IFC file, DWG file and SAT/STP file format, respectively. The arrows at each end of each line describe whether each BIM tool can import and/or export data files or not. For example, Bentley Architecture can export in all three formats, it can import DWG and IFC files, but it cannot import SAT files.

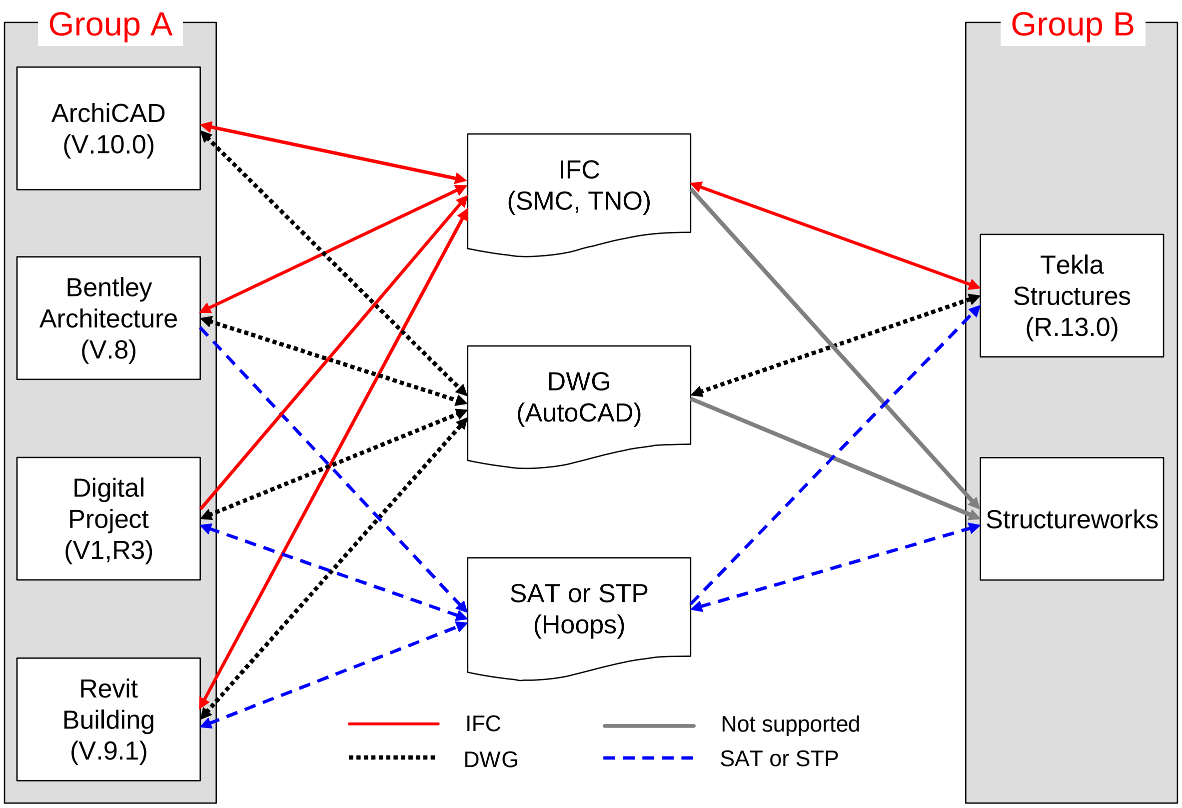


Figure 2 Experiment method and process for testing data communication

In the first step of the tests, all Group A members received the benchmark model in 3D DWG format. Expert modelers from each member of Group A performed the following procedure:

a) Modeled the benchmark model structure from scratch according to that member's best practice.
b) Documented the modeling process, with time spent building the model and any difficulties encountered.

c) Documented what native software objects were used to model each object type in the benchmark structure. For example, units 1 ~ 10 corresponding to steel beams, concrete panels, concrete columns, windows, etc., are shown in Figure 3 and Figure 4.

d) Exported the model in IFC format and any other formats available (DWG, SAT and/or STP).

e) Imported each export file back in to the originating software in order to check that the exported file was accurate and/or to test the capabilities of the import translator. Each member identified the problems encountered in terms of missing entities, switched element types, mislocated objects, etc.

In the second step, expert modelers representing Group B members received all of the files exported by the four members of Group A. The tasks asked of each member of group B, for each set of export files received, were defined as follows:

a) To import the files into the BIM tool from Group B and identify if the imported file was editable, if it was incomplete, and whether any or all of the geometry had to be re-created to be editable.

b) For one file selected by Group B, to perform whatever operations were needed to make a completely editable model, a 'best of best practices'. They were required to document the process, recording time spent building the model and any difficulties encountered.

c) To create simple reinforcement rebar layouts in the concrete objects, create simple connections between the precast façade panels and the bearing beams, and create simple steel connections between the beams, columns and bracings, if possible. These were representative only, and were not required to be thorough or represent structurally sound details.

d) After detailing the structural elements, to export the resulting model back into an IFC format file. Also, to export the model in any other format readable by any of the Group A applications.

e) To import each export file back into their application in order to check that the exported file was accurate, and/or to test the capabilities of the import translator. Within this ‘round trip’ export-import, they were asked to identify the problems encountered in terms of missing entities, switched element types, mislocated objects, etc.

2.3. Benchmark Test Model

The benchmark test structure is shown Figure 3. It was composed of several kinds of structural members, with various materials and with complex geometries. The structural elements included precast concrete, steel and cast-in-place reinforced concrete members. Some of the precast units (see Figure 4) had complex geometric shapes, with a variety of different material properties and cross-section profiles.

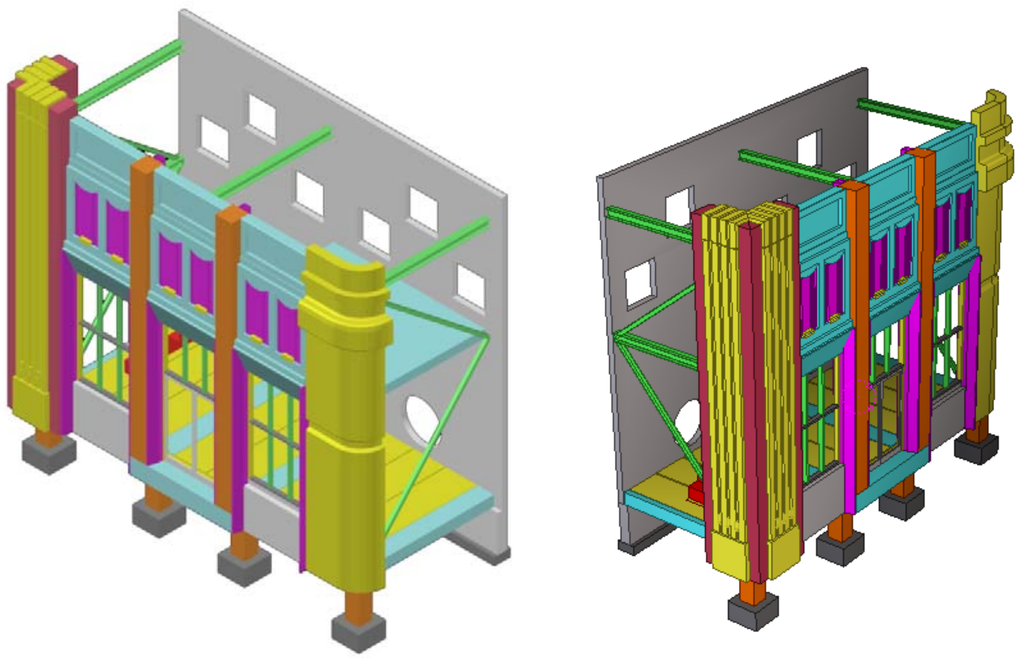
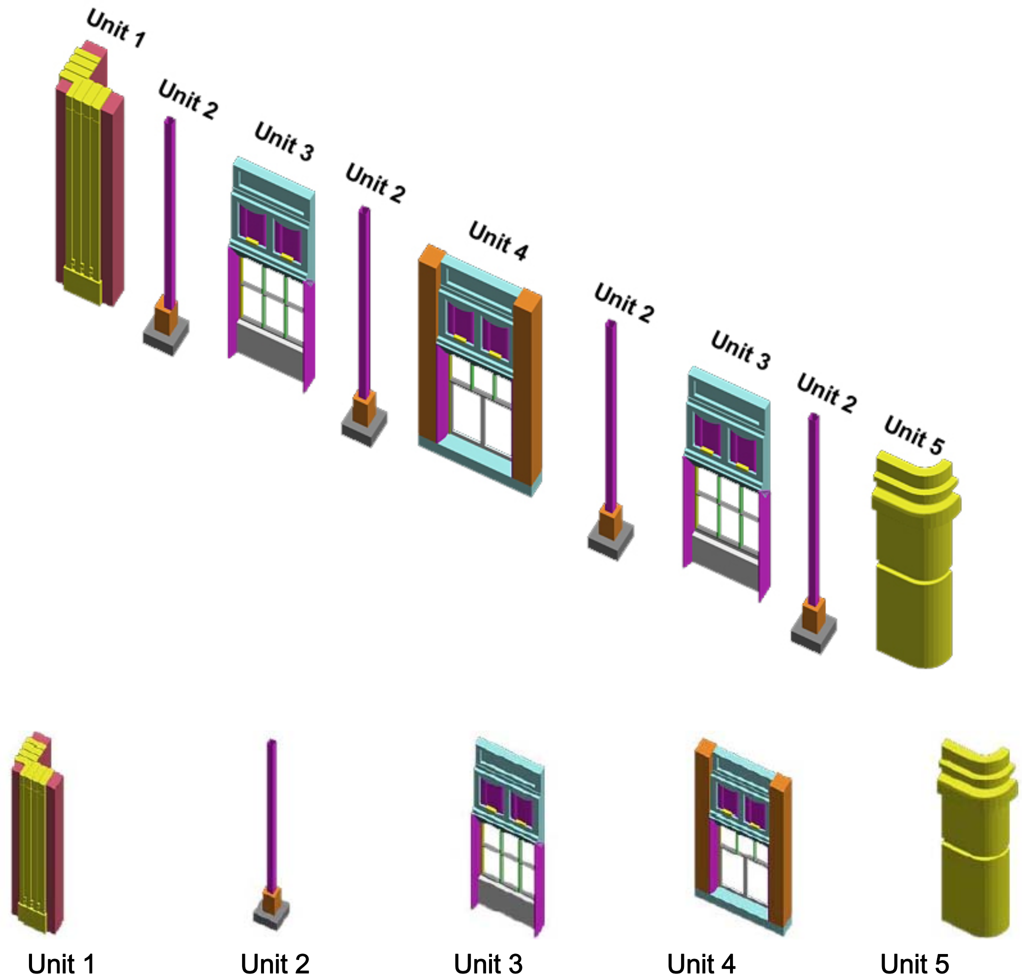


Figure 3 Benchmark Test Model

Units 1, 3, 4 and 5 shown in Figure 4 are façade panels of precast concrete structures with complex geometric shapes and assembly of pieces.

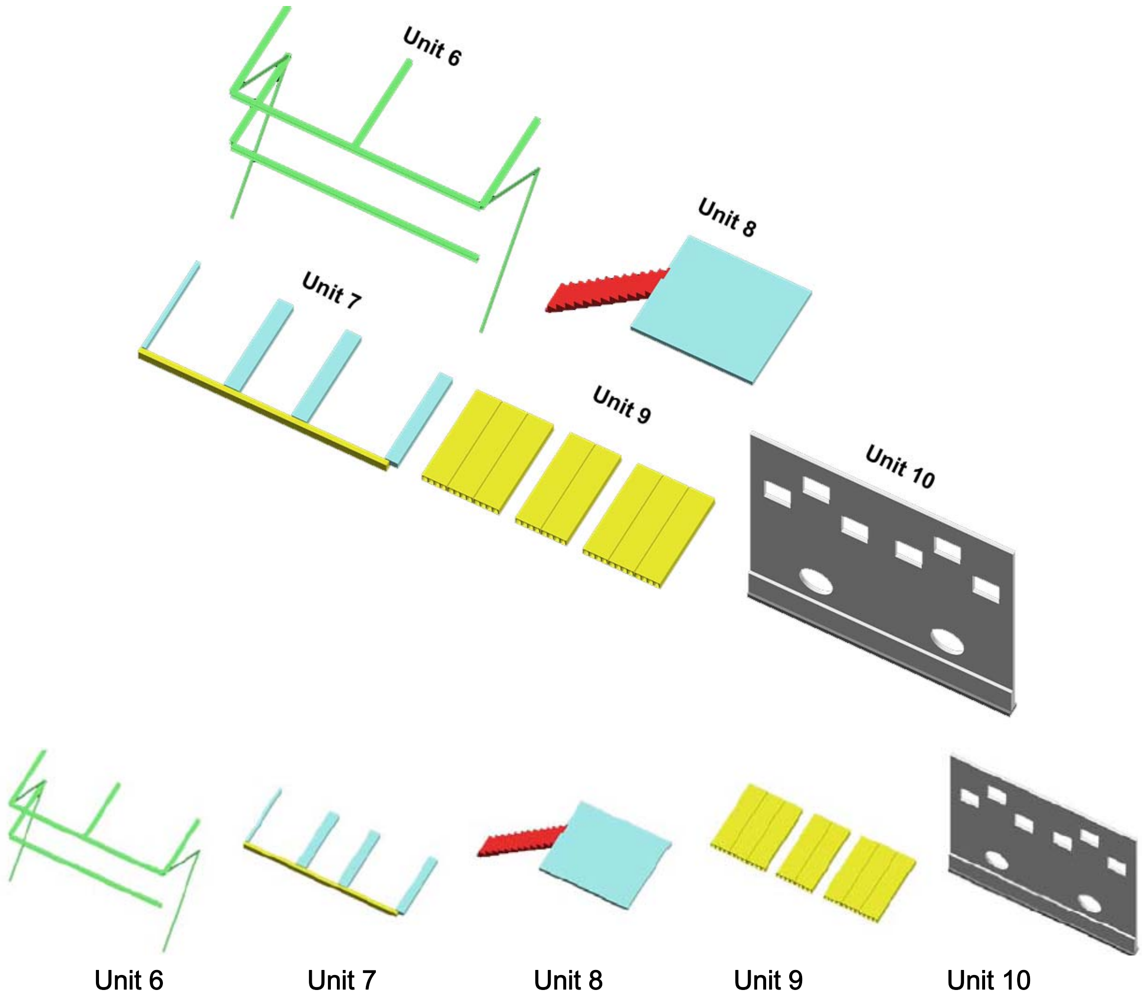
Unit 6 comprises steel structural members. These allow checking whether the cross section profiles of the members are transferred to the other BIM tools.

Units 7, 8, 9 and 10 include cast-in-place reinforced concrete members such as slab, stair, wall and beam members. Some of the units can be broken down and defined as aggregations of design members. For example, Unit 10 can be divided into a wall, a beam and a footing member. Cast-in-place concrete structures are reinforced by reinforcing bars (sometimes also by prestress strands) and contain embeds. The IFC product model can represent reinforcing bars, but currently the BIM tools of Group B do not support a function to export the bars, and so the benchmark tests did not handle transfer of elements for concrete reinforcement.



(a) Modeling Units 1 to 5

Figure 4 Modeling Units of the Benchmark Test Model



(b) Modeling Units 6 to 10

Figure 4 Modeling Units of the Benchmark Test Model

3. Test Results for the Architectural BIM Tools (Group A)

3.1. Introduction

This chapter provides the results of the tests of the export and re-import capabilities among the BIM tools for Group A, as shown in Figure 5. The main focus of this test is to check data interoperability using IFC data format.

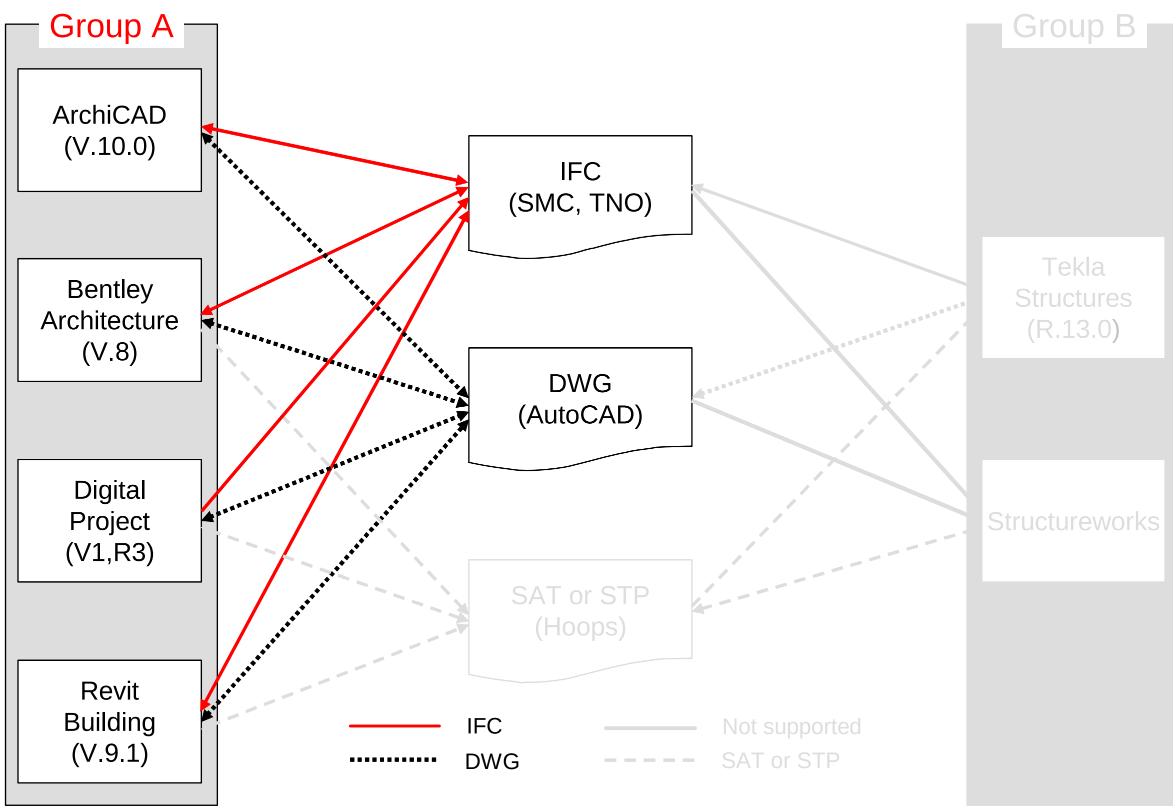


Figure 5 Experiment for testing data communication of Group A

Table 2 shows header descriptions of the IFC files which were exported from the four BIM tools of Group A. The IFC files are written in a physical file format on the basis of Part 21 (ISO TC184/SC4, 1994) of ISO 10303. The header descriptions of an IFC file includes schema version, translator version, file name, date and time, preprocessor of translator. This data description can be used for transferring data history. In order to develop translator modules for data import and export of IFC files.

As can be seen from the headers, Digital Project and Bentley Architecture have both adopted ST-Developer software as their underlying STEP toolkit used in developing their IFC tranlsators. Revit Building uses EURO-STEP and ArchiCAD uses EDM from EPM Technology.

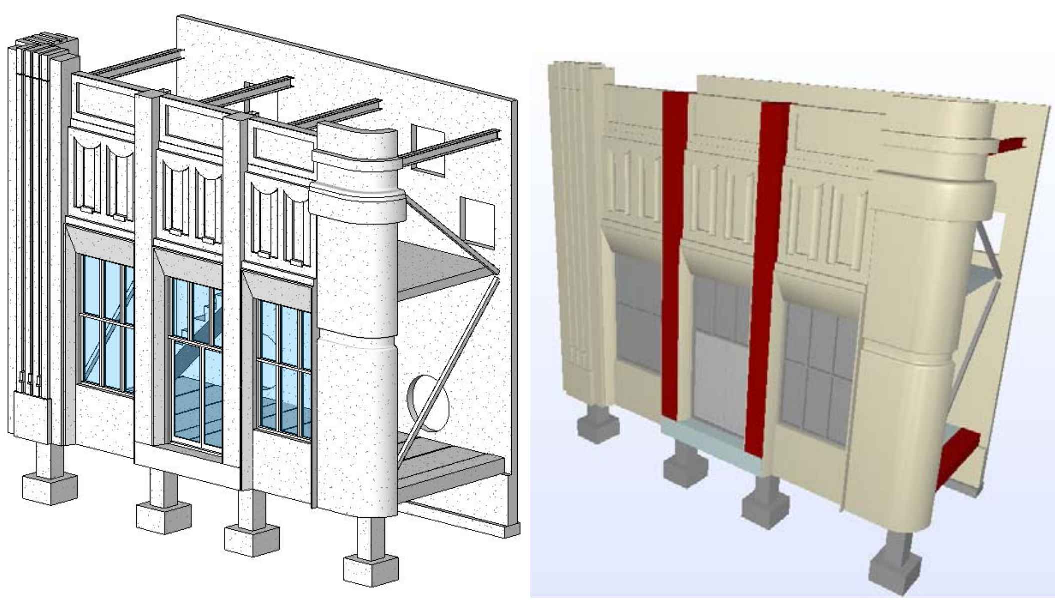
Table 2. Header descriptions of IFC files exported from each BIM tool of Group A

Application	Header file information
ArchiCAD	FILE_DESCRIPTION((' **ArchiCAD 10.00** Release 1 generated IFC file.', 'Build Number of the Ifc 2x3 interface: **63043** (05-03-2007)\X\0D\X\0A'), '2;1'); FILE_NAME(' C:\\Documents and Settings\\Yeon-Suk Jeong\\Desktop\\04_Georgia Tech Final_2X3.ifc','2007-03-09T09:56:47', ('Architect'), ('Building Designer Office'),'PreProc - EDM 4.5.0033', 'Windows System', 'The authorising person ');
Bentley Architecture	FILE_DESCRIPTION((' IFC2X_PLATFORM', 'MicroStation Triforma generated IFC File', 'Triforma IFC version **8.9.2.42'**,'*Comments*'), '2;1'); FILE_NAME(/* name */ 'Building_YS_Modify', /* time_stamp */ '2007-03-04T22:21:28-05:00', /* author */ ('*Author*'), /* organization */ ('*Organization*'), /* preprocessor_version */ 'ST-DEVELOPER v8', /* originating_system */ '*WinNt*', /* authorisation */ '*Administrator*');
Digital Project	FILE_DESCRIPTION(/* description */ ('Digital Project generated ifc file'), /* implementation_level */ '2;1'); FILE_NAME(/* name */ 'Global_Structure[~~~ ', /* time_stamp */ '2007-03-26T11:11:31-04:00', /* author */ ('Yeon-Suk Jeong'), /* organization */ (''), /* preprocessor_version */ 'ST-DEVELOPER v10', /* originating_system */ 'Digital Project', /* authorisation */ '');
Revit Building	FILE_DESCRIPTION(('IFC2X_PLATFORM'), '2;1'); FILE_NAME('C:\\Documents and Settings\\Yeon-Suk Jeong\\Desktop\\04_Model_91.ifc', '2007-03-09T10:22:39', (''), (''), **'Autodesk Revit Building 9.1 - 1.0','20060810_2300',''**);

3.2. Autodesk Revit Building

The modelers using Revit Building provided information describing their detailed modeling methods, modeling time and some modeling issues, as shown in Table **3**. It took them 166 minutes to remodel the benchmark structure, starting from the 3D DWG reference model that was provided to each vendor for this experiment. An IFC file based on IFC 2X3 schema was exported from Revit building.

For the roundtrip test using the IFC file, we tried to open the IFC file back in Revit Building. It took 70 seconds to open the exported IFC file in Revit 9.1. A large number (567) of warnings was issued during IFC import, but they were all only related to Unit 9 (the warning message was “Line in Sketch is slightly off axis and may cause inaccuracies”). However, as shown in Table 4, geometric shape data was imported without data loss and corruption. Some object data based on IFC data structures were changed during restoration of the IFC file back into the authoring application. For example, façade panels which were represented by an IfcCurtainWall entity were restored into “proxy” object data objects. These proxy objects have no defined identity as specific building element types, and so are imported as reference objects that cannot be edited, losing their meaning and behavior as a particular type of building element. Thus, some properties of objects are lost during the export or import process.



(a) Revit Building (b) IFC viewer (Solibri Model Checker)

Figure 6 Modeling results in Revit Building

Table 3 Modeling summary

Object	Native Object Type	Modeling Time (min)	Description
Unit 1	Wall	25	Created half of wall from 5 extrusions and 2 sweeps. Import used for dimensional reference. These were mirrored to produce the remaining half. All parts were unioned using Revit Join Geometry command.
Unit 2	Structural column, Footing Families	7	Used existing content. Only had to create new types to match model dimensions.
Unit 3	Wall, Curtain wall with mullion	45	Modeled top and side panels using in-place modeling tools (Extrusions, voids and sweeps). Side panel was mirrored to create other instance. Panel Family ended up containing 7 parts that were unioned using the Revit join geometry command. Base wall and Curtain wall and mullions were modeled using system content and input dimensional parameters.
Unit 4	Wall, Curtain wall with mullion and panels	25	Used panel from unit 3. Added Slab for threshold and 2 column components. Added partial grids to curtain wall and edited existing door panel to match dimensions.
Unit 5	Wall	10	Created simple sweep using import model to determine sweep profile and path.
Unit 6	Beam	10	Used existing content. Had to create new sizes by input parameters to match example. Created an additional Level Datum "Top of Steel" to aid placement
Unit 7	Beam	10	Used existing concrete beam content. Had to create new sizes by input parameters to match example. Placed a sloped reference plane in side elevation to aid in placing content on slope.
Unit 8	Slab, Stair	12	Placed Stair with correct parameters (riser and tread distances). Created slab type of correct thickness and sketch profile.
Unit 9	Floor	15	Created a single instance by sweeping a profile. This was copied to create the additional instances. (Note: some very small edge profile details were omitted. These can be added back without significant impacting time.)
Unit 10	Wall, Wall foundation	7	Created sub wall types by modifying existing content then created stacked wall type to combine them. Openings were created by editing profile and tracing import. Footing type was defined and placed on wall in one click.

Table 4 Import results of exported IFC file back on Revit Building

Object	Native Object Type	Accurate or Not	Problems that Occurred
Unit 1	Walls ← Walls (Original Model)	Geometry Good Object Good	
Unit 2	Columns ← Structural Columns Generic Models ← Structural Foundations	Geometry Good Object N.G.	
Unit 3	Walls ← Walls Generic Models ← Curtain Panels, Curtain Wall Mullions)	Geometry Good Object N.G.	
Unit 4	Walls ← Walls / Doors ← Curtain Panels, Curtain Wall Mullions Columns ← Columns	Geometry Good Object N.G.	
Unit 5	Walls ← Walls	Geometry Good Object Good	
Unit 6	Structural Framing ← Structural Framing General Model ← Structural Framing	Geometry Good Object N.G.	
Unit 7	Structural Framing ← Structural Framing	Geometry Good Object Good	
Unit 8	Floors ← Floors Stairs ← Stairs	Geometry Good Object Good	
Unit 9	Floors ← Floors	Geometry Good Object Good	
Unit 10	Walls ← Walls	Geometry Good Object Good	Line in Sketch is slightly off axis and may cause inaccuracies.

3.3. Bentley Architecture

Bentley Architecture allows end-users to assign a distinct IFC entity to each building element. Thus, all components are exported into the desired IFC entities and can then be imported back without any changes to entity types. However, some components are restored with data loss and corruption of geometry, as shown in Table 5 and Figure 8. Specifically, the spandrel elements of Unit 3 were corrupted and the door mullion of Unit 4 was lost.

Table 5 Import results of exported IFC file back into Bentley Architecture

Object	Native Object Type	Accuracy	Problems that Occurred
Unit 1	IfcBuildingElementProxy	Geometry Good	
		Object Good	
Unit 2	IfcFooting, IfcColumn	Geometry Good	
		Object Good	
Unit 3	IfcCurtainWall	Geometry N.G.	Spandrel element corrupted
		Object Good	
Unit 4	IfcCurtainWall, IfcDoor	Geometry N.G.	Data loss of door mullion
		Object Good	
Unit 5	IfcWall	Geometry Good	
		Object Good	
Unit 6	IfcBeam	Geometry Good	
		Object Good	
Unit 7	IfcBeam	Geometry Good	
		Object Good	
Unit 8	IfcSlab, IfcStair	Geometry Good	
		Object Good	
Unit 9	IfcSlab	Geometry Good	
		Object Good	
Unit 10	IfcWall, IfcFooting	Geometry Good	
		Object Good	

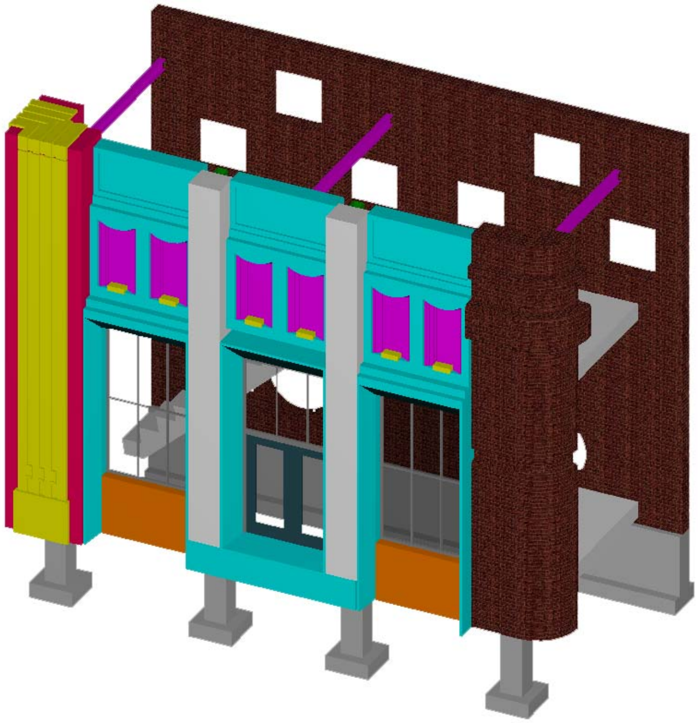


Figure 7 Modeling results in Bentley Architecture

(a) Bentley (b) Solibri Model Checker

Figure 8 Visualization results

3.4. Gehry Technologies Digital Project

Digital Project supports data export of an IFC file, but it does not have an import function for IFC files. Thus, in this case IFC viewers such as Solibri Model Checker (Solibri 2007) and TNO Viewer (TNO 2005) were used for examining the IFC file produced. The IfcQuickBrowser program (G.E.M Team Solutions 2003) was also used for text-based checking of the IFC file. As shown in Figure 10, all geometric shapes except the slab were successfully exported without data corruption and loss. However, many building elements are represented in the IFC file using shell-based surface geometry models. This surface model is often not imported by other BIM tools, because most BIM tools only import 3D-based solid model geometry. Also, since all the building elements other than those with shell-based surface geometry are represented by B-rep solid models; the problem with this is that parametric information, like cross section profiles, is lost. Units of the benchmark test model with complex geometric shapes were represented by the IfcBuildingElement entity used. However, since the IfcBuildingElement entity is a high-level and abstract definition entity, used in the IFC schema as a parent for the more specific building elements (like IfcWall, IfcBeam, etc.), none of the specific properties peculiar to each building element type are carried, and so they cannot be transferred to other BIM tools and are lost in the exchange.

Table 6 Import results IFC export file from Digital Project in IFC viewer

Object	Native Object Type	Accuracy	Problems that Occurred
Unit 1	IfcBuildingElement (shell-based surface model)	Geometry OK	No object properties
Unit 2	IfcColumn (Brep Solid Model)	Geometry OK	No object properties
Unit 3	IfcBuildingElement (shell-based surface model)	Geometry OK	No object properties
Unit 4	IfcBuildingElement (shell-based surface model)	Geometry OK	No object properties
Unit 5	IfcBuildingElement (shell-based surface model)	Geometry OK	No object properties
Unit 6	IfcBeam (Brep Solid Model)	Geometry OK	No object properties
Unit 7	IfcBeam (Brep Solid Model)	Geometry OK	No object properties
Unit 8	IfcSlab (Brep Solid Model) IfcBuildingElement (shell-based surface model)	Geometry not OK	No thickness of slab Corrupted surface of stair No object properties
Unit 9	IfcBeam (Brep Solid Model)	Geometry OK	No object properties
Unit 10	IfcWall (Brep Solid Model) IfcBuildingElement (Brep Solid Model)	Geometry OK	No object properties

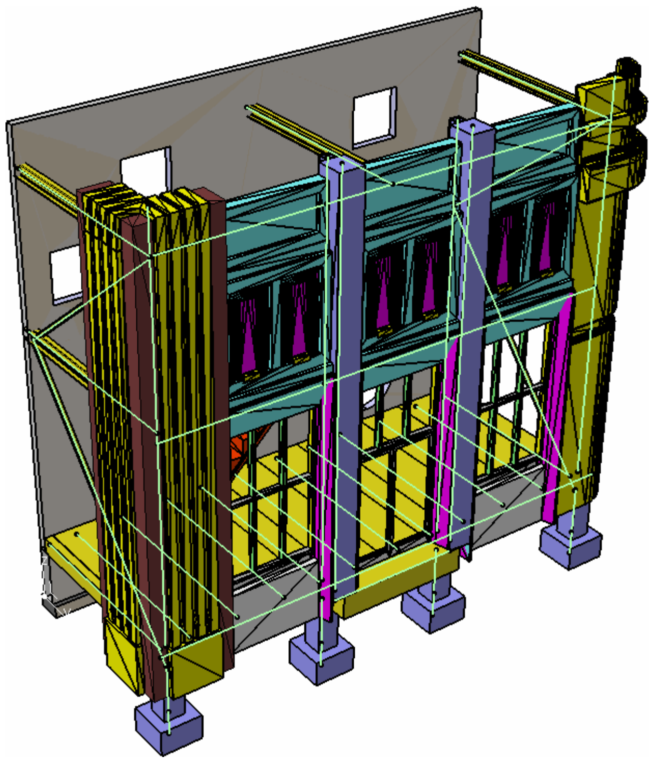
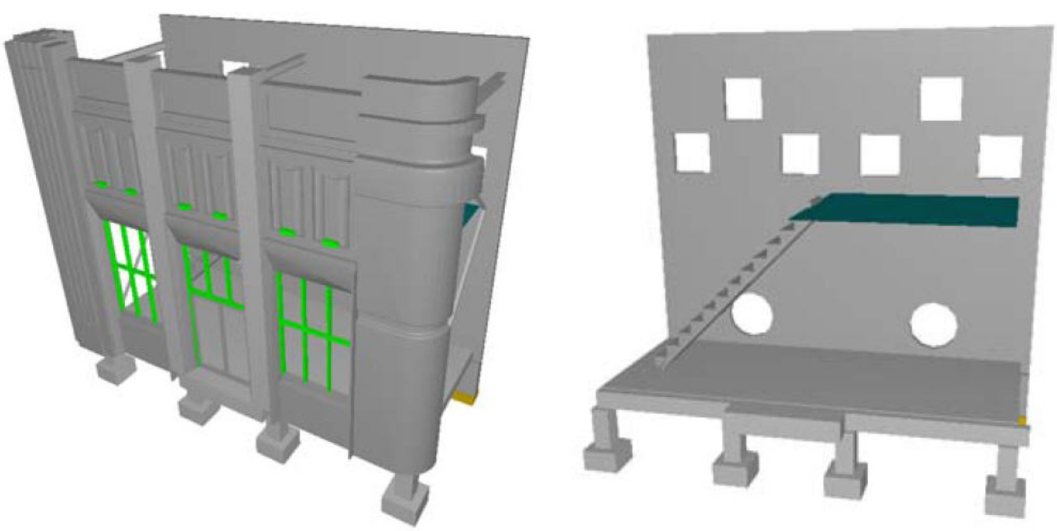


Figure 9 Modeling results in Digital Project



(a) Whole model (b) Slab

Figure 10 Visualization of Digital Project IFC export file.

Note that the slab has no thickness.

3.5. Graphisoft ArchiCAD

The ArchiCAD program supports data import and export of IFC files based on IFC 2X3. As shown in Figure 11, the modeler using ArchiCAD provided good results in preparing the benchmark test model. However, when ArchiCAD attempted to import the same exported IFC file, the program crashed. Since the native object types could not be checked on the ArchiCAD program, IFC viewers like Solibri model checker were used for checking the exported IFC data. The results showed that the IFC file which was exported from ArchiCAD had some problems, as shown in Figure 12:

- The groove feature of Unit 1 was extruded as a solid box, as can be seen in Figure 12 (a). The error occurs because it used an extrusion of a swept-based solid model to represent the geometric shape.
- The spandrel shape of Unit 3 was changed.
- The slab element of Unit 9 was lost.
- The circular hole in the wall of Unit 10 was changed into a rectangular hole, as shown in Figure 12 (c). Unit 10 was represented by an IfcWall entity and IfcRelVoidsElement entities were used to describe the opening elements. In the IFC file, the geometric shape data was represented by extrusion of a rectangular shape (a polyline) with four line elements, and so the circular shape was lost.

Table 7 Import results of the exported IFC file in an IFC viewer

Object	Native Object Type	Accurate or Not	Occurred Problems
Unit 1	IfcColumn, IfcWall, IfcBuildingElementProxy	Geometry errors	Groove is extruded.
Unit 2	IfcColumn,	Geometry OK	
Unit 3	IfcWall, IfcWindow, IfcBuildingElementProxy, IfcSlab	Geometry errors	Spandrel element
Unit 4	IfcWall, IfcDoor, IfcBuildingElementProxy, IfcSlab, IfcColumn	Geometry errors	Spandrel element
Unit 5	IfcBuildingElementProxy	Geometry OK	
Unit 6	IfcBeam	Geometry OK	
Unit 7	IfcBeam	Geometry OK	
Unit 8	IfcSlab, IfcBeam, IfcStair	Geometry OK	
Unit 9	IfcBeam	Geometry errors	Data corrupted
Unit 10	IfcWall	Geometry errors	Circular shape is changed into rectangular shape.

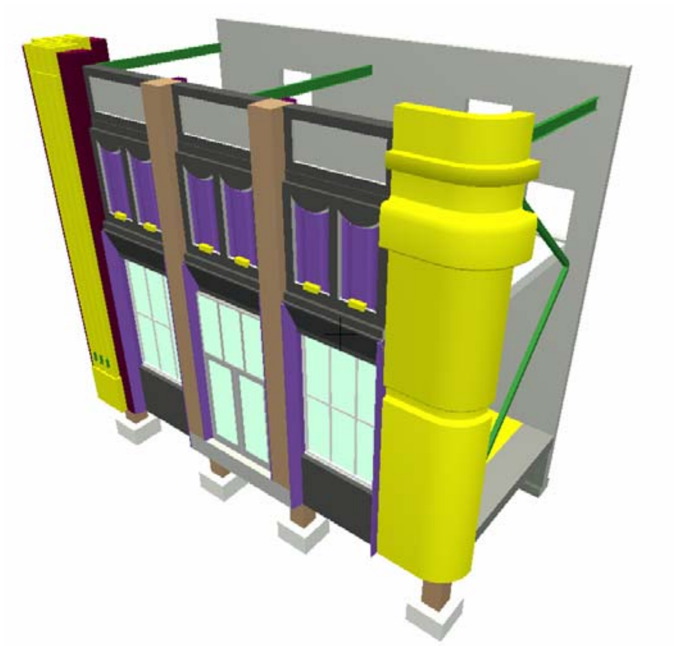
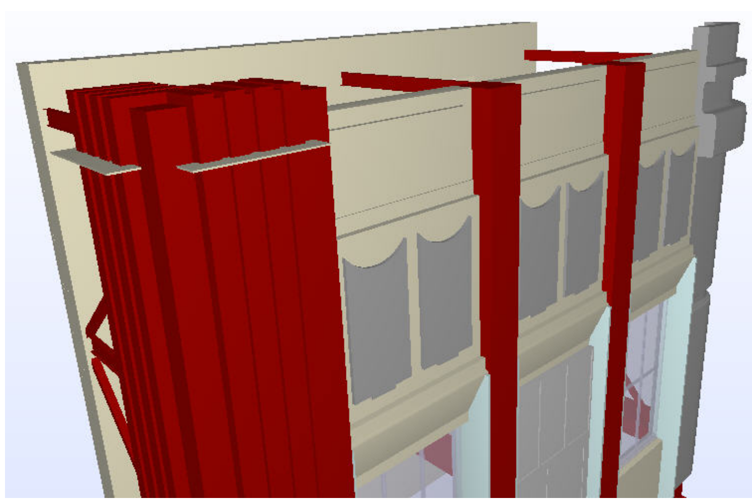
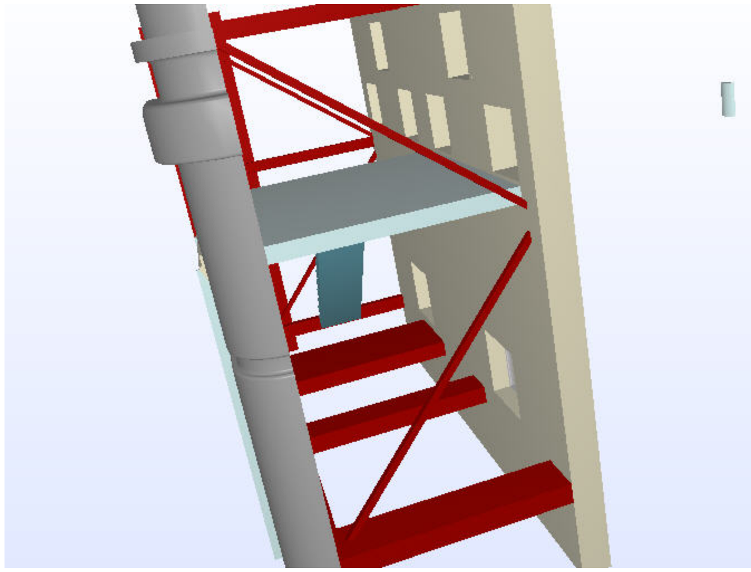


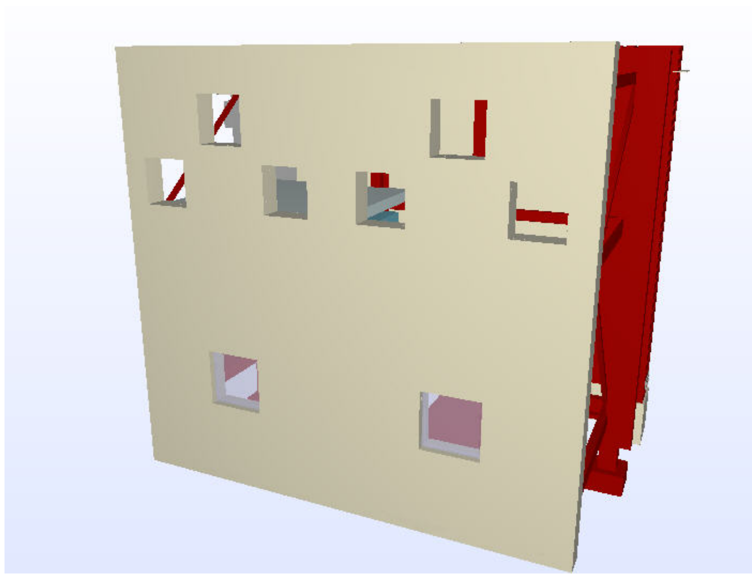
Figure 11 Modeling results in ArchiCAD



(a) Front



(b) Side



(c) Back

Figure 12 Problems found in the IFC file exported from ArchiCAD

3.6. Summary of Architectural Tool Results

3.6.1 Analysis of the IFC files exported

The benchmark test structure was modeled differently by each of the four modelers because each software package has different modeling procedures, different definitions of the native building elements, and different definitions for their export to IFC objects (i.e. each software's IFC export translator applies its own mapping between its internal objets and the IFC schema objects). As a result, different IFC entities were assigned to building members as shown in Table 8. The Table 8 shows a number of entities for representing building elements. In addition, visual results in terms of entities for building elements are shown in the Appendix A. For quick reference, the set of building elements that are supported by the IFC product model schema is shown in Figure 13.

Large disparities between the IFC export files, all of the same single benchmark model, were clearly apparent. This was true not only in the type of IFC objects used, but also in their quantity and the ways in which they were aggregated. For example, the number of objects ranged from 61 (Digital Project) to 131 (Revit Project).

Table 8 Representation of building elements in each of the BIM tools studied.

Building Element	ArchiCAD	Bentley Architecture	Digital Project	Revit Building
IfcBeam	16	9	29	18
IfcBuildingElementProxy	19	26	15	13
IfcColumn	31	4	15	5
IfcCurtainWall	-	42	-	4
IfcDoor	1	1	-	2
IfcFooting	-	15	-	-
IfcMember	-	-	-	52
IfcPlate	-	-	-	17
IfcSlab	8	9	1	10
IfcStair	1	1	-	1
IfcWall	18	3	1	9
IfcWindow	2	-	-	-
Total	96	110	61	131

A striking example is that of Unit 2 (a column on a pad foundation footing), which is one of the simplest elements in benchmark test model. Only ArchiCAD and Digital Project used IfcColumn entities to represent the Unit 2. Bentley Architecture used IfcFooting and IfcColumn, Revit Building used IfcColumn and IfcBuildingElementProxy entities (see Appendix A). This issue can be related to engineering work processes. Structural design of building elements is performed differently according to the types of members in building structures. For example, different regulations are applied to columns and footing members for structural design.

The wide disparity between the ways in which valid IFC files can be exported for the same building model strongly underlines the need for BIM standards that define which IFC objects should be used for which building elements, and how they should be related to one another, in each domain. The Part C document of this report, the Information Delivery Manual (IDM) for precast architectural facades, is a first step in this direction for the domain studied in this research.

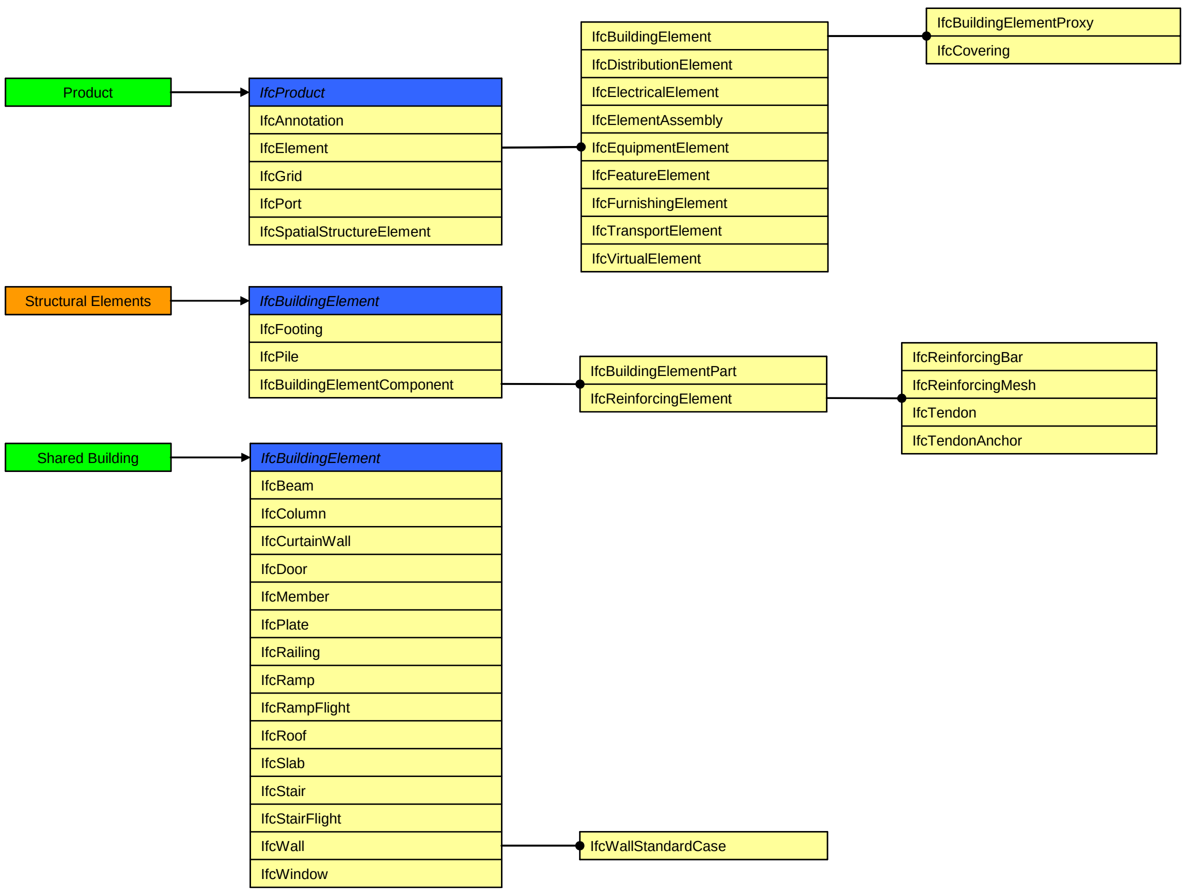


Figure 13 Hierarchical structure of building elements in IFC

3.6.2 Comparison of file sizes

Table 9 shows the sizes of the files that resulted from the modeling of the benchmark structure in each BIM tool according to data file formats. Since some of the original files included the reference DWG model for the benchmark test structure, the file sizes of the native file formats show big differences. Note also that Digital Project provides and additional format, the STP file format. STP files are based on AP 203 of ISO 10303 (ISO TC184/SC4, 1994b).

Table 9 Comparison of file size in MB

Software	Native File	IFC	DWG	SAT	Other
ArchiCAD	10.0	0.4	0.2	X	-
Bentley Architecture	0.3	0.9	0.2	2.0	-
Digital Project	11.5	8.4	15.5	X	11.5 (STP)
Revit Building	3.4	1.1	0.6	3.0	-

3.6.3 Lessons learned

This stage of the benchmark tests provided insights into two aspects, on the modeler side and on the translator side.

First of all, on the modeler side, the same architectural and structural design members were modeled with different native object types in each BIM tool. Second, the piece breakdown or aggregation structure of the building elements was modeled differently by each company. Thirdly, the geometries of the shapes used in the benchmark structure were described differently in the BIM tools, using several kinds of geometric representation methods. For example, some of the software used swept-solid (extruded) models for handling cross section profiles, while others used B-rep geometry. To be useful in a variety of other BIM software tools over a building's design and analysis life-cycle, explicit redefined cross section profiles are needed.

On the translator side, the software export translators mapped same internal geometry to different IFC objects. The geometries exported appeared to remain faithful to the internal geometric representations; this meant, for example, that where swept-solids were used in the native format, they were exported to IFC in the same way. Protocols for information delivery, such as the Information Delivery Manual (IDM) provided by the IAI, are clearly needed.

Most of the software tools tested showed good quality IFC export translator capability, but the import translators were not good.

4. Test Results for Construction BIM Tools

4.1. Introduction

This chapter provides the results of the tests performed on the import and export capabilities of two BIM tools for Group B. The two tools are Tekla Structures and Structureworks, as shown in Figure 14.

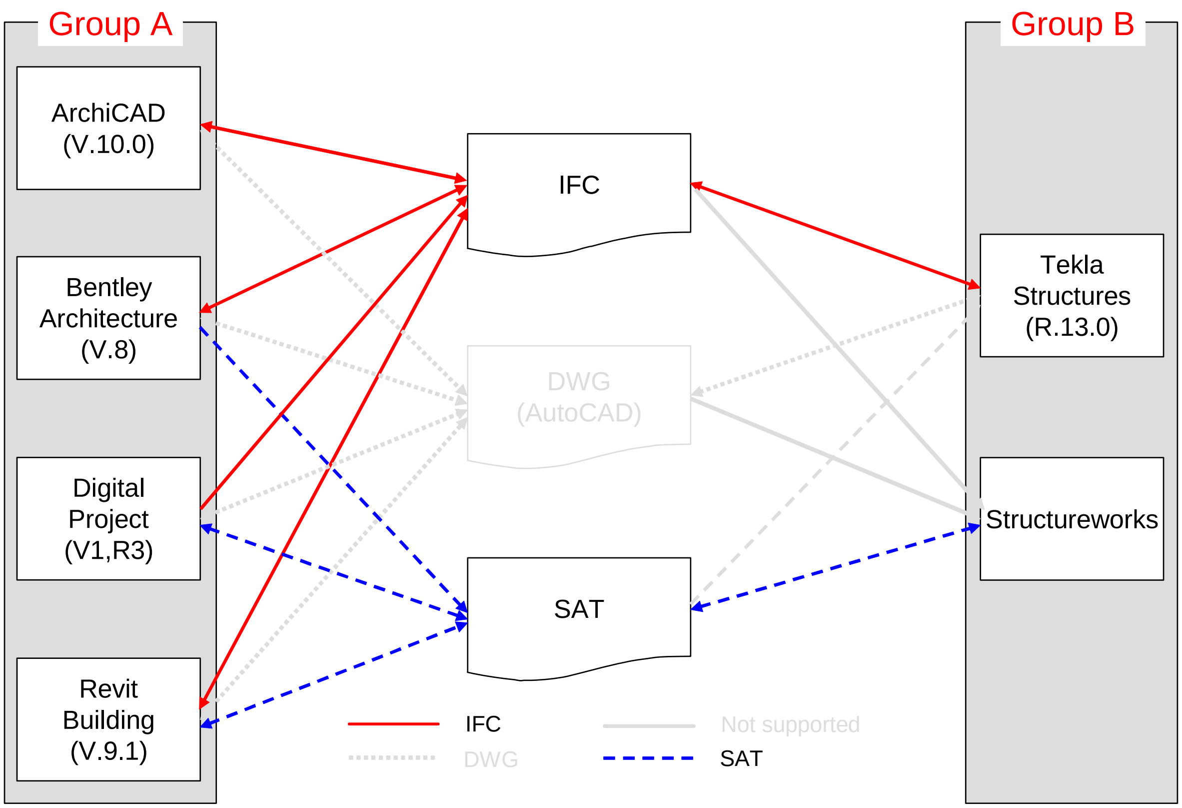


Figure 14 Experiment for testing data communication of Group B tools

These tools are used for compiling detailed fabrication level models of building structures. Tekla Structures caters to all structural systems, such as steel, precast, concrete, cast-in-place concrete, light-gage steel and timber structures; Structureworks is specifically tailored for precast concrete construction. The fundamental test performed was to check whether the data exported from the architects' models can be transferred into the fabricators' modeling software reliably and accurately.

Since only Tekla Structures provides an import function for IFC files, the IFC format could only be used for this tool. As Structureworks does not support import and export functions for IFC files, the SAT data format for representing the ACIS solid model was used for the data communication. Since the ArchiCAD program does not support the export of SAT files, no data communication between ArchiCAD and Structureworks was possible using the formats included in the benchmark tests, and so this exchange could not be tested.

4.2. Tekla Structures

Tekla Structures was tested using IFC files exported from all four of the BIM tools of Group A. The following sections describe the results obtained for each of the four. Among the other tests, each file was carefully inspected visually for discrepancies in the type or geometry of any objects. The results of this inspection are detailed in Table 10, at the end of Section 4.2. The results showed that of the 52 distinct features examined, Revit's IFC file correctly represented 50 features (or 96%), Bentley's 41 (79%), ArchiCAD's 31 (60%) and Digital Project's 11 (21%). The reference features are detailed in Appendix A.

4.2.1. IFC file import from ArchiCAD

General problems: Problems are mainly geometry related. Detailed problems are listed in the summary table (see Table 7). The file does contain several proxy objects that used to represent concrete elements. No suspicious problems were found from observation of the IFC file contents.

Conversion problems: Objects are all modeled in boundary representation method and do not use higher-level geometry representations such as swept objects. Explicit profiles such as 'I' type profile are absent - the file does not contain any 'profile name' anywhere. No conversion is possible where standard items do not appear in any IFC entity or attribute.

Visual comparison after import: see Figure 15.

4.2.2. IFC file import from Bentley Architecture

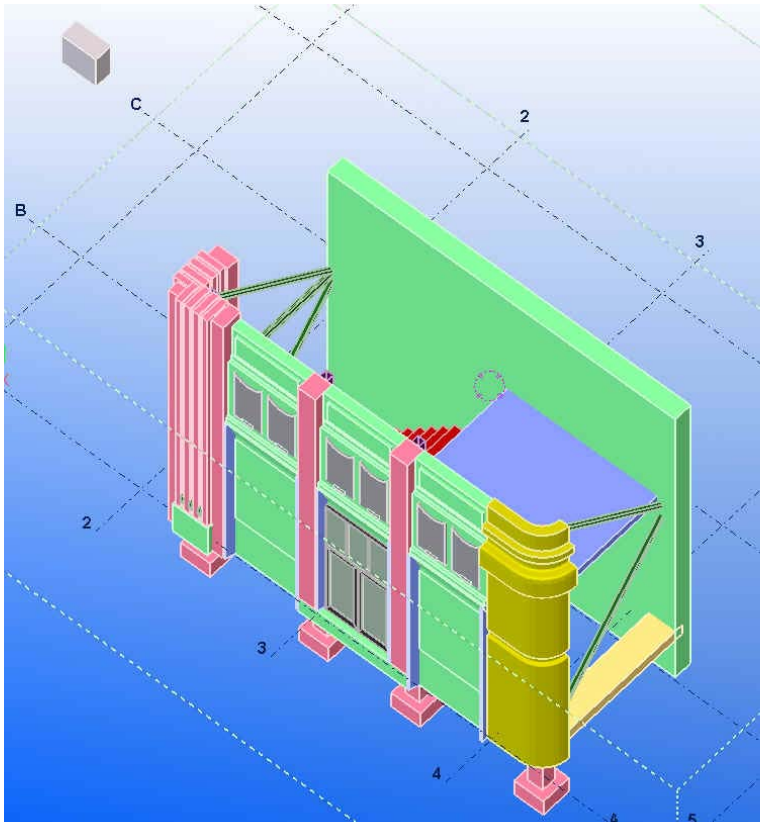
At the outset, the modeler from Bentley commented that the file exported from Bentley Architectural may not contain sufficient structural information. They recommended performing the IFC export from Bentley Structural software instead, but using the same model.

The test file from Bentley Architectural does export swept solids for walls, beams and other objects. However, no standard 'profile' name is retrievable. Others are represented in B-rep solids.

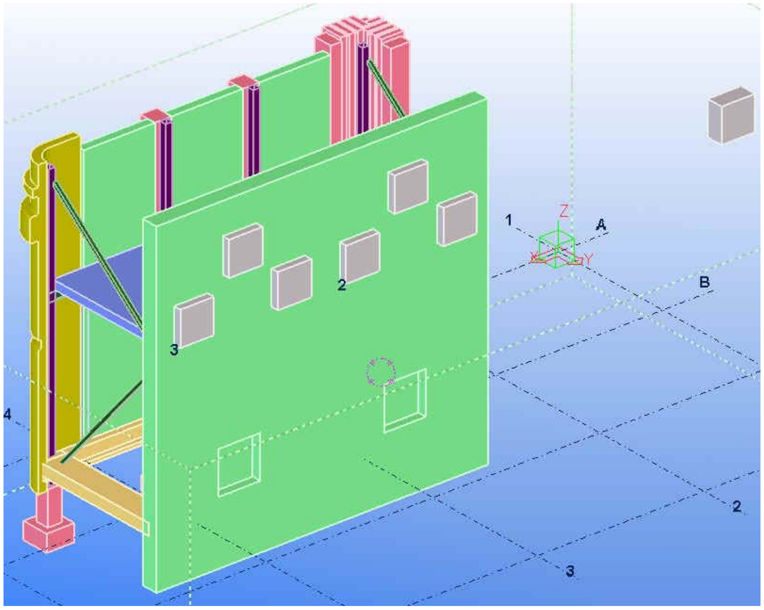
General problems: Minor problems were noted after import into Tekla Structures. These defects are reported in the summary (see Table 7).

Conversion problems: Although Bentley exports extrusions from a profile, neither the profile nor object provides indications of or references to standard profiles. Hence, no additional profile information can be retrieved for conversion.

Visual comparison after import: see Figure 16.

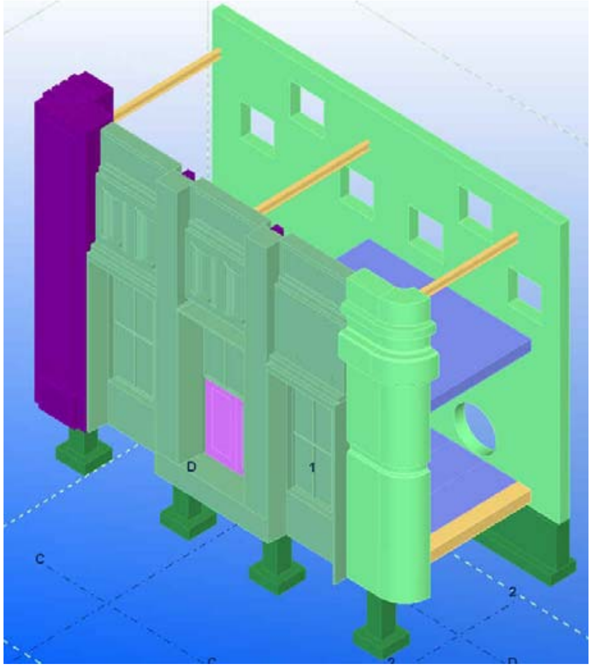


(a) Front side

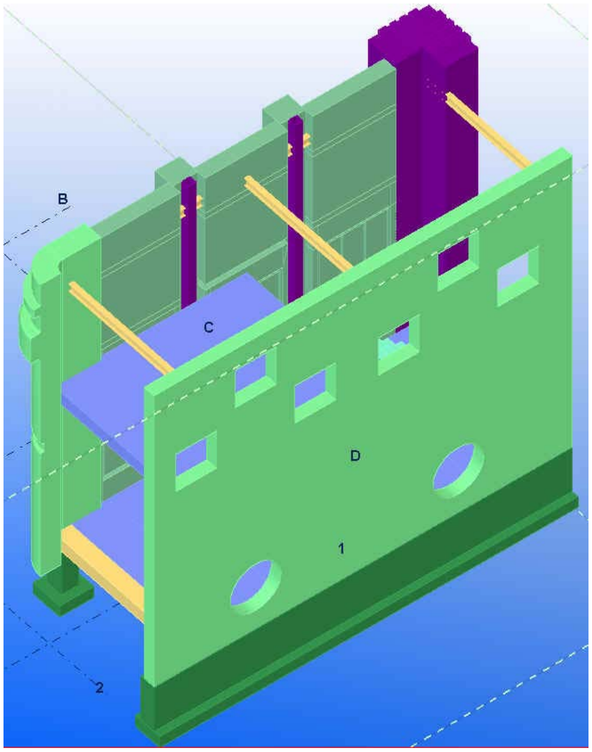


(b) Back side

Figure 15 Visual results of the IFC file imported from ArchiCAD



(a) Front side



(b) Back side

Figure 16 Visual results of the IFC file imported from Bentley Architecture

4.2.3. IFC file import from Digital Project

Several problems were found through the testing in terms of syntactical and semantic level erros in the IFC file. The file is invalid; it is IFC2x3 certified, but it violates several side agreements that are addressed in IFC Building Smart ISG agreements, especially by exporting the Bezier curve. We note, however, that several applications are already sufficienlty advanced to support reading Bezier curves as well as other B-Spline curves; for example, the file is importable and displayable in Solibri and some IFC viewers.

Orientations of a few polygons are in incorrect order. Whereas most vendors agreed to handle polygon orientation in a counterclockwise manner (to derive the normal of a face-surface), also known as 'right-hand rule', this ruloe was not maintained in the IFC export file received (this orientation agreement is for edges on faces in solid model. It does not affect shell-based exporting).

Another problem was the scaling factor, where the model looks enormously large after import. It may have been caused by the modeler who created the original model, by using incorrect units, or it may have been corrupted by the IFC export translator. The source of the error cannot be determined by examination of the exported file.

The following table shows what IFC entities are exported in the file. A few shortcomings are listed at below:

1) Low-level geometry: Most objects are modeled in B-Rep (Boundary Representation) and not extrusions (e.g. sweeping or revolving).

2) Missing objects: Windows, doors, staircases are missing from the export file. Some walls are also incorrectly exported.

Visual comparison after import: see Figure 17.

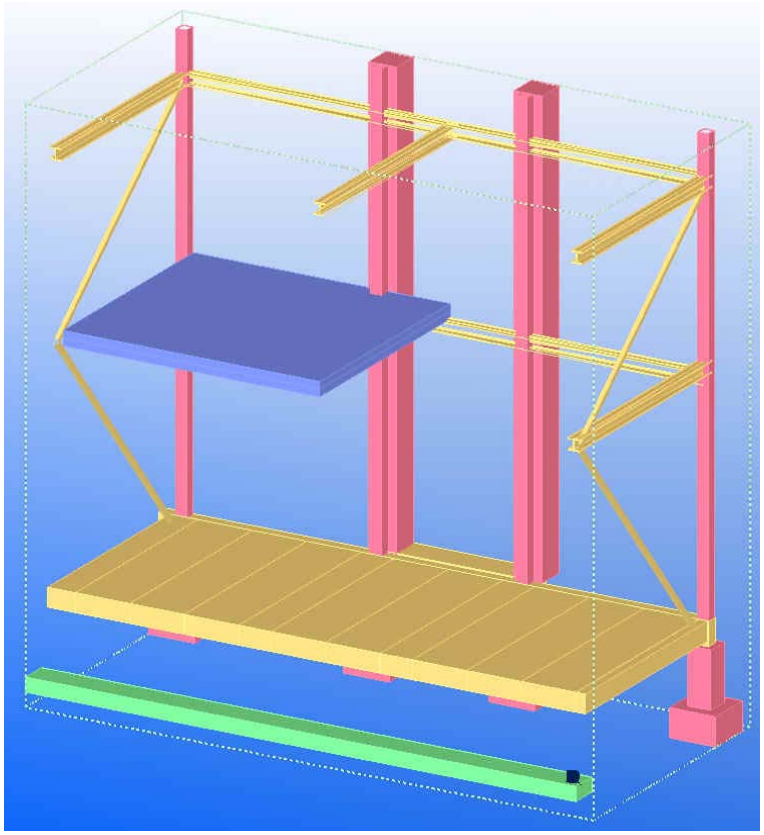


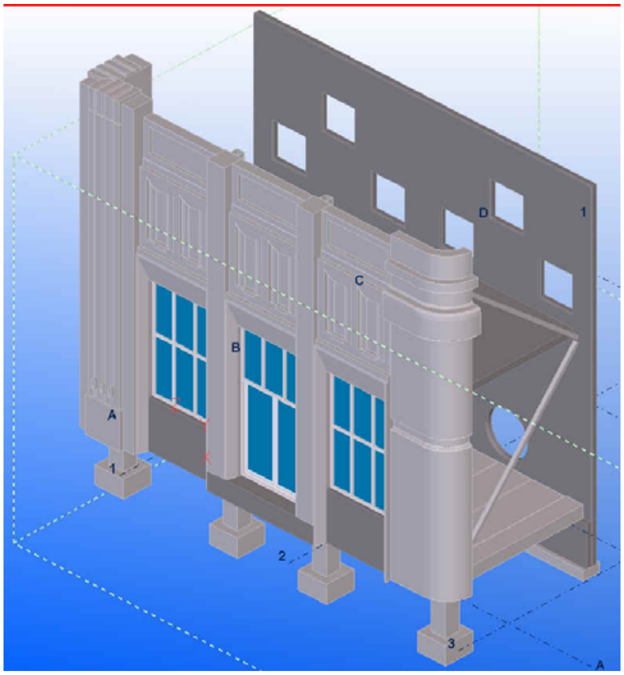
Figure 17 Visual results of the IFC file imported from Digital Project

4.2.4. IFC file import from Revit Building

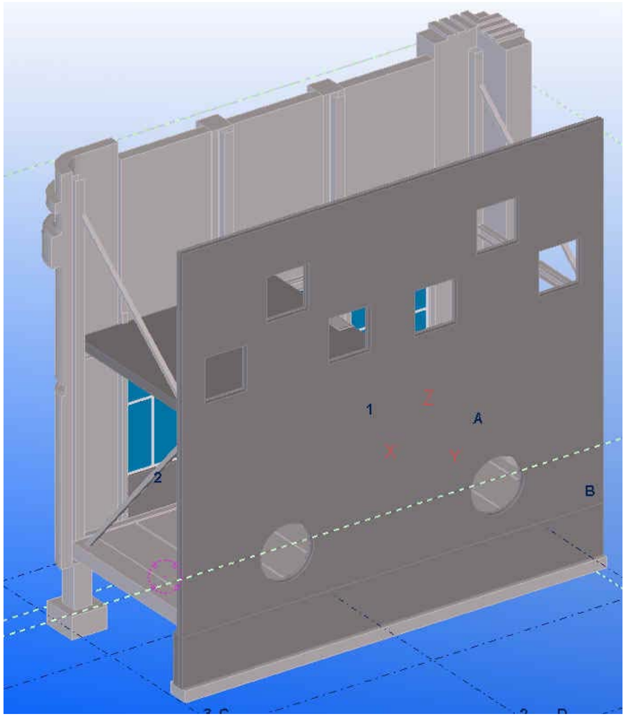
Revit files showed fewer problems than all of the other files. The result is properly displayed in Tekla Structures 13.0. One cannot conclude from this that Revit has the best IFC interface, but more likely that a better match has been achieved between Revit's export function and Tekla's import capability than is available with any of the other tools.

Revit uses both B-Rep and swept solid for geometry representation. It also uses 'mapped items', a buffer for shareable and common geometry that can be instantiated multiple times. All standard profiles do not use the explicit profiles types in IFC such as IfcITypeProfile, but generally use polylines.

Visual comparison after import: see Figure 18



(a) Front side



(b) Back side

Figure 18 Visual results of the IFC file imported from Revit Building

Table 10. Visual Comparison of IFC files imported into Tekla Structures

				Revit Building		Bentley		Digital Project		ArchiCAD	
				IFC	DWG	IFC	DWG	IFC	DWG	IFC	DWG
General	Model scale			O	O	Diff	O	X	X		O
	Default Location and offsetting					Y (global) Direction offset		X	X	X (global) Direction offset	O
Front Façade	Left corner (perpendicular)	Top	geometry	O	O	O	O	X (missing)	X	O	O
		Middle	geometry	O	O	O	O	X (missing)	X	O	O
		Bottom	geometry	O	O	O	O	X (missing)	X	O	O
		decoration	geometry	O	O	O	O	X (missing)	X	O	O
		Upper gap	geometry	O	O	O	O	X (missing)	X	X: cutting piece is not removed	O
	Right Corner (rounding)	Top	geometry	O	O	O	O	X (missing)	X	O	O
		Middle	geometry	O	O	O	O	X (missing)	X	O	O
		Bottom	geometry	O	O	O	O	X (missing)	X	O	O
	Top panels	number	geometry	O	O	O	O	X (missing)	X	O	O
		geometry	geometry	O	O	O	O	X (missing)	X	X: Not concaved	O
	Middle relief	Decorated window	geometry	O	O	Not curved, upper right missing	O	X (missing)	X	X: No curve relief	O
	Front Windows	Mullins	geometry	O	O	X Missing	O	X (missing)	X	X	O
		Jambs	geometry	O	O	O	O	X (missing)	X	O	O

				Revit Building		Bentley		Digital Project		ArchiCAD	
				IFC	DWG	IFC	DWG	IFC	DWG	IFC	DWG
		Opening	geometry	O	O	? (cannot verify)	O	X (missing)	X	X	O
		Glazing	geometry	O	O	? (cannot verify)	O	X (missing)	X	X	O
		Sill	geometry	O	O	O	O	X (missing)	X	O	O
	Front Door	Door upper windows	geometry	O	O	O	O	X (missing)	X	O	O
			position	O	O	O	O	X (missing)	X	X (causing gap between jamb)	O
		Openings	geometry	O	O	O	O	X (missing)	X	O	O
		Doors	geometry	O	O	O	O	X (missing)	X	O	O
		Door openings	geometry	O	O	O	O	X (missing)	X	O	O
		Door footing step	geometry	O	O	Gap between right jamb	O	X (missing)	X	O	O
		Door jambs	geometry	O	O	O (?)	O	X (missing)	X	O	O
	Front façade structural members	Façade Columns	geometry	O	O	O	O	O	X	O	O
			position	O	O	X	O	X	X	O	O
		Inside steel framing	geometry	O	O	O	O	X (geometry problem)	X	O	O
			position	O	O	X	O	X	X	O	O
			number	O	O	O (embed in corner columns due to the wrong position	O	X	X	O	O
		Left side steel framing	geometry	O	O	Missing Diagonal bracing	O	X (wrong size, geometry problem)	X	O	O

				Revit Building		Bentley		Digital Project		ArchiCAD	
				IFC	DWG	IFC	DWG	IFC	DWG	IFC	DWG
		Right side steel framing	geometry	O	O	Missing diagonal bracing	O	X (wrong size, geometry problem)	X	O	O
Back Wall	Back side concrete wall	Upper rectangular openings	number	O	O	O	O	X (missing)	X	X (no openings)	O
			geometry	O	O	O	O	X (missing)	X	X	O
		Lower circular openings	number	O	O	O	O	X (missing)	X	X (no openings)	O
			geometry	O	O	O	O	X (missing)	X	X	O
		Wall footing	number	O	O	O	O	O	X	X (not shown, possibly embedded in wall	O
			geometry	O	O	O	O	O	X	X	O
		Wall basis	geometry	O	O	O	O	X (missing)	X	X	O
Slabs	Slabs and floors	lower slab	number	O	O	O	O	O	X	X	O
			geometry	O	O	O	O	O	X	X	O
		upper slab	geometry	O	O	O	O	O	X	O	O
		slab beams	geometry	O	O	O	O	O	X	O	O
			number	O	O	O	O	O	X	O	O
			position	O	O	O	O	O	X	O	O
	Stair	steps	number	O	O	O	O	X (missing)	X	O	O
		landing position	geometry	? (Last step merges into slab)	? (Last step merges into slab)	?	? (Last step merges into slab)	X (missing)	X	?	? (Last step merges into slab)
			Position	? (Toward front)	? (Toward front)	?	? (Toward front)	X (missing)	X	?	? (Toward front)

				Revit Building		Bentley		Digital Project		ArchiCAD	
				IFC	DWG	IFC	DWG	IFC	DWG	IFC	DWG
Foundations	Footing and foundation	Columns footing	number	O	O	O	O	X (missing)	X	O	O
			geometry	O	O	O	O	X (missing)	X	O	O
		Wall footing	number	O	O	O	O	O	O	X	O
			geometry	O	O	O	O	O	O	X	O
SUMMRAY	Correct Features			**50/52** **96%**		**41/52** **79%**		**11/52** **20%**		**31/52** **60%**	

4.3. Structureworks

4.3.1. Overview

Structureworks does not support IFC exchange. As an alternative, the SAT and STEP file format was used as an alternative, although it is limited to geometry exchanges alone – it offers no facility for exchange of logical object data or topological relationships. Due to the absence of an SAT file export function in ArchiCAD, only the other three BIM tools from Group A could be used (Bentley Architecture, Revit Building and Digital Project).

Due to the nature of the SAT files, the geometric shape elements, such as surfaces and solids, that appear in the files exported from the BIM tools are not combined into the proper logical architectural panels. They must be combined 'manually' after the files are converted into Structureworks. Thus, any corrupted surface and solid data must be fixed in Structureworks. Only after fixing problems related to the geometric shape data, can modeling of detailed design members for fabrication be performed.

Also, since data which is transferred from other programs is defined slightly differently by different modelers, design members must be grouped for the fabrication process. For example, precast fabricators can assign reinforcing members such as embeds and reinforcing bars to the grouped members. Grouping of design members is called "panelization". Structureworks provides automatic generation of 2D drawings for fabrication based on the grouped members. Figure 19 shows the results of data import into Structureworks from the SAT files generated from the BIM tools of Group A (except ArchiCAD).

4.3.2 SAT file import from Bentley Architecture

The SAT file from Bentley Architecture is imported by Structureworks without missing geometric shape data. The benchmark test model is restored and composed of 133 part files as shown in Figure 19. Since all the geometric shapes are represented by solid bodies, units for fabrication and construction can be defined through assembling the parts directly.

Correct geometry around the corner of the panels is obtained and they are panelized into two parts which can be combined into an assembly to display, like the Revit file (see **Error! Reference source not found.**).

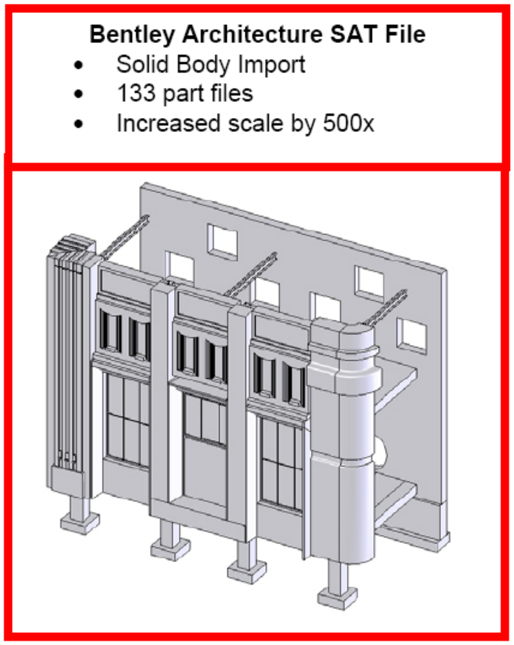


Figure 19 Import of the SAT file from Bentley Architecture into Structureworks

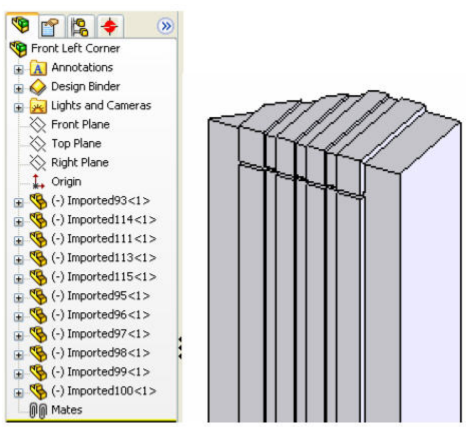


Figure 20 Corrupted geometric shape data from Bentley Architecture

Correct geometry was obtained around the right front corner and the piece was panelized into two parts which could be combined into an assembly to display the same as the Revit file.

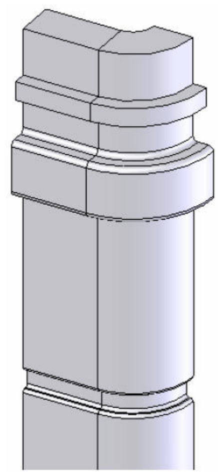


Figure 21 Incorrect geometry of Unit 5 in Bentley Architecture

4.3.3 SAT file import from Revit Building

The SAT file from Revit Building has some surface bodies where errors are occurred in the geometric shapes during file import as shown in Figure 22. Thus, surface bodies corrupted are fixed on Structureworks which allows end-users to easily modify geometric shapes.

The left front corner area is missing multiple surfaces shown in Figure 23(a). Surfaces had to be filled in with SolidWorks surface lofts and planar surface features. Once the surfaces were filled in and turned into solids, the panels were then panelized correctly (see Figure 23 (b)).

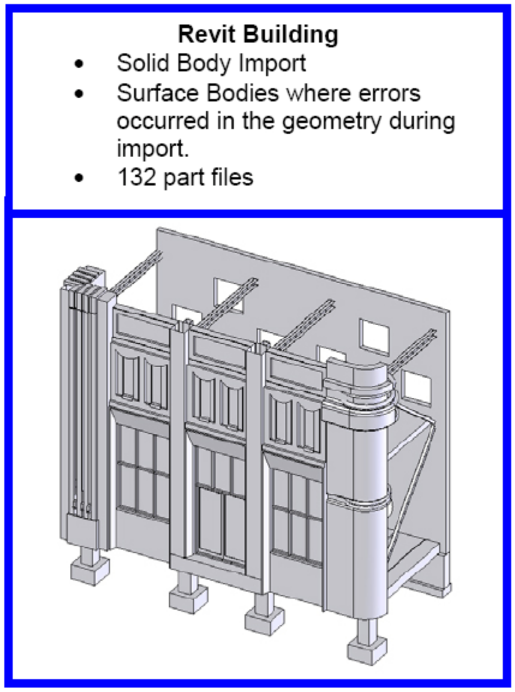
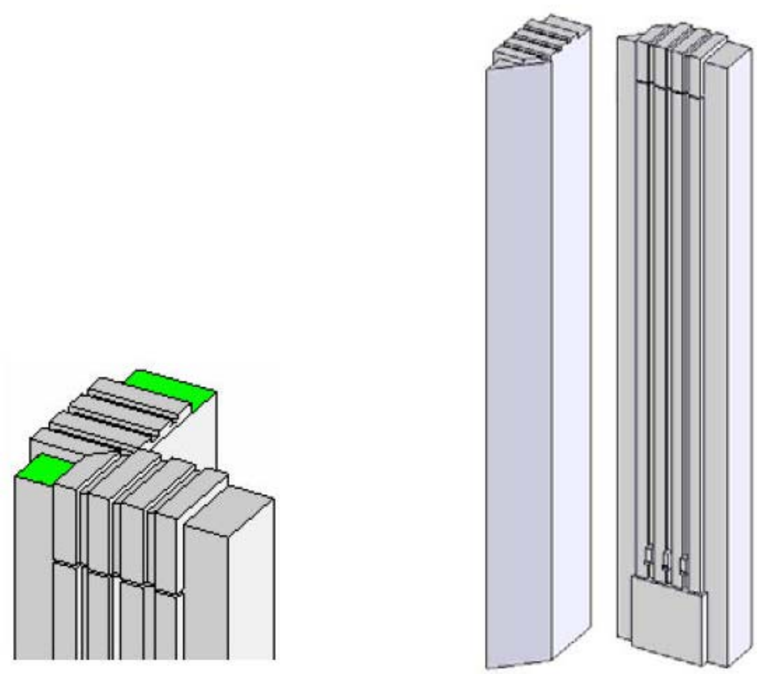


Figure 22 Import of the SAT file from Revit Building into Structureworks



(a) (b)

Figure 23 Corrupted geometric shape data from Revit Building

The interior fillets on the right front corner did not import correctly. Therefore, the panel was not split into two panels as during the Bentley import. Surfaces had to be filled in, turned into solids and panelized. After panelizing the part the two bodies that existed could be saved off as their own part files to have two independent panels.

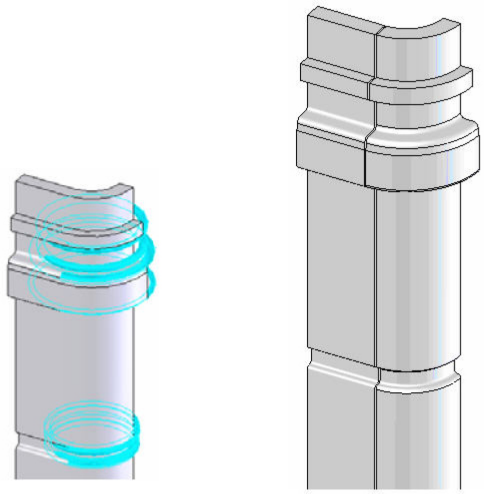


Figure 24 Incorrect geometry of Unit 5 in Revit Building

4.3.4 STEP file import from Digital Project

Digital Project does not support export of SAT format files. Instead, the STEP file format with data structures of AP 203 in ISO 10303 was used for data communication checking. The STEP file from Digital Project was imported on the level of solid body and surface body. Multiple surface errors occurred during the file import. The whole shapes are composed of just three part files. Each part file with many bodies had to be decomposed into several parts files for panelization.

The left front corner area was missing multiple surfaces and was faceted into multiple faces when not necessary, causing the knitting of the surfaces into a solid(s) to fail (see Figure 26 (a)). In the same way as occurred with the SAT file generated from Revit Building, the surfaces had to be filled in with SolidWorks surface lofts and planar surface features. Once the surfaces were filled in and turned into solids, the panels could then be panelized correctly (see Figure 26 (b)).

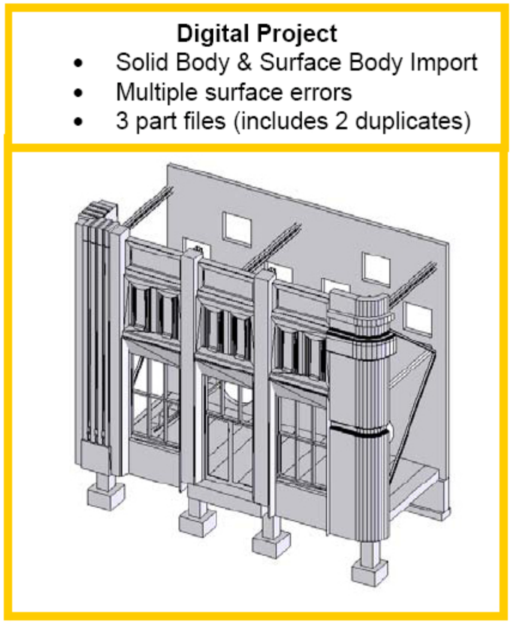


Figure 25 Import of the SAT file from Digital Project into Structureworks

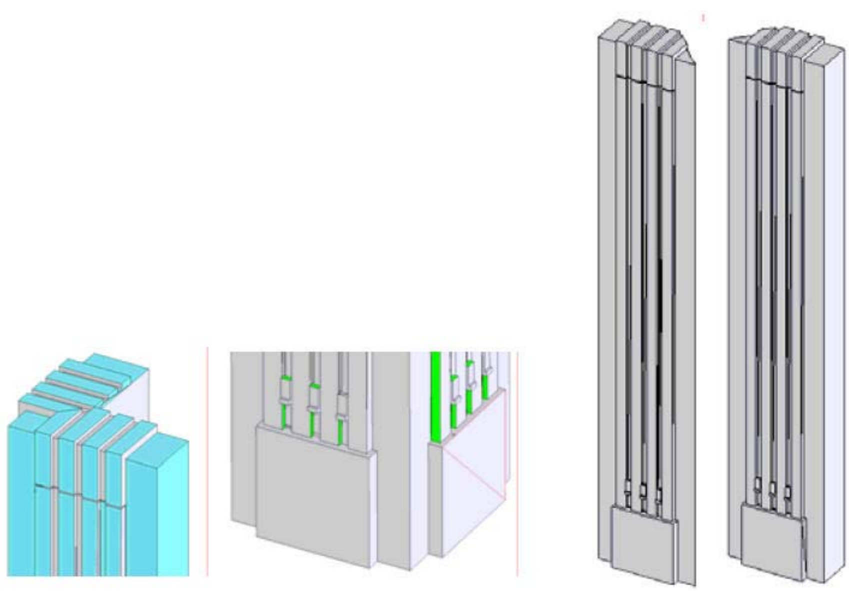


Figure 26 Corrupted geometric shape data from Digital Project

The interior fillet of the right front part was brought in with multiple surfaces. Therefore, the panel was not split into two panels as during the Bentley import. Surfaces had to be filled in, turned into solids and panelized. After panelizing the part the two bodies that existed could be saved off as their own part files to have two independent panels.

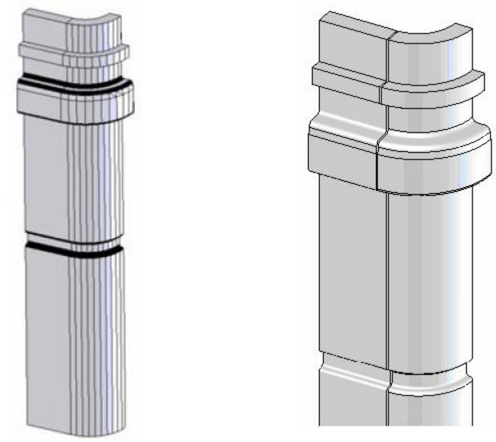


Figure 27 Incorrect geometry of Unit 5 in Digital Project

4.3.5. General observations – body grouping

For the architectural detail area – the bodies had to be grouped together specifically for proper panelization, which is not difficult but is time consuming. It is repeatable for each file type. For example, the image below (Figure 28) was comprised of five bodies, grouped together in order to turn them into a product.

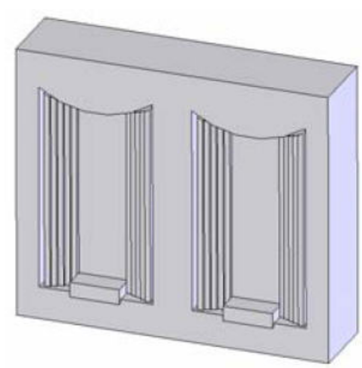


Figure 28 Body grouping of Unit 3

If the bodies were grouped in the original software from which the export was made, then they would be imported as one rather than five in this example. A large amount of time is consumed in combining bodies (parts from the export) into the proper panels. Below (Figure 29) the bodies are separate rather than grouped. Figure 30 shows a fabrication 2D drawing generated for the piece.

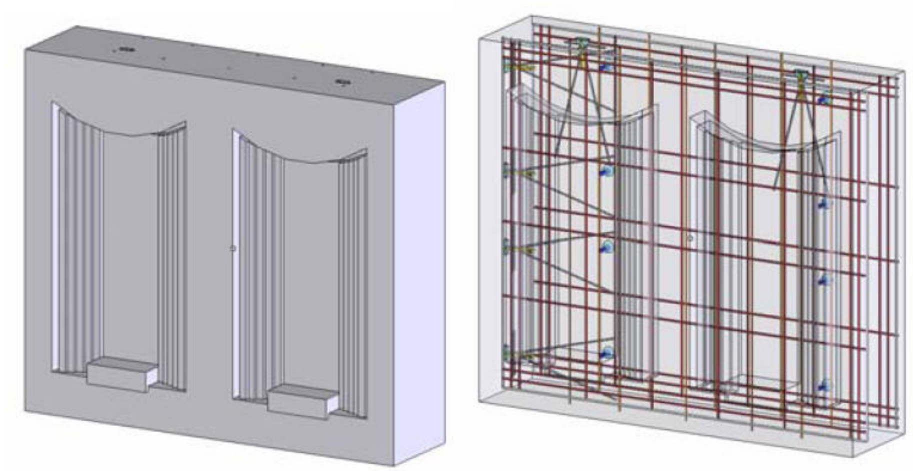


Figure 29 Finished pieces for precast fabrication

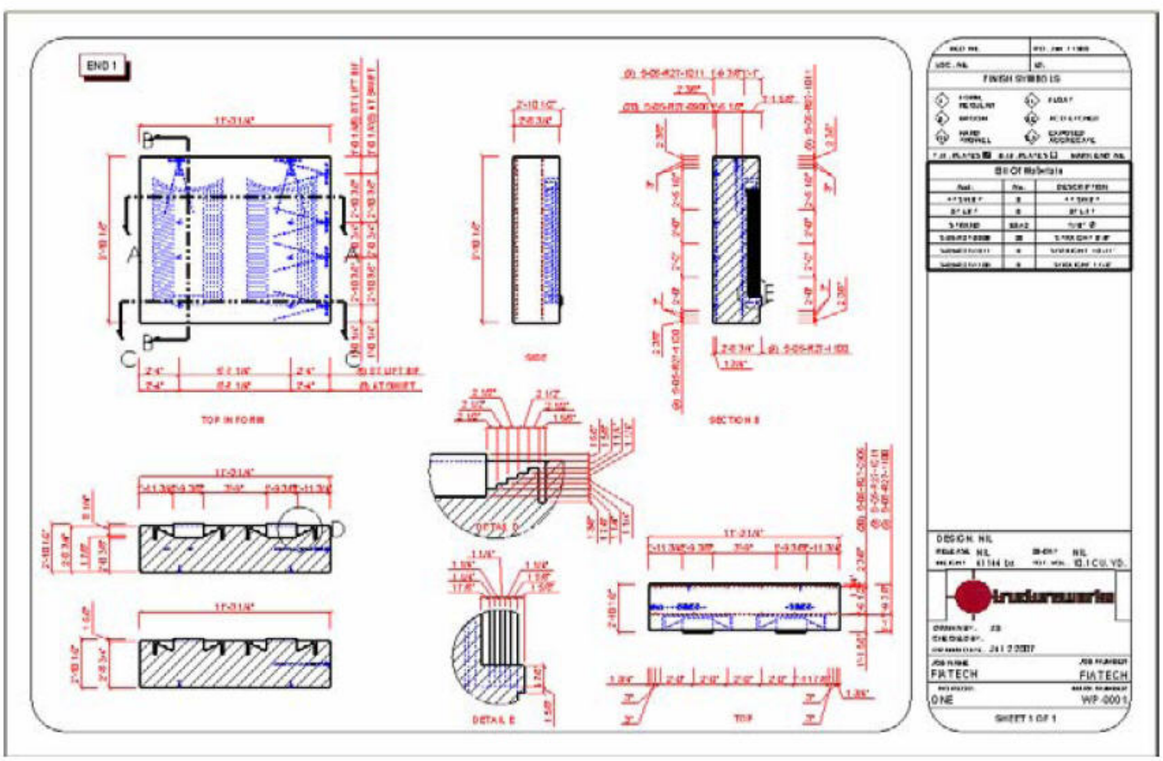


Figure 30 2D drawings automatically generated

5. Concluding Remarks

The benchmark tests were designed to explore the state-of-the-art of interoperability for exchange of building model data between architects and engineers, with special focus on the domain of precast concrete architectural facades. The benchmark building model contained structural components made of steel, cast-in-place concrete, precast and prestressed concrete. The pieces used incorporated a variety of complex geometric features designed to test the reliability of exchange of convex and concave curved surfaces, reveals and openings, which are common in architectural precast.

The results of the tests were evaluated at two levels:

a) exchange of geometry
b) exchange of semantically meaningful information

Numerous limitations were found at both levels. None of the exchanges were able to carry all of the geometry completely accurately, whether due to failing in the export functions from the architectural BIM tools or the import functions into the precast fabrication BIM tools. The results for the object data exchanges were limited to those for the architectural BIM tools to Tekla Structures, since Structureworks lacks an IFC import function. Here too, the exchanges were found to be imperfect, with most problems arising from the lack of uniformity in the way the internal object schemas were mapped to IFC objects and properties.

Because of the lack of semantically defined objects within both the architectural BIM tools and also within the IFC exchange schema, the tests showed clearly the need for a mutually agreed upon standard that defines how precast architectural facades should be modeled and mapped to the IFC schema. Such definition is essential for coherent interoperability for this (and indeed any) domain. This goes beyond the definition of use cases, as reviewed in Part A, in that the objects needed for the definition of an architectural precast view have not been adequately defined within the IFC and will have to be added to the platform.

The tests used IFC, DWG and SAT file formats. The study confirms that the IFC format is the only candidate for exchange of both geometry and semantically meaningful information. However, much remains to be improved before everyday production work can be practical. The two immediate steps needed are:

- Establishment of a standard for the exchange, including an Information Delivery Manual (IDM) and guidelines for modeling practice within the BIM tools. A proposed draft for such an information delivery manual has been developed as part of this project, and is provided in document Part C delivered with this report. It is intended to form the cornerstone of the BIMS for architectural precast.
- Specification of architectural precast concrete objects within the IFC standard, that clearly package objects, relations and attributes needed for this type of product.
- Implementation of robust IFC export and import functions in all of the BIM tools, in conformance with the NBIM standard. In particular, they should employ swept solid representations (discussed below).

Table 11 summarizes the status of possible exchanges between all four architectural tools and the two precast tools that were tested. Each cell details the status of the exchange of geometry and object data respectively.

The sections that follow the table outline some detailed observations concerning the exchanges. They also provide some background to the issues discussed.

Table 11. Summary of existing exchange capabilities for architectural precast facades.

Precast / Architectural	Tekla Structures v13	Structureworks
Revit Building v9.1	IFC bi-directional, geometry and object data. Geometry exchanged accurately (Table 10: 96%). Almost all objects recognized; some footing and bracing elements are represented as 'proxy'[1] elements.	SAT Geometry only
ArchiCAD v10.0	IFC bi-directional, geometry and object data. Geometry exchanged with numerous errors (Table 10: 60%). Standard structural objects recognized, but façade elements are represented as 'proxy' and 'wall' elements.	None
Digital Project v1 R3	IFC export only, geometry and object data. Geometry exchange was inaccurate (Table 10: 20%). Most geometry data was represented by 2D surface elements. The elements were not recognized by the Tekla Structures import functions. Most elements were represented as 'proxy' elements.	SAT Geometry only
Bentley Architecture v8	IFC bi-directional, geometry and object data. Geometry exchanged fairly accurately (Table 10: 79%). Standard structural objects recognized; façade elements are represented as 'curtain wall' elements. This represents better modeling practice than 'proxy' elements.	SAT Geometry only

[1] 'Proxy' elements (IfcBuildingElementProxy) are used in IFC files where the exporting software does not identify (or 'map' to) an IFC object appropriate for their internal object. There are three possible reasons: 1) the part is modeled in the native application as an amorphous 'mass element' which is not defined as any specific building part; 2) the IFC schema does not have an appropriate object that corresponds logically to the native internal building object (e.g. no 'prestress strand' object); 3) erroneous programming or mapping of the translator. The figures in Appendix 1 show that in Revit and Bentley, the first reason is applicable (e.g. the modeler used proxy elements instead of footing or column elements). In the case of ArchiCAD, complex geometry of the façade panels appears to have led the modeler to use mass elements instead of curtain wall or wall objects. In Digital Project, all walls and facades were delivered in this way.

5.1. Data Communication Using IFC File

Geometric 3D solid shapes in IFC can be represented by CSG (Constructive Solid Geometry), by B-rep (Boundary Representation), or by swept solids as shown in **Error! Reference source not found.**. Most of the BIM tools support B-rep and swept solid data for the representation of building members. All combinations of these representations are used in modern BIM design tools.

5.1.1. B-Rep and Swept Solid

B-Rep, which stands for Boundary Representation, is one of the most common representations for solids. It is known as an 'evaluated' representation. Evaluated representation means that both swept solids and CSG compositions can be evaluated into a corresponding B-Rep. B-Rep is used almost exclusively for display, evaluating mass properties and other analyses of 3D shapes. Unfortunately, once evaluated, there are very few editing operations that can be applied to it. The geometry is presented faces, edges and vertices and the topological relations that connects ('binds') those entities together to represent a solid.

Swept- solids are basically a profile swept along a curve or line. That is, an area feature is swept by moving a primitive along a path to form a solid feature. Profiles are easily defined and edited and are the most basic shape representation in modern BIM tools. Profiles are used in all the BIM design tools for representing most building elements.

CSG is the third type of solid representation. It allows a shape to be derived from a sequence of union, subtraction and intersection operations on shapes. The shapes may be swept solids, B-reps or predefined primitives. While similar at a high level, there are many detailed variations, providing different editing functionality in each of the BIM design tools.

Because of its generality, most shape exports in IFC use the B-Rep. It almost guarantees that is can be imported into another system. However, the side effect is that the shapes normally imported are hardly editable. As a result, if editing on the importing system is necessary, the parts have to be re-defined - essentially copied – in the importing system. This makes exchanges slow and requires much manual entry.

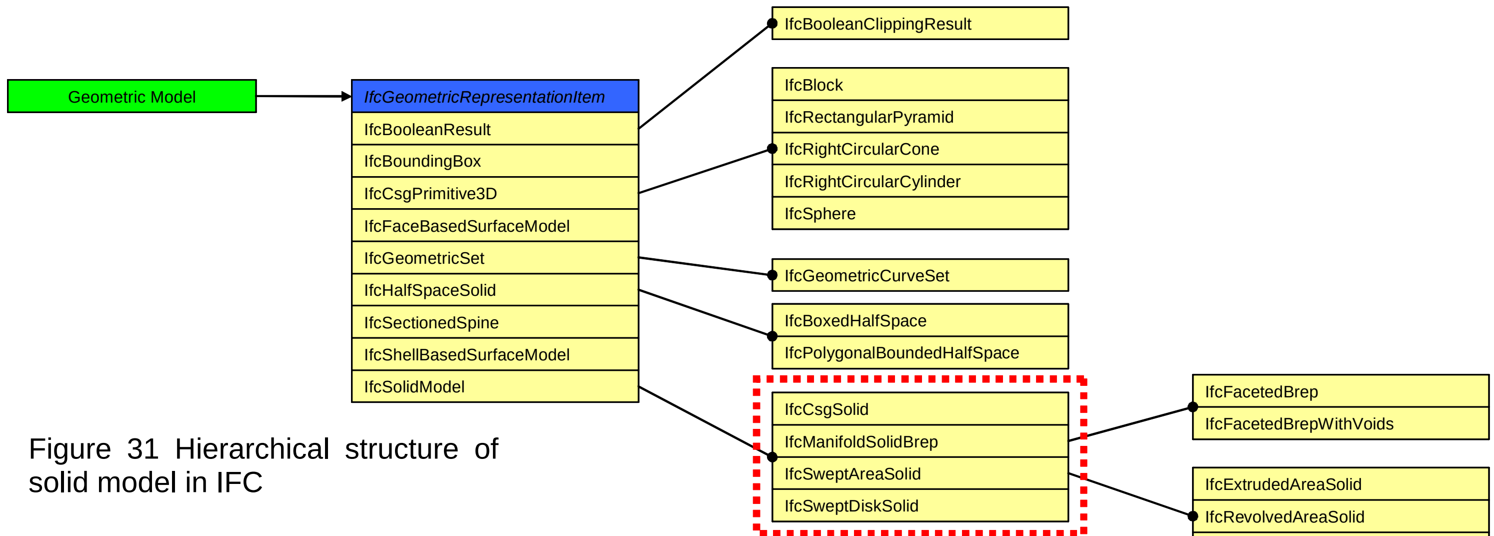


Figure 31 Hierarchical structure of solid model in IFC

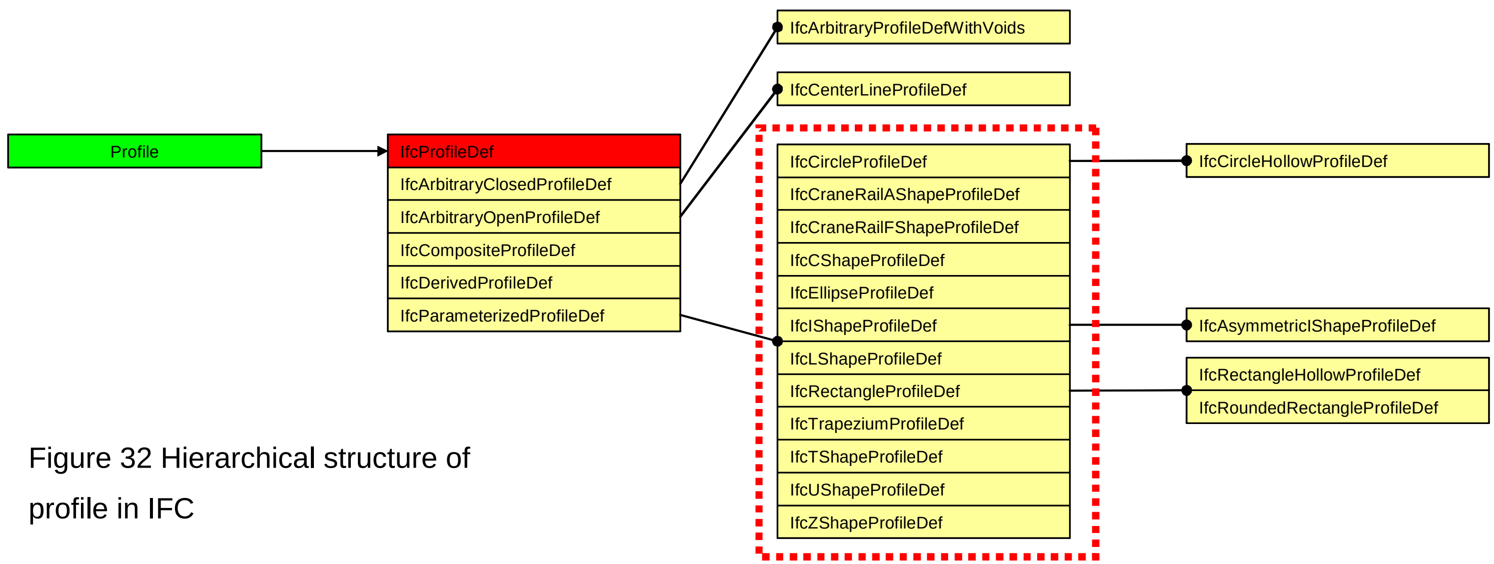


Figure 32 Hierarchical structure of profile in IFC

The main implication is to encourage all BIM vendors to use higher-level or dual geometric representations.

5.2. Data Communication Using SAT File

We also tested DXF and SAT file formats for exchange. DXF allows the import of editable geometry into AutoCAD and non-editable geometry into all BIM design tools, including Revit. However, SAT is more interesting.

SAT files are direct exports and imports of geometry from those BIM design tools that use the ACIS geometrical modeling package. ACIS, developed by the Spatial Corporation, is a geometrical modeling library used in the majority of BIM and solid modeling tools. SAT is able to represent complex geometry since the ACIS kernel supports most geometry types. Extrusions are exported and can be imported as extrusions, CSG sequences of operations can be exchanged.

Upon testing of SAT file exchange, it was found that Revit, Bentley and Digital Project were able to export SAT files that could be read by Structureworks. These exchanges had errors, but the import file was largely directly editable within the receiving application. This capability is potentially important, i.e. the direct exchange of geometry in an editable form.

Table 12 Number of geometric elements in SAT files

Element Type	Bentley Architecture	Revit Building
Segment	759	393
Shell	130	131
Triangle	6,470	9,456
Vertex	8,174	11,131

The shortcoming of SAT is that it is not an object based file and therefore cannot carry a unique ID for objects. In addition, since the SAT files that are exported from various BIM tools have different assemblies of part geometries, the parts' geometries have to be reorganized, for example, in order to build the benchmark test model.

This experience with the SAT files suggests that editable geometric models can be exchange in IFC. IFC supports representation of B-reps, Swept solids and CSG solids. If care is taken in the matching of geometry types, it seems very likely that IFC can support the exchange of editable models, possibly only requiring minor edits before continuing.

5.3. Other Issues

Both the benchmark tests and the Rosewood experiment (Part A of the Pankow project report) showed that **the piece extents for the fabrication model were different from**

those in the architectural model. This reflects different approaches to panelization of the facades. The result is that the actual piece geometries exchanged, even if they were intelligent shapes (carrying object data and composed of swept solids, as discussed above), do not have one-to-one correspondence with objects in the receiving application. This aspect of data exchange must be considered in an information delivery manual (IDM). An IDM defines what information is required at the different life-cycle stages and for each working area (architectural side and precast fabrication side). Precast panels exchanged should be related by globally unique identifier (GUID) tags that are managed between the two sides, and are the outcome of consultation concerning the panelization during design. Ideally, such management should be transparent to the users.

Some complex geometric shapes with Bezier and B-spline curves and surfaces can be lost because of lack of coverage of the IFC model schema. The implementers of the IFC chose not to include complex curved surfaces, because many of the BIM tools cannot support them and because only a few technologies, such as milling can fabricate them. As growing numbers of architects begin using systems with Spline Bezier surfaces, the pressure to deal with these types of surfaces in objects will also increase.

Standard parametric cross-section profiles should be exchanged by name. Standard profile catalogs exist for steel, piping and other structural elements. Thus, BIM tools can support reference to the catalogs which are predefined by each field. This allows definition of the profile from its name, instead of sending over all the data needed to create it. The catalogs should include not only parametric data but also geometric shape data. Through this approach, end-users can select profiles from the predefined catalogs and then, each BIM tool can provide modeling functions to support profiles from catalogs. For custom objects like precast concrete, standard profiles can be provided at the project level. This capability exists in IFC, but has not been effectively implemented. That is, only a few systems have implemented it, and often use their own naming schemes.

Precast practice places important constraints on the way in which precast facades should be modeled within the architectural and the fabrication BIM tools:

- Proper allocation of objects to parts is an important fabrication issue during fabrication modeling.
- Correct panelization is important, but will vary for each different precast fabricator; it depends on the production equipment available to the precast company.
- There is a need for further automation in the checking of design intent and validation of geometric shape data.
- Global process structures vary greatly from project to project.

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European Conference on Product Data Technology, 39-46.

Appendix 1: Visualization in Terms of IFC Entities

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	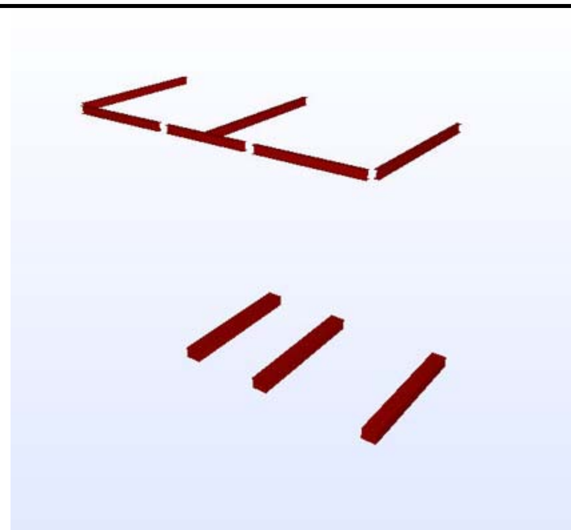
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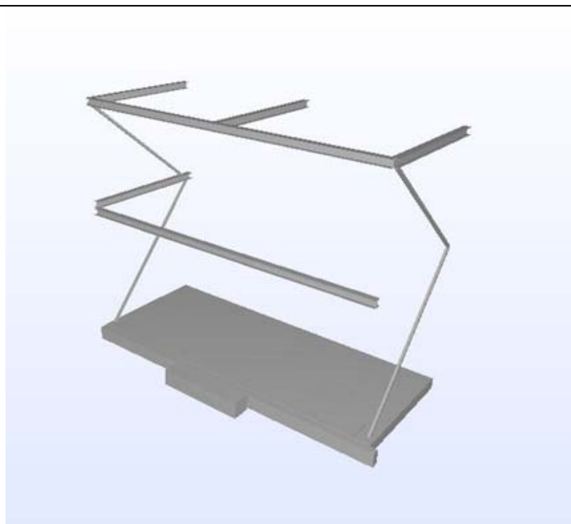	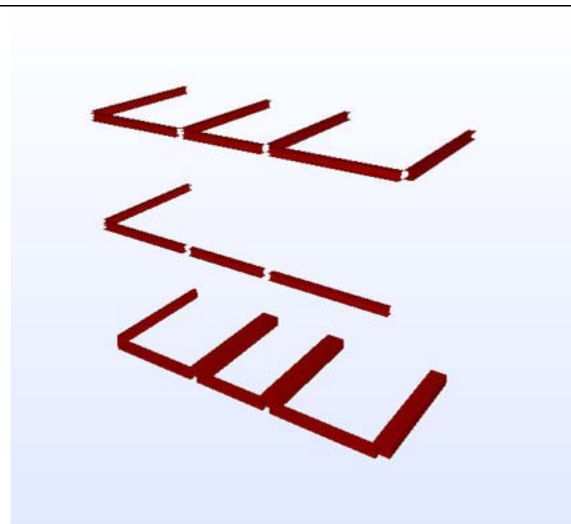
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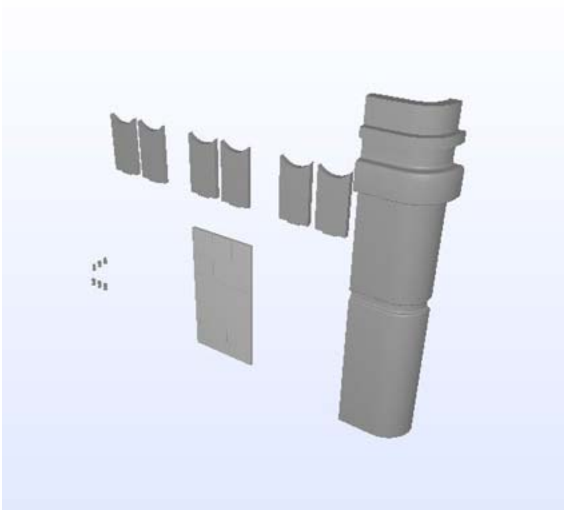	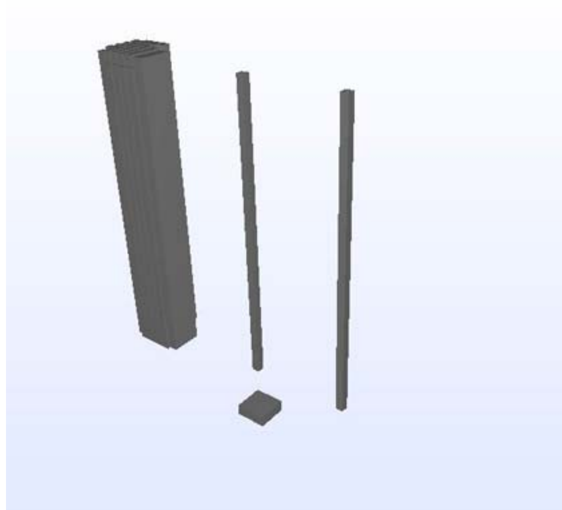
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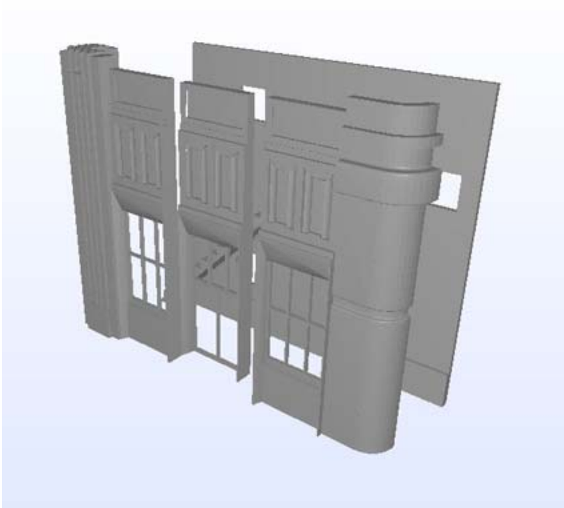	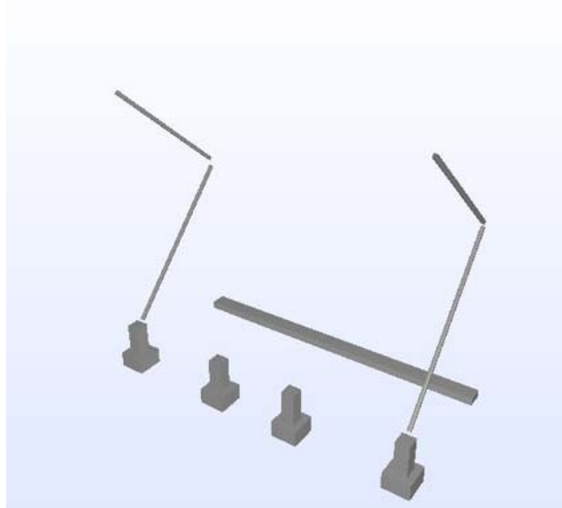
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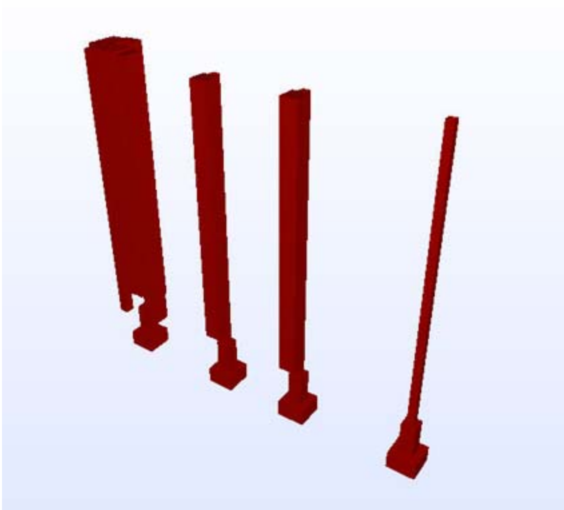	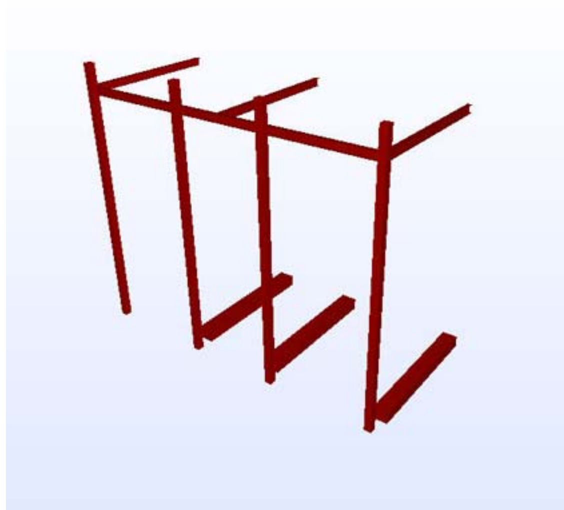
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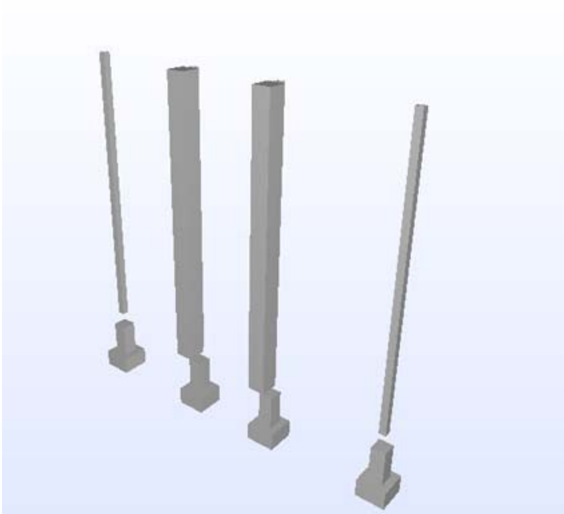	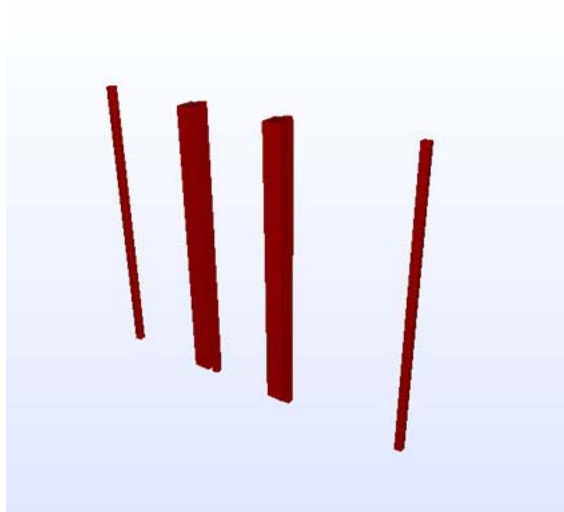
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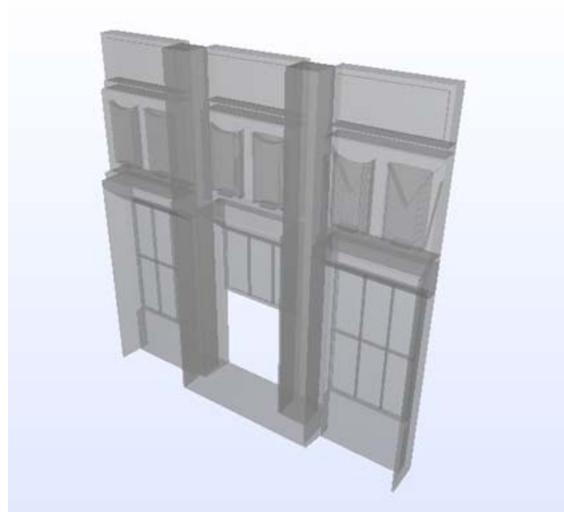
-	
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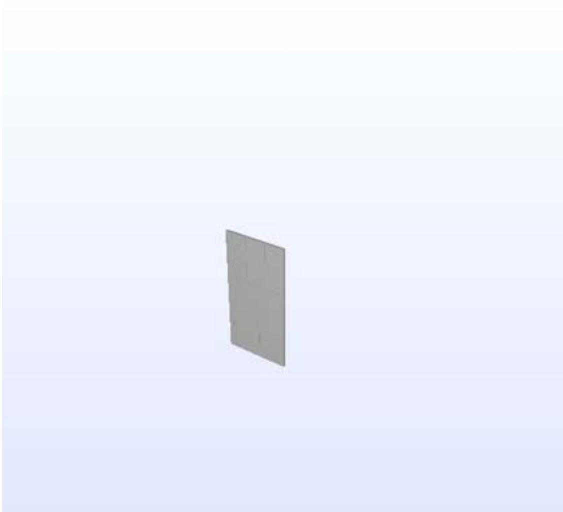	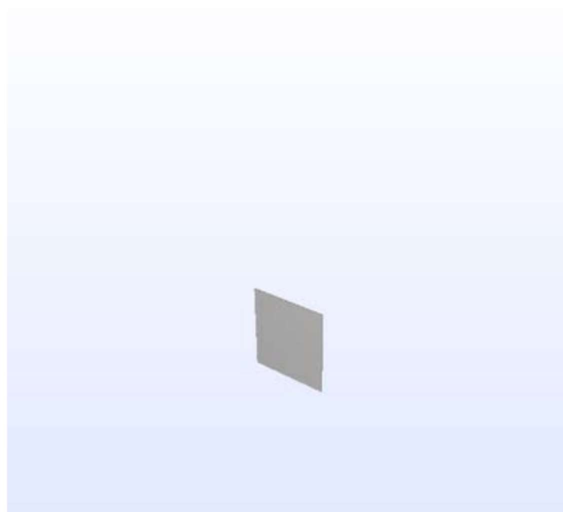
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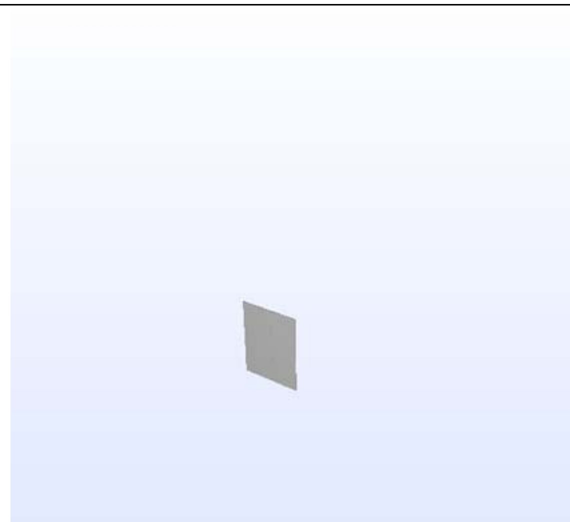
-	
Digital Project	Revit Building

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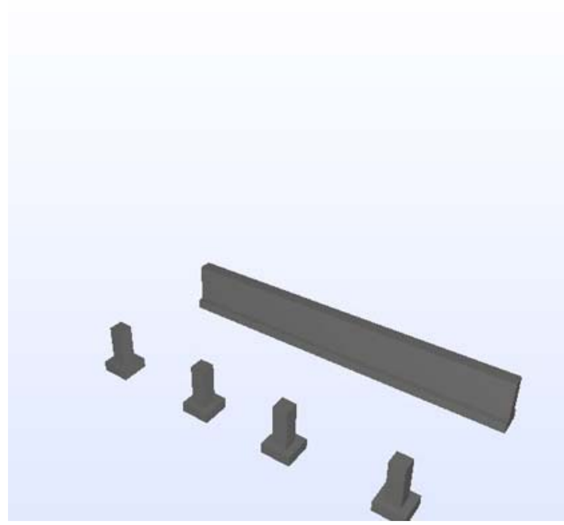
-	
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Digital Project	Revit Building

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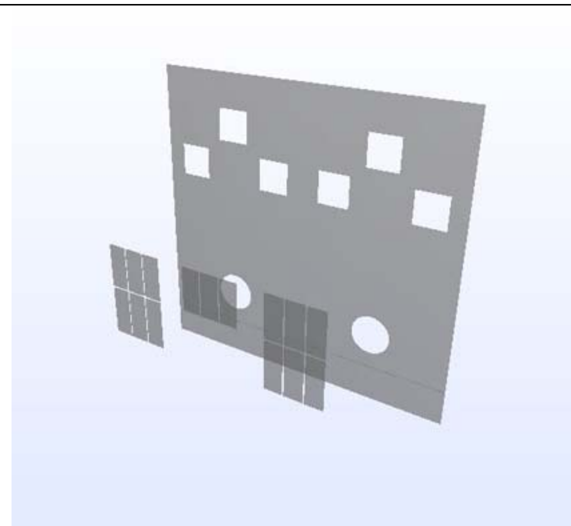
-	
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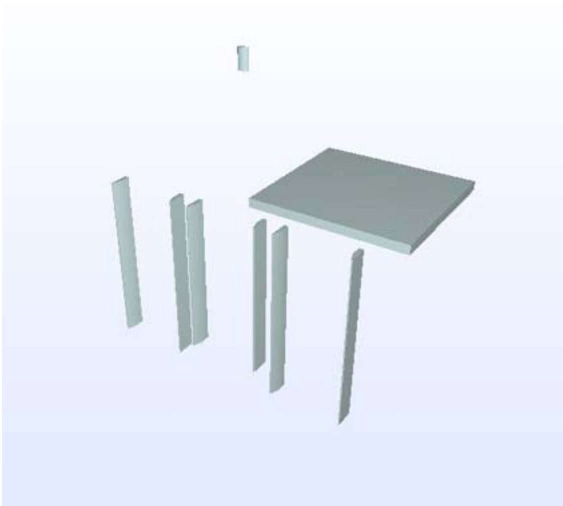	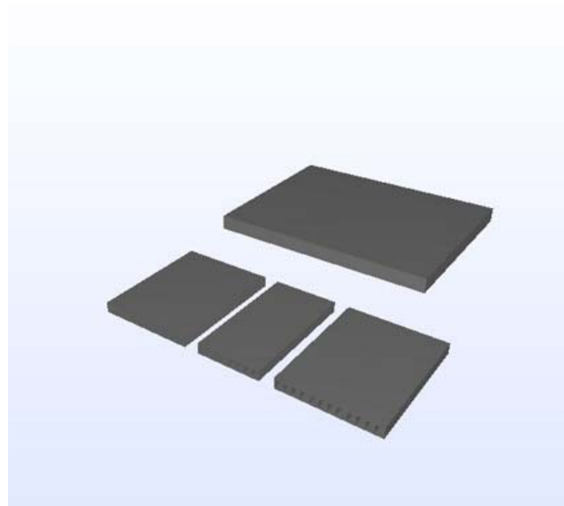
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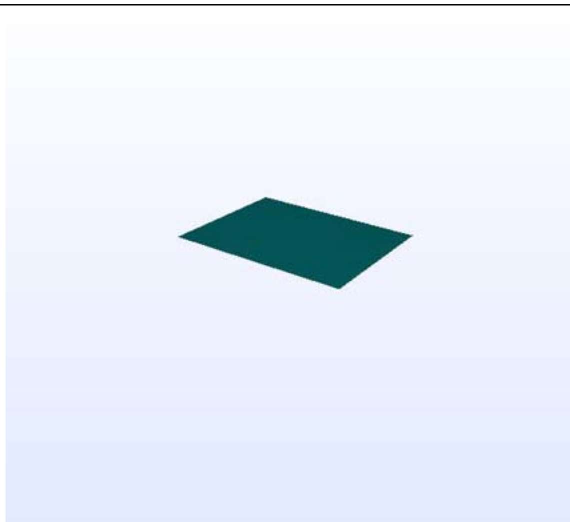	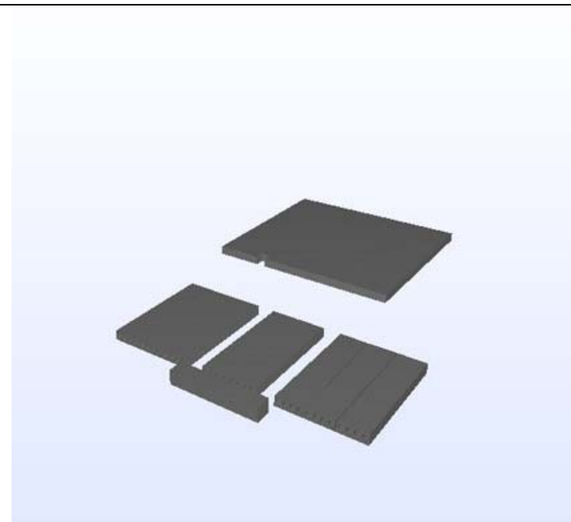
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	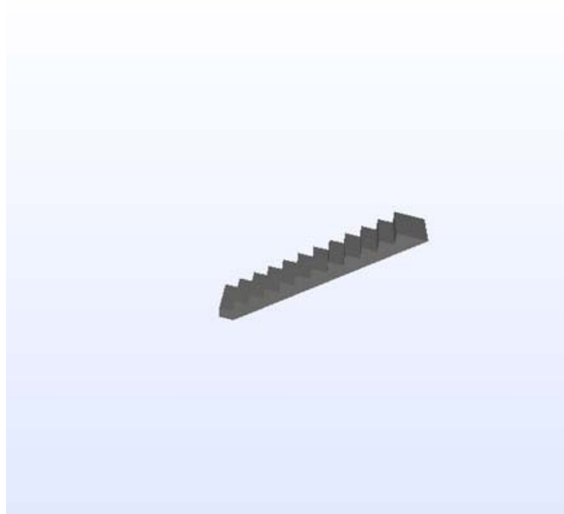
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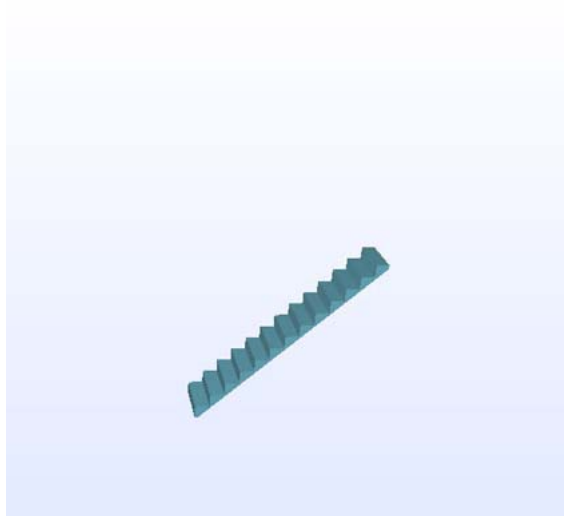
-	
Digital Project	Revit Building

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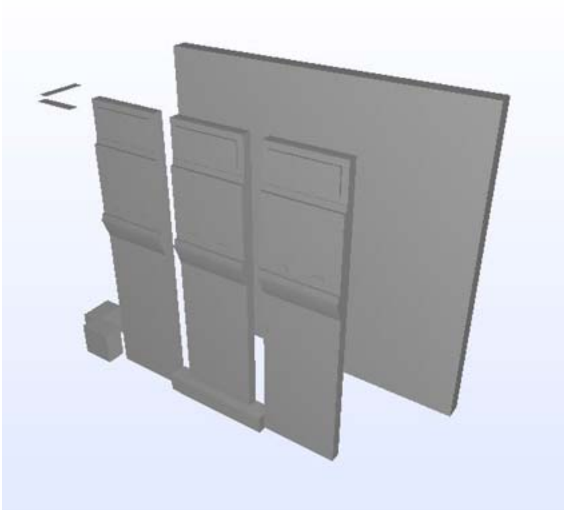	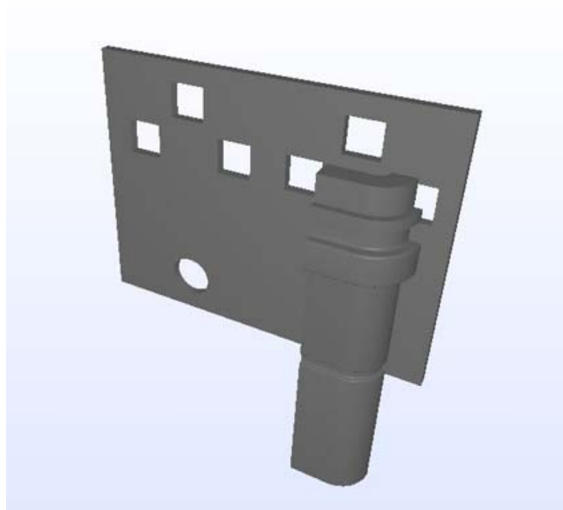
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	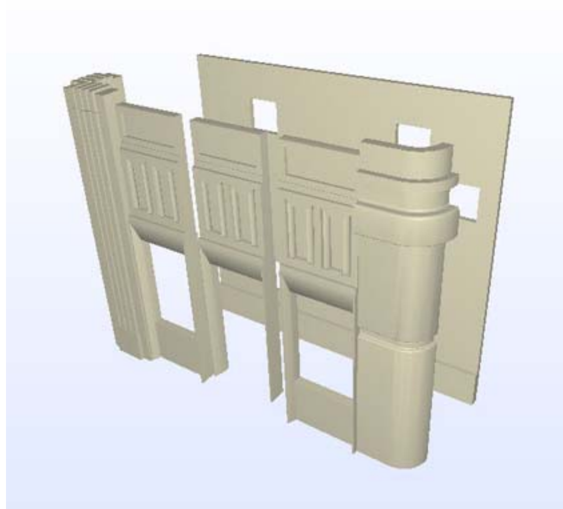
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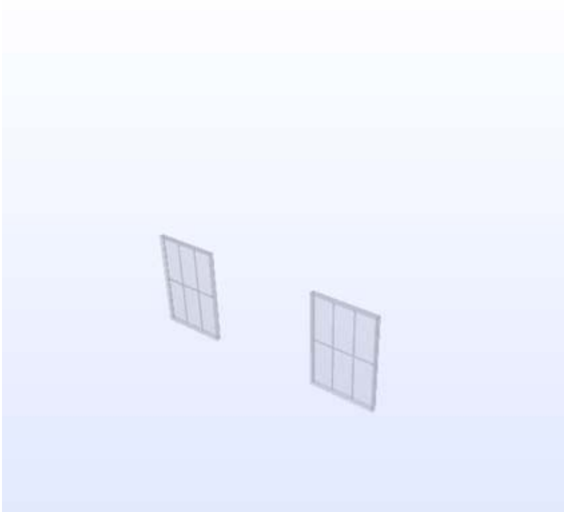	-
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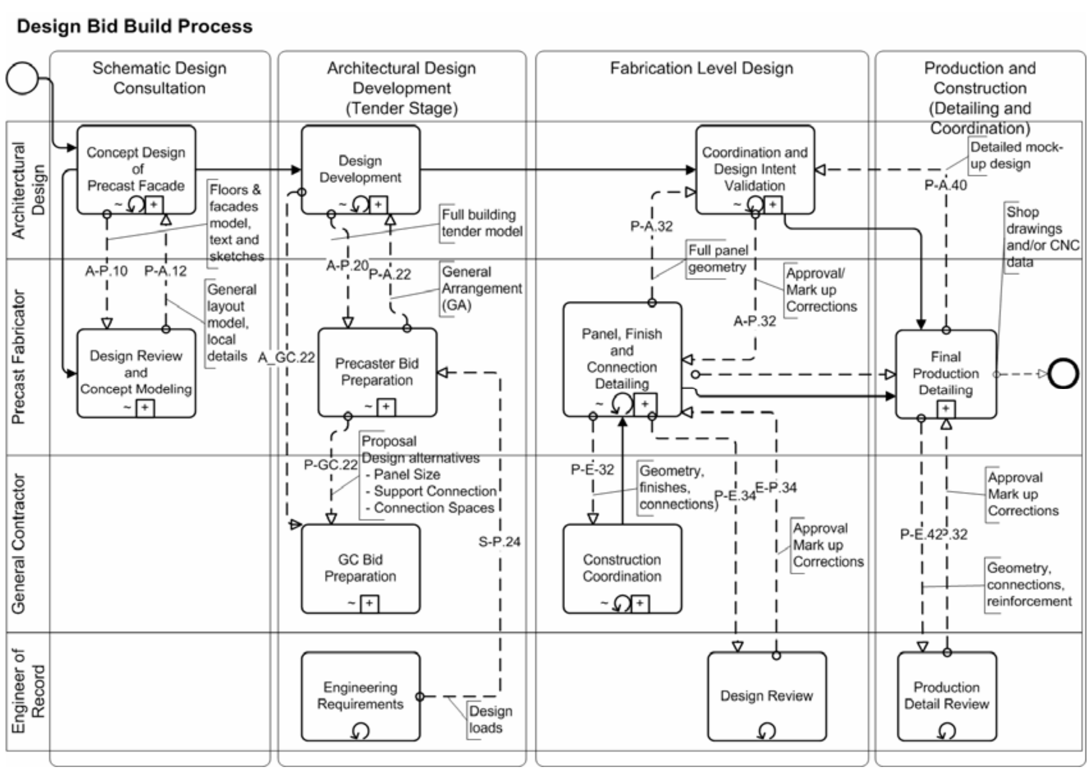
PART C:

Information Delivery Manual



Introduction

This document defines the data exchange requirements and workflow scenarios for exchanges between an architect and precast fabrication contractor. It is formatted according to a template developed in conjunction with the NBIMS Scoping Committee*.

The template anticipates multiple types of views for NBIMS documentation: on a website server, of scrollable pdf and paper documents. The classifications used are those defined in Omniclass, as developed by the Construction Specification Institute. Our experience in using these templates for architectural precast and other building systems indicate that they are ready for prime-time use.

Architectural precast, as a building system, highly interacts with many aspects of the building. It provides all or part of the external shell. It must transfer its loads to the building structure. It has multiple internal components, including fenestration and reinforcing. These result in many exchanges for coordination and compatibility throughout the design and fabrication process. This IDM incorporates exchanges between precast fabricator and structural engineer of record and between precast fabricator and general contractor.†

Building procurement processes are undergoing change. We defined workflows for two primary construction contracting arrangements: design-bid-build (DBB) and design-build (DB). While there is much overlap in the information exchanged, the specific flows are quite different, especially early in the design process.

The draft IDM provides important input for codifying this exchange scenario for the Facilities Information Council and as an early example of good practices for the development of a national BIM standard.

* Special thanks to Dianne Davis, Robert Lipman, Kristine Fallon and Donghoon Yang for their guidance and help in reviewing the template.

† No energy analysis considered. It was not identified in any actual process models encountered in the field. Future work should address this issue, especially during architectural design.

Documenting NBIMS Use Cases – Guide

Level 1 : Use Case Domain

The Use Case Domain provides a high-level overview of the range of processes and information exchanges considered to be in the scope of the domain. It is an overview of the major uses cases within a specified domain.

<table>
<tr><th colspan="2">Level 1 : Use Case Domain</th></tr>
<tr><td>Domain Name</td><td>Architectural Precast</td></tr>
<tr><td>Domain ID</td><td>PC-1 Architectural Precast Design-Bid-Build
PC-2 Architectural Precast Design-Build[‡]</td></tr>
<tr><td>History</td><td>10/27/2007 –Created – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner</td></tr>
<tr><td>Description</td><td>This Use Case Domain addresses the design of precast concrete architectural facades at all levels of specificity, from concept development, architectural intent, to fabrication detail. While the primary roles in this Use Case are architects and precast fabricators/consultants, related roles include the contractor and structural engineer.</td></tr>
<tr><td>Use cases in this domain</td><td>This specific Use Case Domain addresses: Conceptual Design of a precast façade, general arrangement documentation needed for bidding, and detailed fabrication documentation, needed for precast panel production. The cases deal with simple file level exchange.
Two different Use Case scenarios are defined: (1) for a design/bid/build project delivery process, and (2) a design/build collaborative design delivery method.</td></tr>
<tr><td colspan="2">Process diagram</td></tr>
<tr><td colspan="2">The information exchanges are between architectural designer (33-21-11-00), precast fabricator (33-41-14-00) and general contractor (33-41-11-00) and structural engineer (33-21-31-14).

The Design-Bid-Build process (PC-1) identifies eight specific exchanges:
1. Concept Design of Precast Façade (PC-1-1)
2. Design Development & Bid Preparation (PC-1-2)
3. Precaster Bid Preparation (PC-1-3)
4. Engineering Requirements (PC-1-4)
5. Fabrication-Level Design and Coordination (PC-1-5)
6. Structural Design Review (PC-1-67)
7. Final Production Detailing & Review (PC-1-7)

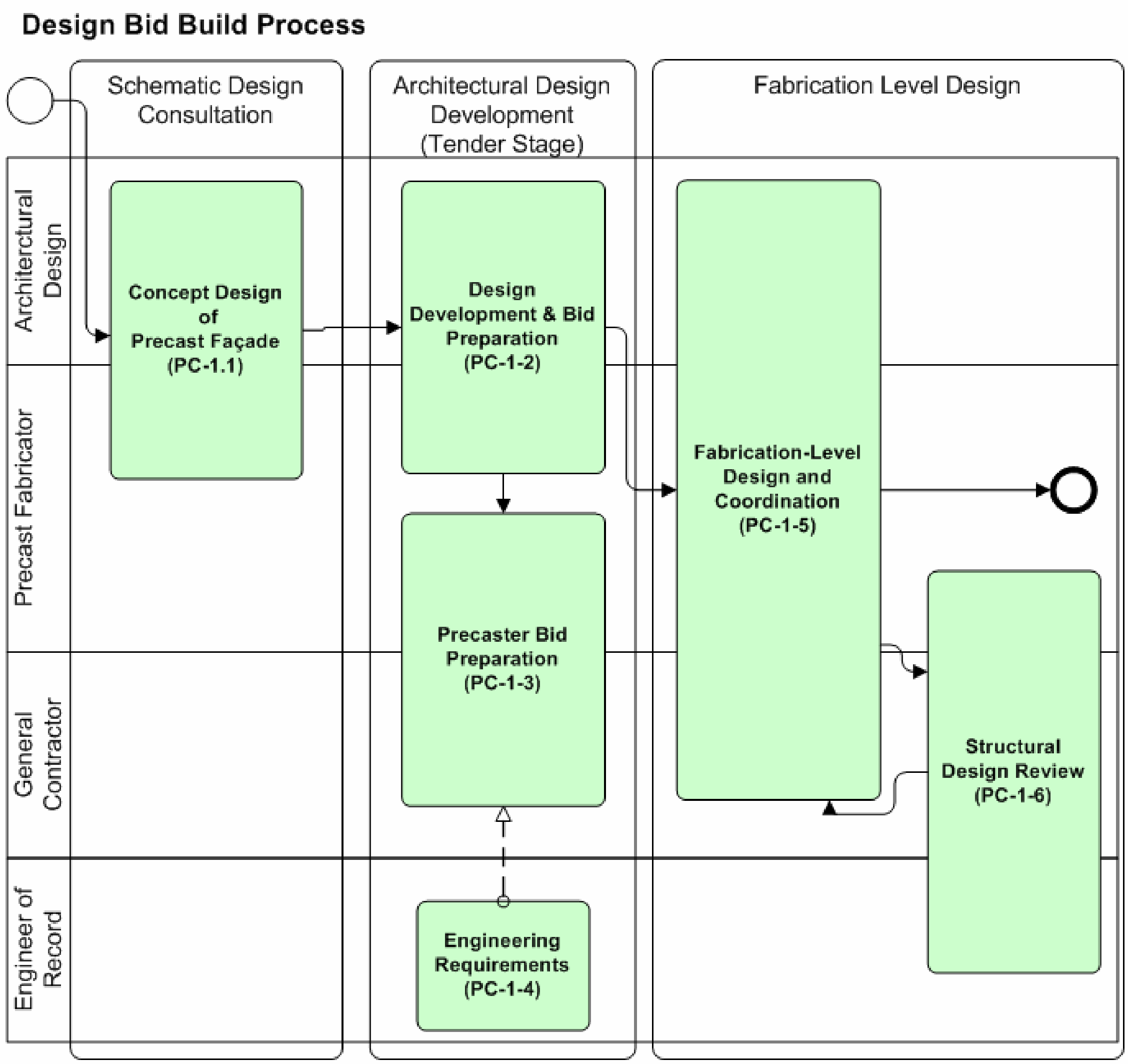
The Design-Build Process (PC-2) exchanges are similar, with three different replaced exchanges
1. Concept Design & Feasibility of Precast Façade (PC-2-1)
2. Structural Engineering Requirements & Design (PC-2-2)
3. Precaster Coordination Package (PC-2-3)

Each of these Level 2 process are defined below</td></tr>
</table>

[‡] The Domain, Use Case and Information Exchange IDs are temporarily assigned here, until they are replaced by official IDs.

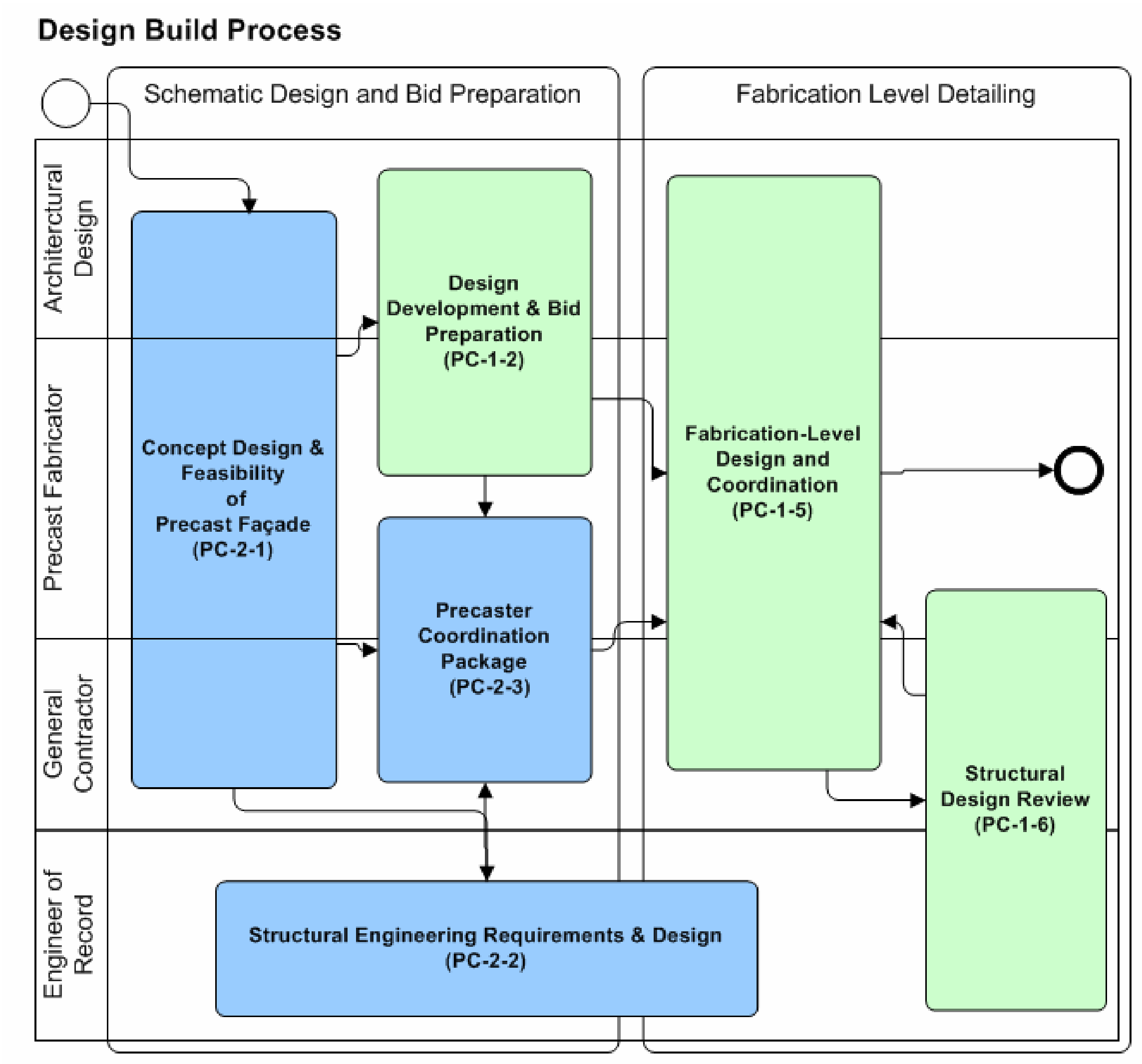
Architectural Precast Design-Bid-Build Process

Process Model PC-1



Architectural Precast Design-Build Process

Process Model PC-2

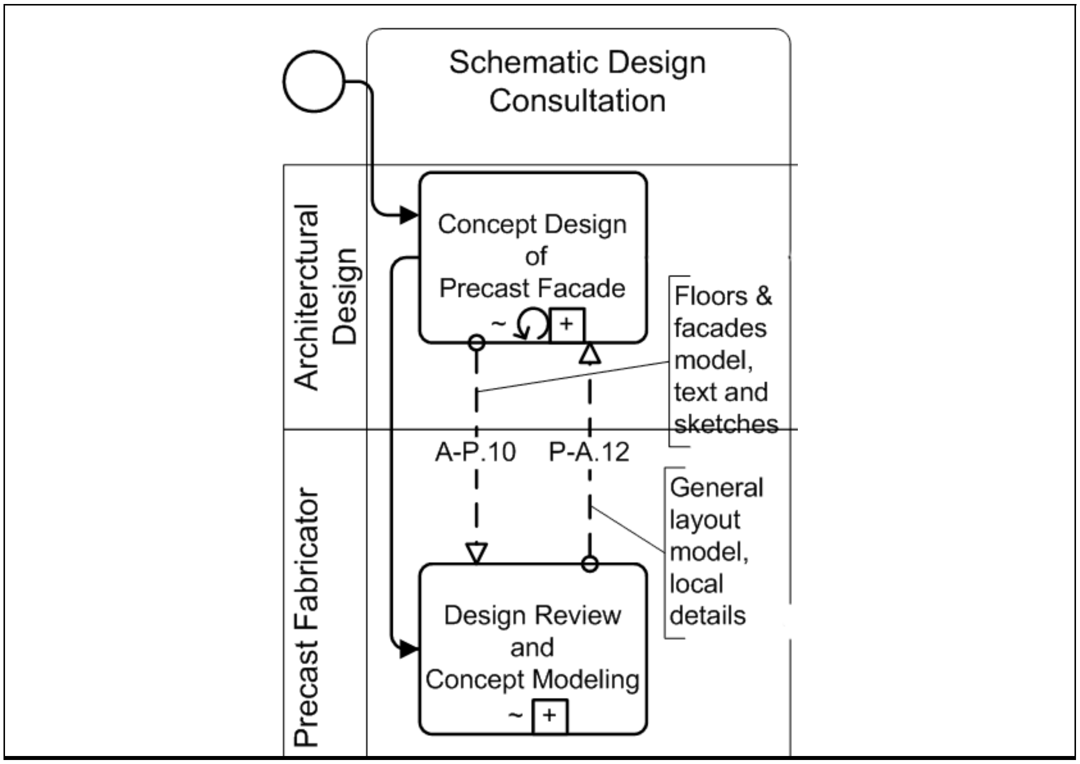


Level 2 : Use Case Definition Design-Bid-Build

This Use Case provides optional early input to the architect, in order to anticipate production practices that are the domain of the precast fabricator. The architect provides an early stage concept model regarding design intent, and the precast consultant responds with details or sketches that allow the precast design to be more “production ready”.

<table>
<tr><th colspan="3">Level 2 : Use Case Definition</th></tr>
<tr><td>Name</td><td colspan="2">Concept Design of Precast Facade</td></tr>
<tr><td>Use Case ID</td><td colspan="2">PC-1-1[§]</td></tr>
<tr><td>Domain ID</td><td colspan="2">PC-1 (Design-Bid-Build)</td></tr>
<tr><td>History</td><td colspan="2">10/27/2007 –Created) – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner</td></tr>
<tr><td rowspan="2">Information provider</td><td>Roles involved</td><td>Lifecycle stage</td></tr>
<tr><td>34-25-21-00 Architect</td><td>31-20-10-21 Preliminary design stage</td></tr>
<tr><td rowspan="2">Information receiver</td><td>Roles involved</td><td>Lifecycle stage</td></tr>
<tr><td>34-35-17-00 Subcontractor Precast Fabricator OR 34-35-21-00 Engineer (precast consultant)</td><td>31-10-41-21 Preliminary design development phase</td></tr>
<tr><td>Information passed</td><td colspan="2">Architect provides the identification, use and location of the building, floors, facade models, preliminary sections and finishes. Precast fabricator returns revised facade models, preliminary sections and additional sketches and text</td></tr>
<tr><td>Existing methods</td><td colspan="2">General arrangement drawings, façade layouts, written descriptions, rendered images</td></tr>
<tr><td>Software Involved</td><td colspan="2">BIM design tools (e.g. Autodesk REVIT, Bentley Architecture, Graphisoft ArchiCAD)</td></tr>
<tr><td>Benefits</td><td colspan="2">Communicate the building scheme to the precast fabrication consultant. Enables the precast fabrication consultant to make recommendations for panelization, formwork details, casting alternatives within a model before these get fixed in the design.</td></tr>
<tr><td>Information Exchanges in the Use Case</td><td colspan="2">A-P.10 from architect to precast consultant
P-A.12 from precast consultant to architect</td></tr>
<tr><td>Automation Level of Use Case</td><td colspan="2">This use case has one-way or optionally two-way exchanges. They can both be provided with simple file exchange. The first can also be provided by exposing a model view on a model server.</td></tr>
<tr><td colspan="3">Process Model</td></tr>
</table>

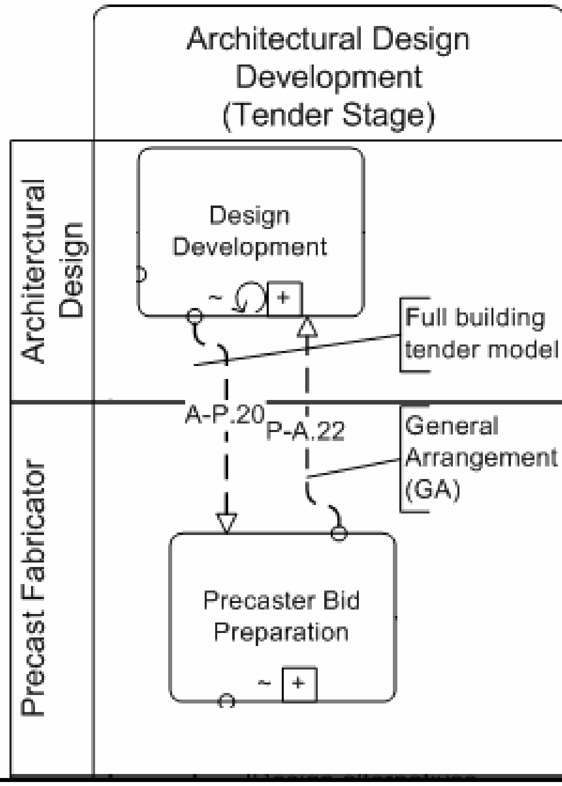
[§] These IDs, for Domain, Use Case and Information Exchanges, are temporary, until official assignments are made.


Schematic Design Consultation
Architerctural Design
Precast Fabricator
Concept Design of Precast Facade
Floors & facades model, text and sketches
A-P.10
P-A.12
General layout model, local details
Design Review and Concept Modeling

Level 2 : Use Case Definition Design-Bid-Build

This Use Case provides late stage review of the precast architectural system for consultation review. Its purpose is to gain expert review of the bid drawings so they provide needed information for bidding of the precast architectural system. The likely issues reviewed include panelization, finishes, erection sequence, interactions with other systems.

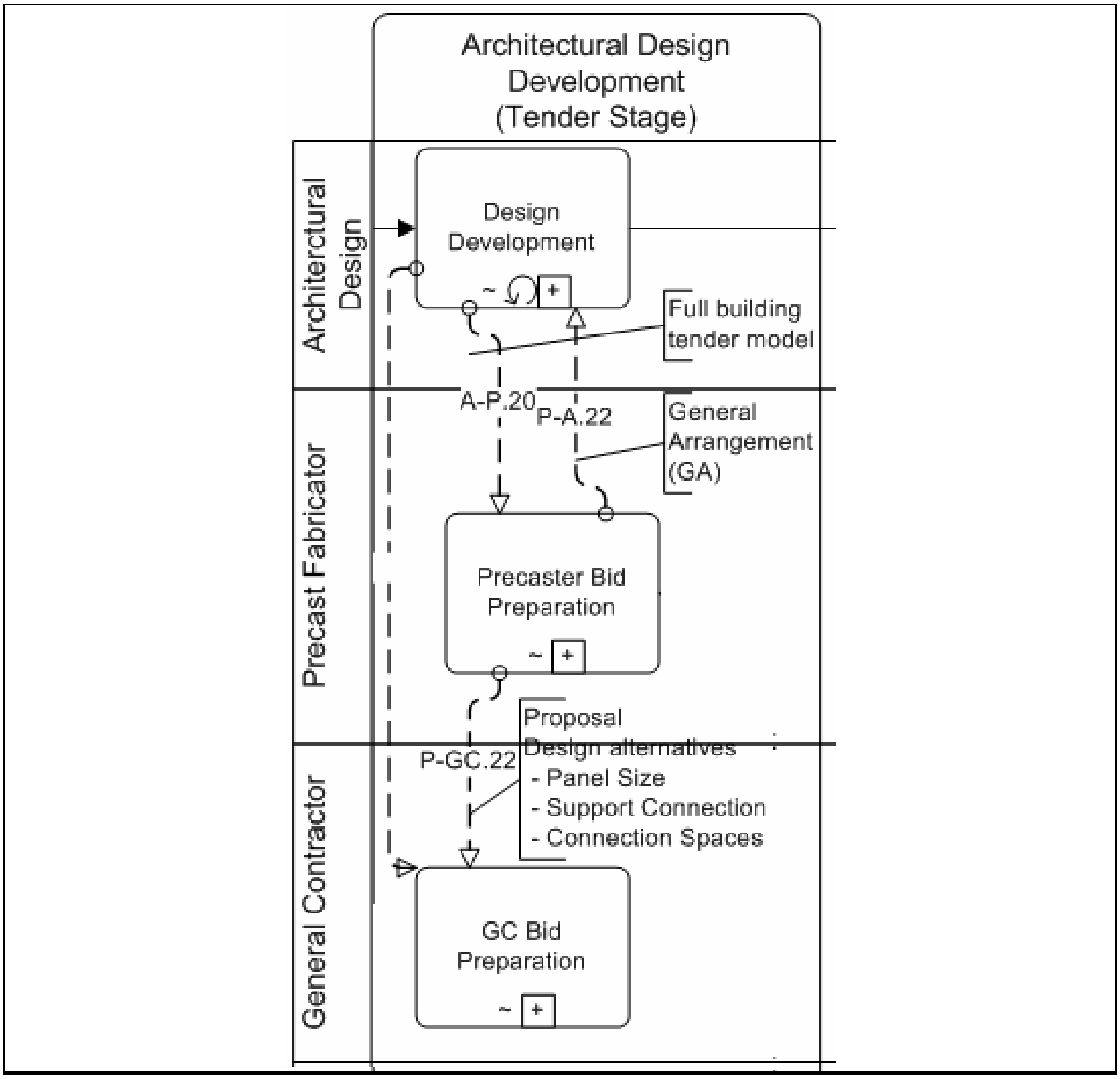
Level 2 : Use Case Definition		
Name	**Design Development & Bid Preparation**	
Use Case ID	**PC-1-2**	
Domain ID	**PC-1 (Design-Bid-Build)**	
History	10/27/2007 –Created – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner	
Participants	Roles involved	Lifecycle stage
Information provider	34-25-21-00 Architect OR 34-35-17-00 Subcontractor – Precast Fabricator OR 34-35-21-00 Engineer (precast consultant)	31-20-20-14 Final Design Phase (for architect) OR 31-25-10-11 Construction Document Preparation Phase (for precast consultant)
Information receiver	34-35-14-00 Contractor	31-30-40-14 Proposal Evaluation Phase
Information passed	The building's geometry: its floor levels, column and structural wall locations, façade units and layouts (materials, window locations and approximate sizes), material of structure (steel, CIP concrete or precast concrete). Finish information (sample or image)	
Existing methods	General arrangement drawings, façade layouts, verbal descriptions, samples.	
Software Involved	BIM design tools (e.g. Autodesk REVIT, Graphisoft ArchiCAD, Bentley Architecture) precast detailing tools (Tekla Structures, Structureworks, Vico Constructor)	
Benefits	Communicate the building scheme to the precast fabrication consultant in machine readable form, allowing detailed review prior to bidding.	
Information Exchanges in the Use Case	A-P.20 from architect to precast consultant P-A.22 from precast consultant to architect	
Automation Level of Use Case	This use case has two alternative one-way exchanges – from architect, or precast consultant to the contractor. They can both be provided with simple file exchange.	
Process Model		


Architectural Design
Development
(Tender Stage)
Architerctural
Design
Precast Fabricator
Design
Development
Full building
tender model
A-P.20
P-A.22
General
Arrangement
(GA)
Precaster Bid
Preparation

Level 2 : Use Case Definition Design-Bid-Build

This Use Case provides release to the General Contractor the final bid documentation for bidding on architectural precast.

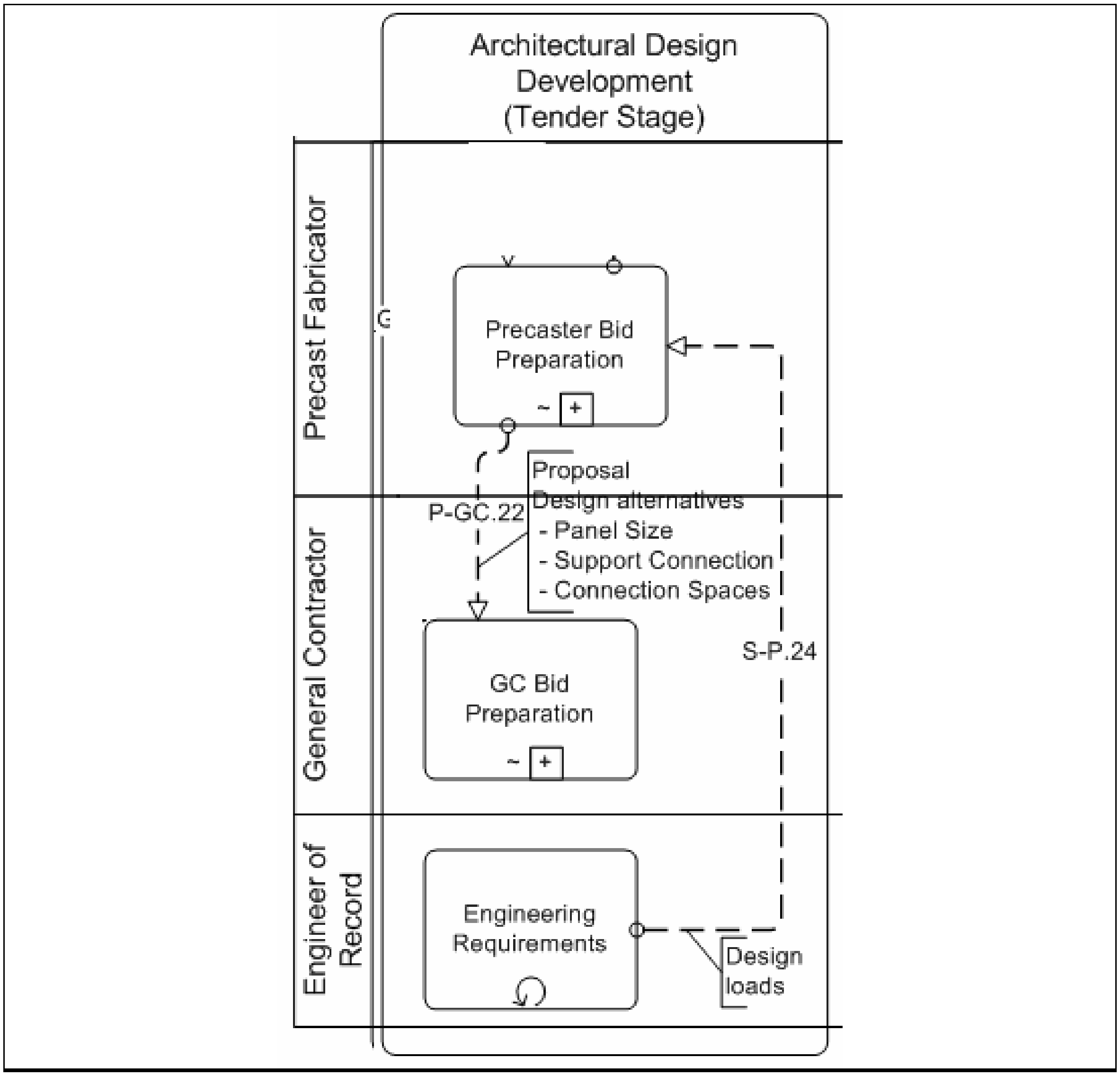
Level 2 : Use Case Definition		
Name	**Precaster Bid Preparation**	
Use Case ID	**PC-1-3**	
Domain ID	**PC-1 (Design-Bid-Build)**	
History	10/27/2007 –Created – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner	
Participants	Roles involved	Lifecycle stage
Information provider	34-25-21- 00 Architect OR Precast Fabricator OR 34-35-21-00 Engineer (precast consultant	31-20-20-14 Final Design Phase (for architect)
Information receiver	34-35-14-00 General Contractor	31-25-20-00 Construction Document Production Phase
Information passed	The building's geometry: its floor levels, column and structural wall locations, façade layouts (materials, window locations and sizes), proposed panelization. decoration applied, specifications, material finish information (sample or image)	
Existing methods	General arrangement drawings, plans, sections, elevations, specifications and samples.	
Software Involved	BIM design tools (e.g. Autodesk REVIT, Graphisoft ArchiCAD, Bentley Architecture) precast detailing tools (Tekla Structures, Structureworks, Vico Constructor)	
Benefits	Communicate the building precast system to precast bidders in machine readable form, allowing auto extraction of BOM, quick development of production plan for bid generation.	
Information Exchanges in the Use Case	A-P.20 from architect to precast consultant P-A.22 from precast consultant to architect A-GC.22 from architect to contractor P-GC.22 from precast consultant to contractor	
Automation Level of Use Case	This use case has two alternative one-way exchanges – from architect, or precast consultant to the contractor. They can both be provided with simple file exchange.	
Process Model		


Architectural Design Development (Tender Stage)
Architercturul Design
Precast Fabricator
General Contractor
Design Development
Full building tender model
A-P.20
P-A.22
General Arrangement (GA)
Precaster Bid Preparation
Proposal
Design alternatives
- Panel Size
- Support Connection
- Connection Spaces
P-GC.22
GC Bid Preparation

Level 2 : Use Case Definition Design-Bid-Build

This Use Case provides release to the General Contractor the final bid documentation for bidding on architectural precast.

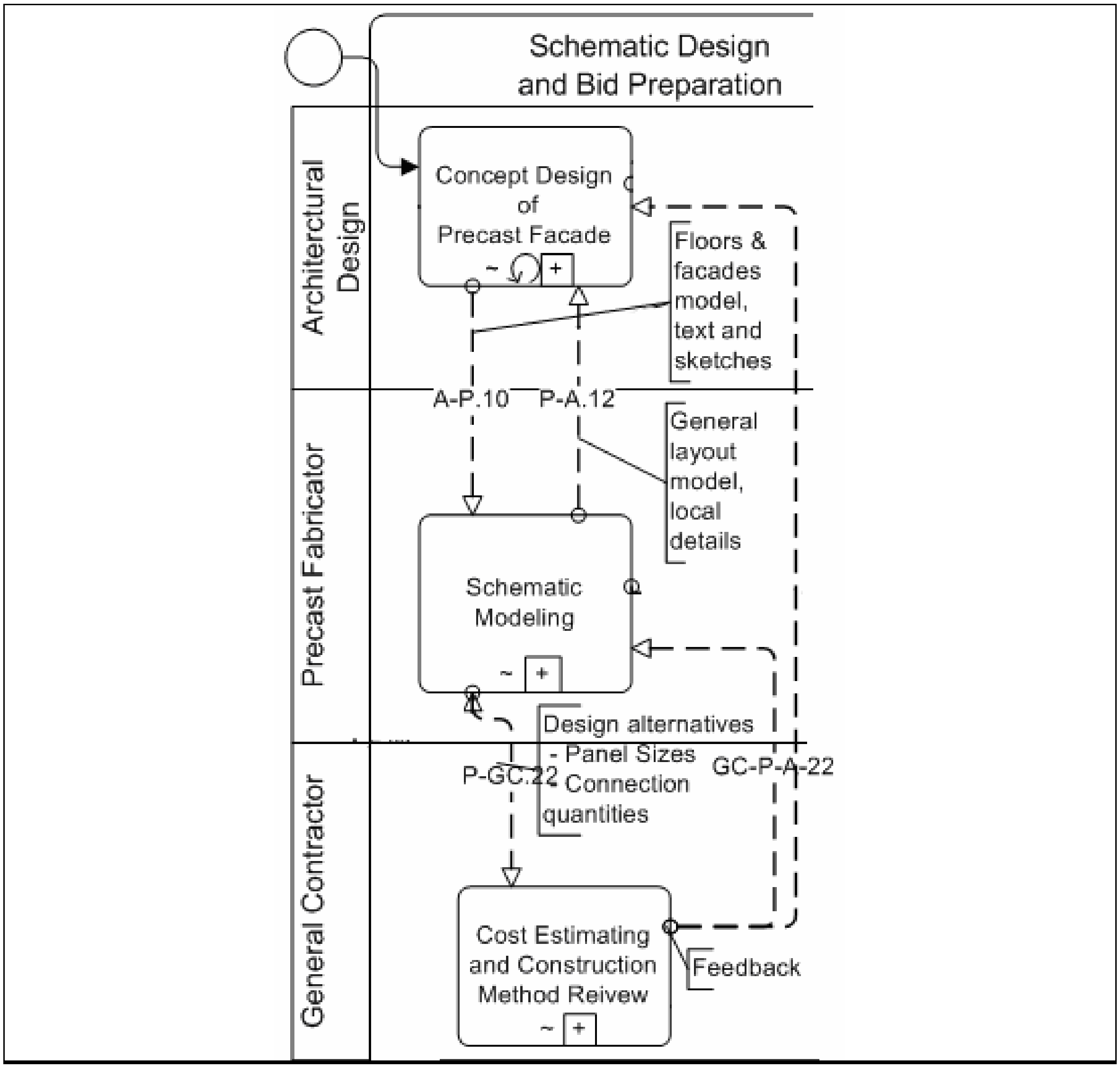
Level 2 : Use Case Definition		
Name	**Engineering Requirements**	
Use Case ID	**PC-1-4**	
Domain ID	**PC-1 (Design-Bid-Build)**	
History	11/03/2007 –Created – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner	
Participants	Roles involved	Lifecycle stage
Information provider	34-25 31 00 Engineer (Structural)	31-20 20 21 Engineering Analysis Phase
Information receiver	34-35-14-00 General Contractor	31-25-20-00 Construction Document Production Phase
Information passed	Loading conditions, design method (LRFD, ASD), types of connections assumed for the building structure, assumptions regarding precast panel loads (if any)	
Existing methods	Written submittal report	
Software Involved	Structural design/analysis tools (e.g. STAAD-Pro, ETABS, GT-STRUDL, RISA, etc.)	
Benefits	Provide loading conditions in machine readable form for later use in detailing..	
Information Exchanges in the Use Case	S-P.24 from structural engineer to precast consultant	
Automation Level of Use Case	This use case is a one-way flow, but possibly iterated	
Process Model		


Architectural Design Development (Tender Stage)
Precast Fabricator
General Contractor
Engineer of Record
Precaster Bid Preparation
Proposal
Design alternatives
- Panel Size
- Support Connection
- Connection Spaces
P-GC.22
S-P.24
GC Bid Preparation
Engineering Requirements
Design loads

Level 2 : Use Case Definition Design-Build

This Use Case provides overall collaborative exchange s for the architect, precast fabricator or consultant and general contractor, in a Design-Build or teaming project delivery method.

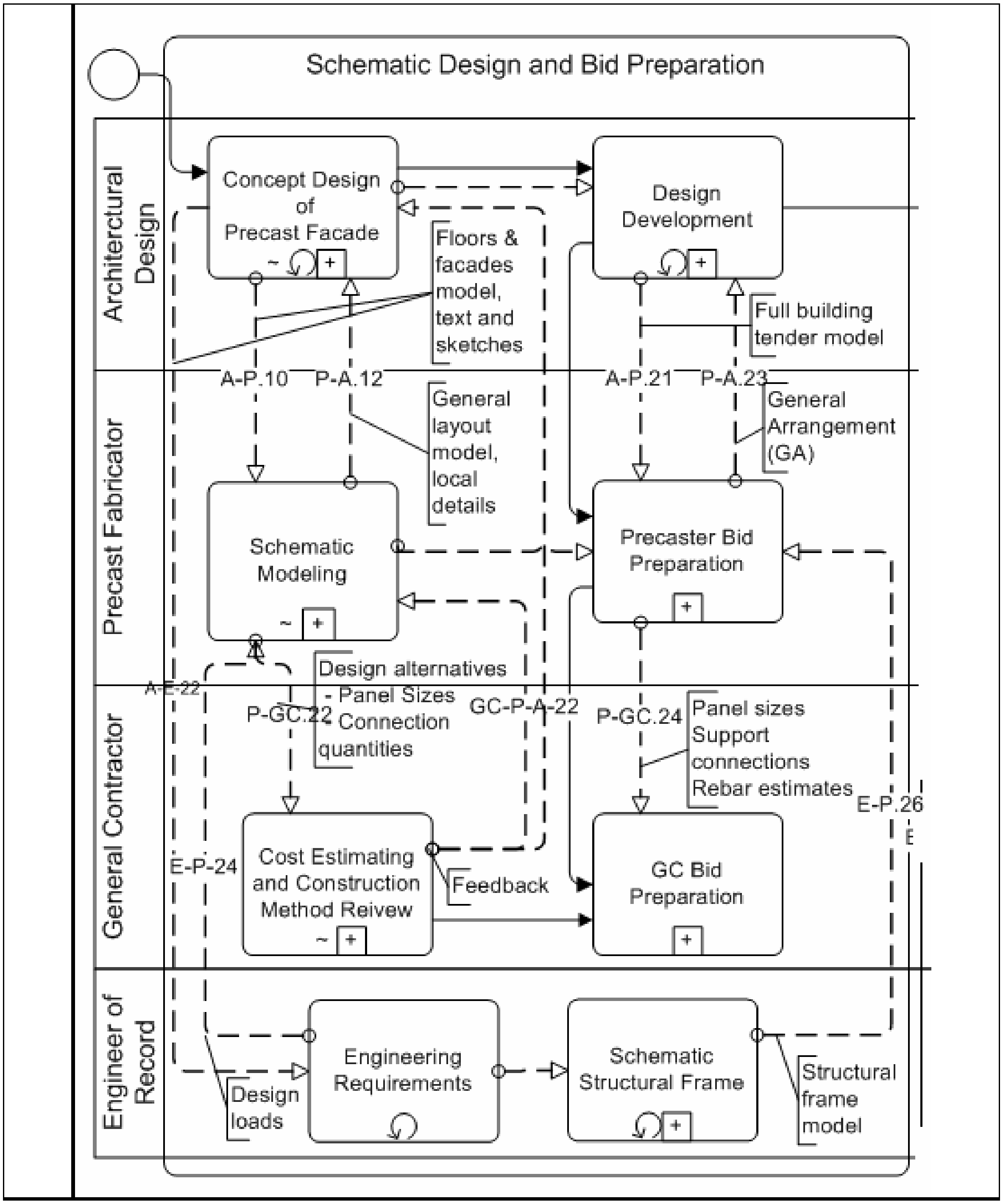
Level 2 : Use Case Definition		
Name	**Concept Design and Feasibility of Precast Facade**	
Use Case ID	**PC-2-1**	
Domain ID	**PC-2 (Design-Build or Teaming)**	
History	11/03/2007 –Created – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner	
Participants	Roles involved	Lifecycle stage
Information provider	34-25-21-00 Architect , 34-35-17-00 Subcontractor Precast Fabricator (OR 34-35-21-00 Engineer (precast consultant)), 34-25 31 00 34-35-14-00 General Contractor	31-20-10-21 Preliminary design phase, 31-10-41-21 Preliminary design development phase 31-20 10 11 Preliminary Engineering Phase
Information receiver	34-25-21-00 Architect, 34-35-17-00 Subcontractor Precast Fabricator (OR 34-35-21-00 Engineer (precast consultant)). 34-35-14-00 General Contractor	31-20-10-21 Preliminary design phase, 31-10-41-21 Preliminary design development phase 31-20 10 11 Preliminary Engineering Phase
Information passed	*Architect* provides the identification, use and location of the building, floors, facade models, preliminary sections and finishes. *Precast fabricator* advises on the facade models, preliminary sections and additional sketches and text; precast consultant passes revised sections, may build 3D architectural precast planning model;	
Existing methods	Preliminary architectural drawings, if done – this is a new process.	
Software Involved	BIM design tools (e.g. Autodesk REVIT, Graphisoft ArchiCAD, Bentley Architecture); precast detailing tools (Tekla Structures, Structureworks, Vico Constructor)	
Benefits	Provide early close collaboration allowing precast fabricator to advise on early developments led by architect and to develop parallel model for detailing.	
Information Exchanges in the Use Case	A-P.10 from architect to precast consultant P-A.12 from precast consultant to architect P-GC.22 from precast consultant to Contractor GC-P-A-22 from contractor to precast consultant and architect	
Automation Level of Use Case	This use case is an iterated, parallel two-way flow.	
Process Model		


Schematic Design
and Bid Preparation
Architerctural Design
Precast Fabricator
General Contractor
Concept Design
of
Precast Facade
Floors &
facades
model,
text and
sketches
A-P.10
P-A.12
General
layout
model,
local
details
Schematic
Modeling
Design alternatives
- Panel Sizes
- Connection
quantities
P-GC.22
GC-P-A-22
Cost Estimating
and Construction
Method Reivew
Feedback

Level 2 : Use Case Definition Design-Build

This Use Case provides collaborative interaction between a structural engineer and the project team (emphasis on precast fabricator/consultant).

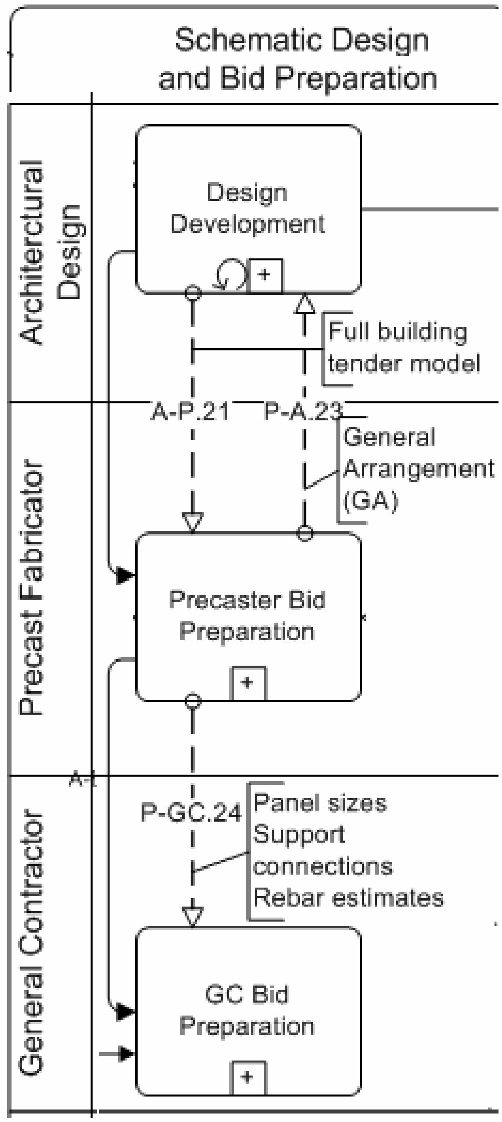
Level 2 : Use Case Definition		
Name	**Structural Engineering Requirements and Design**	
Use Case ID	**PC-2-2**	
Domain ID	**PC-2 (Design-Build or Teaming)**	
History	11/03/2007 –Created – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner	
Participants	Roles involved	Lifecycle stage
Information provider	34-25 31 00 Engineer (Structural)	31-20 10 11 Preliminary Engineering Phase
Information receiver	34-35-17-00 Subcontractor Precast Fabricator (OR 34-35-21-00 Engineer (precast consultant)).	31-10-41-21 Preliminary design development phase 31-20 10 11 Preliminary Engineering Phase
Information passed	*Structural engineer* reviews project and in parallel with structural system concept development, advises on the architectural precast approaches for connection with the structure; Estimates loading and load combinations applicable.	
Existing methods	Preliminary approaches for connections and loads, in sketches on drawings and writing.	
Software Involved	BIM design tools (e.g. Autodesk REVIT, Graphisoft ArchiCAD, Bentley Architecture); structural design/analysis tools (e.g. STAAD-Pro, ETABS, GT-STRUDL, RISA, etc.)	
Benefits	Provide early close collaboration allowing structural engineer to resolve connections and detailing early, eliminating activities typically applied during shop model phase.	
Information Exchanges in the Use Case	A-E-22 from architect to structural engineer E-P-24 from structural engineer to precast consultant E-P-26 from structural engineer to precast consultant	
Automation Level of Use Case	This use case is an iterated, parallel two-way flow.	
Process Model		


Schematic Design and Bid Preparation
Architerctural Design
Precast Fabricator
General Contractor
Engineer of Record
Concept Design of Precast Facade
Design Development
Floors & facades model, text and sketches
Full building tender model
A-P.10
P-A.12
A-P.21
P-A.23
General layout model, local details
General Arrangement (GA)
Schematic Modeling
Precaster Bid Preparation
A-E-22
Design alternatives - Panel Sizes - Connection quantities
P-GC.22
GC-P-A-22
P-GC.24
Panel sizes Support connections Rebar estimates
E-P.26
Cost Estimating and Construction Method Reivew
Feedback
GC Bid Preparation
E-P-24
Engineering Requirements
Schematic Structural Frame
Design loads
Structural frame model

Level 2 : Use Case Definition Design-Build

This Use Case provides collaborative interaction between a structural engineer and the project team (emphasis on precast fabricator/consultant).

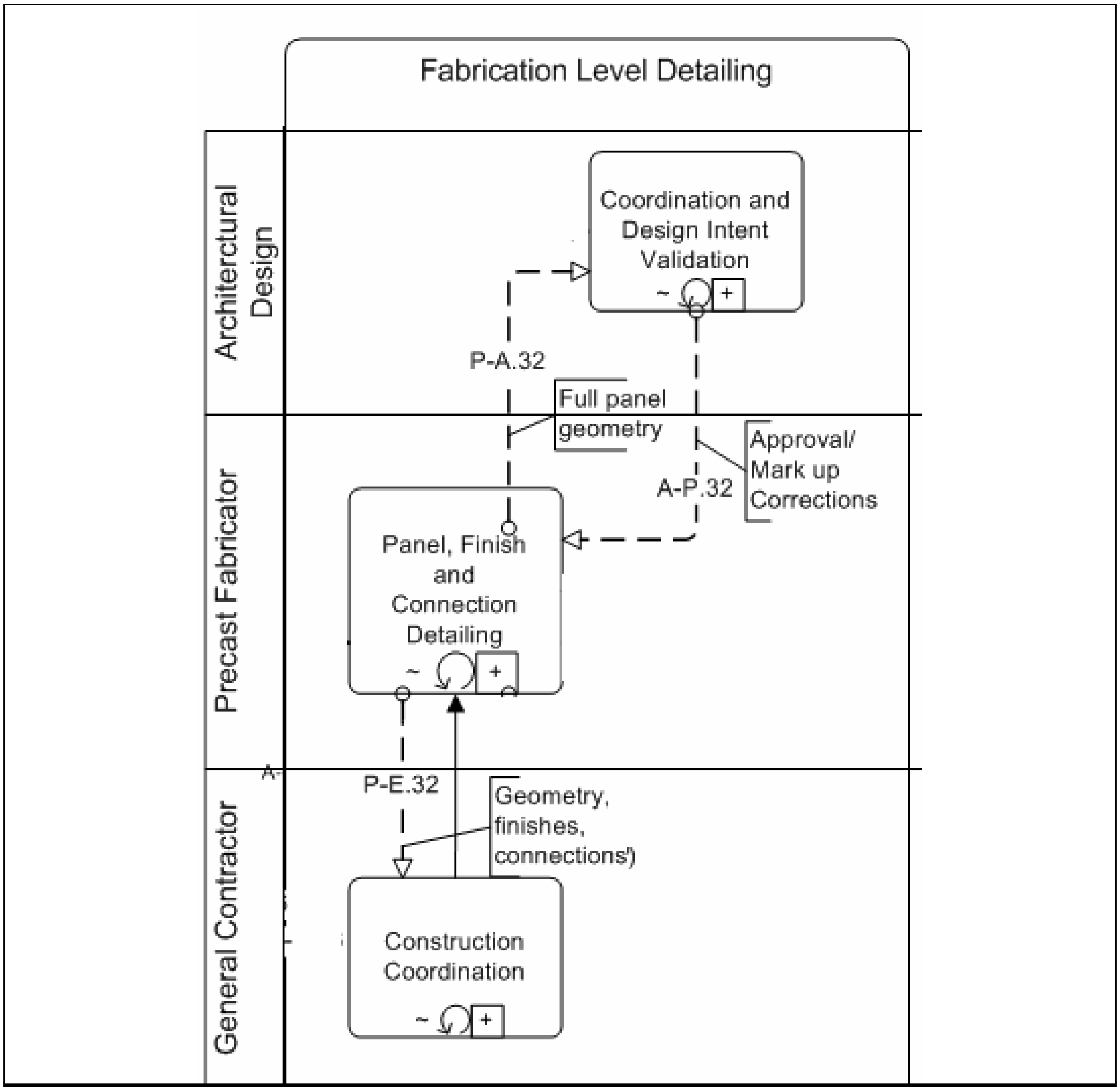
Level 2 : Use Case Definition		
Name	**Precaster Coordination Package**	
Use Case ID	**PC-2-3**	
Domain ID	**PC-2 (Design-Build or Teaming)**	
History	11/04/2007 –Created – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner	
Participants	Roles involved	Lifecycle stage
Information provider	34-35-17-00 Subcontractor Precast Fabricator (OR 34-35-21-00 Engineer (precast consultant)). 34-25-21-00 Architect	31-20 10 11 Preliminary Engineering Phase
Information receiver	34-25-21-00 Architect 34-35-14-00 General Contractor	31-10-41-21 Preliminary design development phase 31-20 10 11 Preliminary Engineering Phase
Information passed	*Structural engineer* reviews project and in parallel with structural system concept development, advises on the architectural precast approaches for connection with the structure; Estimates loading and load combinations applicable.	
Existing methods	Preliminary approaches for connections and loads, in sketches on drawings and writing.	
Software Involved	BIM design tools (e.g. Autodesk REVIT, Graphisoft ArchiCAD, Bentley Architecture); structural design/analysis tools (e.g. STAAD-Pro, ETABS, GT-STRUDL, RISA, etc.)	
Benefits	Provide early close collaboration allowing structural engineer to resolve connections and detailing early, eliminating activities typically applied during shop model phase.	
Information Exchanges in the Use Case	A-P.21 from architect to precast consultant P-A.23 from precast consultant to architect P-GC.24 from precast consultant to general contractor	
Automation Level of Use Case	This use case is an iterated, parallel two-way flow.	
Process Model		


Schematic Design
and Bid Preparation
Architerctural Design
Precast Fabricator
General Contractor
Design Development
Full building tender model
A-P.21
P-A.23
General Arrangement (GA)
Precaster Bid Preparation
P-GC.24
Panel sizes
Support connections
Rebar estimates
GC Bid Preparation

Level 2 : Use Case Definition Design-Bid-Build

This Use Case provides collaborative interaction between a structural engineer and the project team (emphasis on precast fabricator/consultant).

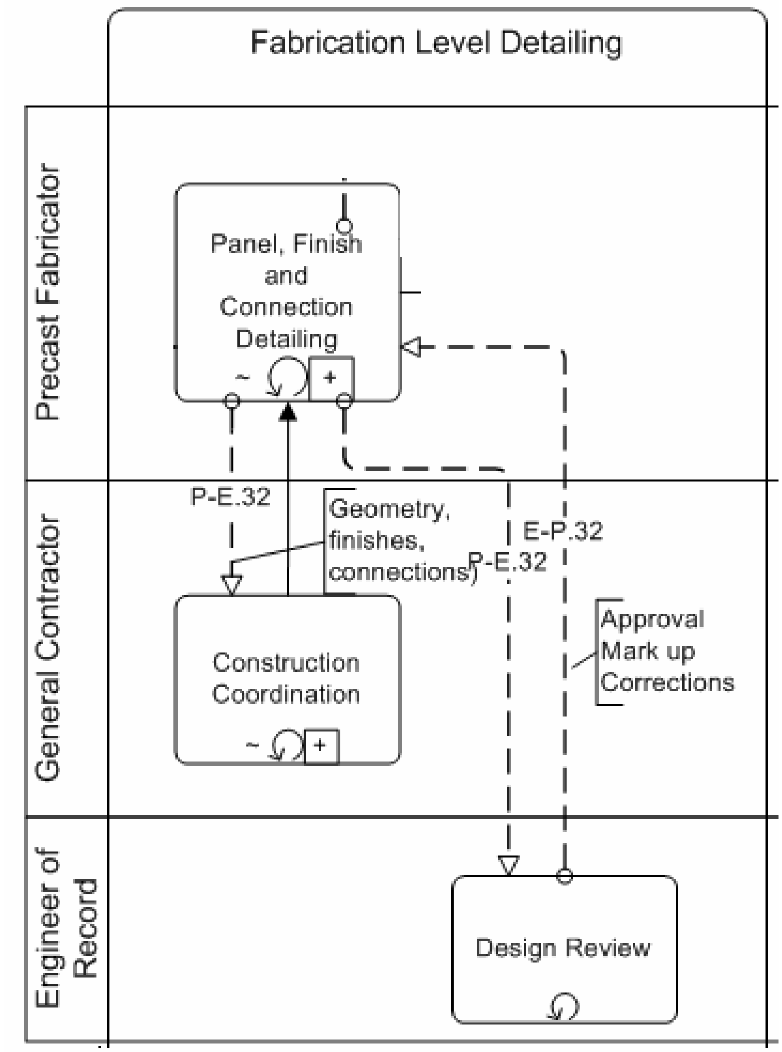
Level 2 : Use Case Definition		
Name	**Fabrication-Level Design and Coordination**	
Use Case ID	**PC-1-5**	
Domain ID	**PC-1 (Design-Bid-Build)**	
History	11/04/2007 –Created – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner	
Participants	Roles involved	Lifecycle stage
Information provider	34-35-17-00 Subcontractor Precast Fabricator (OR 34-35-21-00 Engineer (precast consultant)). 34-25-21-00 Architect	31-20 10 11 Preliminary Engineering Phase
Information receiver	34-25-21-00 Architect 34-35-14-00 General Contractor	31-10-41-21 Preliminary design development phase 31-20 10 11 Preliminary Engineering Phase
Information passed	*Precast fabricator* distributes shop-level model for review-coordination. Distributes to architect for coordination and verification of design intent; to contractor for project coordination.	
Existing methods	Exchange of shop drawings, drawn on similar template, examining for conflicts on a light table.	
Software Involved	Precast detailing tools (Structureworks, Tekla Structures) and model coordination software, such as Navisworks and Solibri Model Checker	
Benefits	Provide fabrication model coordination with other systems; validation design intent issues.	
Information Exchanges in the Use Case	A-P.32 from architect to precast fabricator P-A.32 from precast fabricator to architect P-C.32 from precast fabricator to general contractor	
Automation Level of Use Case	This use case is an iterated, sequential two-way flow.	
Process Model		


Fabrication Level Detailing
Architerctural Design
Precast Fabricator
General Contractor
Coordination and Design Intent Validation
P-A.32
Full panel geometry
Approval/ Mark up Corrections
A-P.32
Panel, Finish and Connection Detailing
P-E.32
Geometry, finishes, connections')
Construction Coordination

Level 2 : Use Case Definition Design-Bid-Build

This Use Case provides structural review capabilities for the architectural precast during fabrication-level detailing..

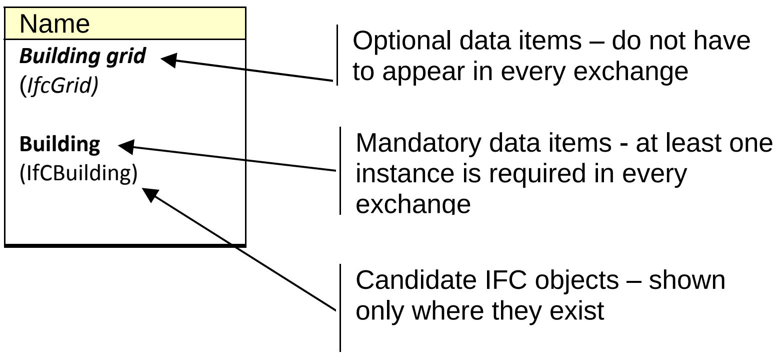
Level 2 : Use Case Definition		
Name	**Structural Design Review**	
Use Case ID	**PC-1-6**	
Domain ID	**PC-1 (Design-Bid-Build)**	
History	11/04/2007 –Created – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner	
Participants	Roles involved	Lifecycle stage
Information provider	34-25 31 00 Engineer (Structural) 34-35-17-00 Subcontractor Precast Fabricator (OR 34-35-21-00 Engineer (precast consultant)).	31-40-30-17 Product Evaluation Phase
Information receiver	34-35-17-00 Subcontractor Precast Fabricator (OR 34-35-21-00 Engineer (precast consultant)); 34-25 31 00 Engineer (Structural)	31-10-41-21 Preliminary design development phase 31-20 10 11 Preliminary Engineering Phase
Information passed	*Structural engineer reviews* shop-level model for final structural review. Problems reviewed with precast fabricator.	
Existing methods	Exchange of shop drawings, drawn on similar template, examining for conflicts on a light table.	
Software Involved	Precast detailing tools (Structureworks, Tekla Structures) and possibly structural analysis tools (STAAD-PRO, ETABS, CSI, RISA, ROBOT, etc.)	
Benefits	Final validity check for structural integrity of architectural precast.	
Information Exchanges in the Use Case	E-P.34 from engineer (structural) to precast fabricator P-E.34 from precast fabricator to engineer (structural)	
Automation Level of Use Case	This use case is an iterated, sequential two-way flow.	
Process Model		


Fabrication Level Detailing
Precast Fabricator
General Contractor
Engineer of Record
Panel, Finish and Connection Detailing
Construction Coordination
Design Review
P-E.32
Geometry, finishes, connections)
P-E.32
E-P.32
Approval Mark up Corrections

Level 3: Information Exchange Definitions

The following tables list the information exchanges for all of the use cases for both the design-bid-build and the design-build methods.

Some data items are shown in bold text and others in italics as can be seen in the legend diagram below. At least one object instance of each item shown in non-italic text must be present in an exchange for it to be valid. The items shown in italic text are optional – they need not be instanced in every exchange.



The information exchanges identify at a descriptive level all the relevant information required to realize the objectives of the exchange. They are realized in the following steps; identify if the Information Exchange is a request for information (information pull), or a transfer to another role (information push), identify business operation.

Contents

A-P.10

Level 3: Information Exchanges			
Name	Architect to precast fabricator - initial schematic design		
Information Exchange ID	**A-P.10**		
Use Case ID	**PC-1-1, PC-2-1**		
History	10/29/2007 – Created – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The architect must have modeled the building to a level of detail positioning floor slabs, column positions, and approximate size and placement of window and other openings. The structural system must be known (although more than one alternative may be considered in separate exchanges). Precast architectural panels are being considered for the façade system.		
Metadata	Architect-Owner, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
	Building grid (*IfcGrid)*	***3D control planes***	***Names, directions, spacings***
	Building (IfcBuilding)	***Data structure***	**GUID, Name, Location ,Building elements *,Approval status***
	Façades *(IfcCurtainWall)*	***Panelization Grid***	**GUID, x-spacing, y-spacing, sections Panelization data and geometry**
	Storeys (IfcBuildingStorey)	**Zone**	**Elevation, plan, thickness**
	Floors *(None)*	***Data structure***	***GUID, location, polygon, section,***
	Beams *(IfcBeam)*	***Data structure***	***GUID, Location and geometry***
	Columns *(IfcColumn)*	***Data structure***	***GUID, Location, polygon, section***
	Foundations *(IfcFooting)*	***Data structure***	***GUID, Location and geometry***
	Slabs *(IfcSlab)*	***Data structure***	***GUID, Location and geometry***
	Walls *(IfcWall)*	***Data structure***	***GUID, Location and geometry***

P-A.12

Level 3: Information Exchanges			
Name	Precast consultant recommendations to architect		
Information Exchange ID	**P-A.12**		
Use Case ID	**PC-1-1**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	Precast fabricator model contains feedback or proposed objects		
Metadata	Precast consultant reviewer, version or timestamp, design status		
Information passed	Name	Data Type	Included Attributes
Case One:	***Building grid*** *(IfcGrid)*	***3D control planes***	***Names, directions, spacings***
	Building (IfCBuilding)	***Data structure***	**GUID, Name, Location ,Building elements**, ***Approval status***
	Façades *(IfcCurtainWall)*	***Panelization Grid***	**GUID, x-spacing, y-spacing, sections Panelization data and geometry**
	Storeys (IfcBuildingStorey)	**Zone**	**Elevation, plan, thickness**
	Floor *(none)*	***Data structure***	***GUID, location, polygon, section***
	Beams *(IfcBeam)*	***Data structure***	***GUID, Location and geometry***
	Columns *(IfcColumn)*	***Data structure***	***GUID, location, polygon, section***
	Foundation *IfcFooting)*	***Data structure***	***GUID, Location and geometry***
	Slabs *(IfcSlab)*	***Data structure***	***GUID, Location and geometry***
	Walls *(ifcWall)*	***Data structure***	***GUID, Location and geometry***
	Precast Façade Panels (None)	***Data structure***	**GUID, Location and geometry, Piece Mark, Location Number**
Case Two: ***Informal response, with sketches and notes***			

A-P.20

Level 3: Information Exchanges			
Name	Architect to precast fabricator design development		
Information Exchange ID	**A-P.20**		
Use Case ID	**PC-1-2**		
History	10/29/2007 – Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The architect must have completed the model to a degree of detail satisfactory for tendering.		
Metadata	Architectural author, precast fabricator reviewer, version or timestamp, status of model		
Information passed	Name	Data Type	Included Attributes
	Building grid (IfcGrid)	**3D control planes**	**Names, directions, spacings**
	Building (IfCBuilding)	**Data structure**	**GUID, Name, Location Building elements, Approval status**
	Façades (IfcCurtainWall)	**Panelization Grid**	**GUID, x-spacing, y-spacing, sections ,reveals**
	Storeys (IfcBuildingStorey)	**Zone**	**GUID, geometry**
	Floor (None)	***Data structure***	**Elevation, plan, thickness**
	Beams (IfcBeam)	***Data structure***	**GUID, location, polygon, section, floor layer data**
	Columns (IfcColumn)	***Data structure***	**GUID, Location and geometry**
	Foundation (IfcFooting)	***Data structure***	**GUID, location, polygon, section**
	Slabs (IfcSlabs)	***Data structure***	**GUID, Location and geometry**
	Walls (ifcWall)	***Data structure***	**GUID, Location and geometry**
	Precast Façade Panels *(None)*	***Data structure***	***GUID, Location and geometry, piece mark, location number concrete material, finishes***

P-A.22

Level 3: Information Exchanges			
Name	Precast fabricator bid model for architect review		
Information Exchange ID	**P-A.22**		
Use Case ID	**PC-1-2**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The precast fabricator must have completed a full tender model, ready for submission to the architect at a level of detail allowing review.		
Metadata	Precast fabricator author, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
	Building grid (IfcGrid)	**3D control planes**	**Names, directions, spacings**
	Building (IfCBuilding)	**Data structure**	**GUID, Name, Location Building elements , Approval status**
	Façades (IfcCurtainWall)	**Panelization Grid**	**GUID, x-spacing, y-spacing, sections ,reveals, finishes**
	Storeys (IfcBuildingStorey)	**Zone**	**GUID, geometry**
	Floor (None)	**Data structure**	**Elevation, plan, thickness**
	Beams (IfcBeam)	**Data structure**	**GUID, Location, polygon, section,**
	Columns (IfcColumn)	**Data structure**	**GUID, Location and geometry**
	Foundation (IfcFooting)	**Data structure**	**GUID, Location, polygon, section**
	Slabs (IfcSlab)	**Data structure**	**GUID, Location and geometry**
	Walls (ifcWall)	**Data structure**	**GUID, Location and geometry**
	Precast Façade Panels (None)	**Data structure**	**GUID, Location and geometry, location numbers, reveals, windows, *typical connections, review status*, *connected elements***

P-GC.22

<table>
<tr><th colspan="4">Level 3: Information Exchanges</th></tr>
<tr><td>Name</td><td colspan="3">Precast fabricator bid design development for GC approval and preparation of the overall bid</td></tr>
<tr><td>Information Exchange ID</td><td colspan="3">P-GC.22</td></tr>
<tr><td>Use Case ID</td><td colspan="3">PC-1-3</td></tr>
<tr><td>History</td><td colspan="3">10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner</td></tr>
<tr><td>Preconditions</td><td colspan="3">The precast fabricator must have completed a full tender model, although this exchange may also be done iteratively before all of the information is complete.</td></tr>
<tr><td>Metadata</td><td colspan="3">Precast fabricator author, version or timestamp, status</td></tr>
<tr><td rowspan="9">Information passed</td><td>Name</td><td>Data Type</td><td>Included Attributes</td></tr>
<tr><td>Building grid (IfcGrid)</td><td>3D control planes</td><td>Names, directions, spacings</td></tr>
<tr><td>Building (IfCBuilding)</td><td>Data structure</td><td>GUID, Name, Location Building elements, approval status</td></tr>
<tr><td>Beams (IfcBeam)</td><td>Data structure</td><td>GUID, location, polygon, section,</td></tr>
<tr><td>Columns (IfcColumn)</td><td>Data structure</td><td>GUID, Location and geometry</td></tr>
<tr><td>Foundation (IfcFooting)</td><td>Data structure</td><td>GUID, location, polygon, section</td></tr>
<tr><td>Slabs (IfcSlab)</td><td>Data structure</td><td>GUID, Location and geometry</td></tr>
<tr><td>Walls (ifcWall)</td><td>Data structure</td><td>GUID, Location and geometry</td></tr>
<tr><td>Precast Façade Panels</td><td>Data structure</td><td>GUID, Location and geometry, location numbers, reveals, windows, typical connections, review status, connected elements, production management data, typical embeds, BOM.</td></tr>
</table>

A-GC.22

Level 3: Information Exchanges			
Name	Architect bid design development for GC information at tender stage		
Information Exchange ID	**A-GC.22**		
Use Case ID	**PC-1-3**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The architectural design must include the basic geometry and any typical details embeds and connection for approval.		
Metadata	Architect author, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
	Building grid (IfcGrid)	**3D control planes**	**Names, directions, spacings**
	Building (IfCBuilding)	**Data structure**	**GUID, Name, Location Building elements Approval status**
	Beams (IfcBeam)	**Data structure**	**GUID, location, polygon, section,**
	Columns (IfcColumn)	**Data structure**	**GUID, Location and geometry**
	Foundation (IfcFooting)	**Data structure**	**GUID, location, polygon, section**
	Slabs (IfcSlab)	**Data structure**	**GUID, Location and geometry**
	Walls (ifcWall)	**Data structure**	**GUID, Location and geometry**
	Precast Façade Panels	**Data structure**	**GUID, Location and geometry, reveals, windows, review status, *production management data,* BOM.**

E-P.24

Level 3: Information Exchanges			
Name	Engineer of record provides design loads		
Information Exchange ID	**E-P.24**		
Use Case ID	**PC-1-4**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The basic building structure must be set so that lateral loads can be defined		
Metadata	Engineer author, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
Case 1:	***Building grid*** *(IfcGrid)* **Building** (IfCBuilding) **Façades** (IfcCurtainWall) **Floors** (None)	***3D control planes*** **Data structure** **Panelization Grid** **Data structure**	***Names, directions, spacings*** **GUID, Name, Location, Building elements** **Approval status** **GUID, lateral design loads** **GUID , vertical design loads**
Case Two: ***Formal offline response, in a document with sketches and notes***			

A-P.32

Level 3: Information Exchanges			
Name	Architect final fabrication design for precast fabricator		
Information Exchange ID	**A-P.32**		
Use Case ID	**PC-1-5**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	Architect finalizes the design model of the precast facades. This exchange may also be iterative and therefore be done with incomplete information		
Metadata	Architect author, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
	Building grid (IfcGrid)	**3D control planes**	**Names, directions, spacings**
	Building (IfCBuilding)	**Data structure**	**GUID, Name, Location, Building elements, approval status**
	Façades (IfcCurtainWall)	**Panelization Grid**	**GUID, x-spacing, y-spacing, sections ,reveals, finishes**
	Storeys (IfcBuildingStorey)	**Zone**	**GUID, geometry**
	Floor(None)	**Data structure**	**GUID, Elevation, plan, thickness**
	Beams (IfcBeam)	**Data structure**	**GUID, location, polygon, section,**
	Columns (IfcColumn)	**Data structure**	**GUID, Location and geometry**
	Foundation (IfcFooting)	**Data structure**	**GUID, location, polygon, section**
	Slabs (IfcSlab)	**Data structure**	**GUID, Location and geometry**
	Walls (IfcWall)	**Data structure**	**GUID, Location and geometry**
	Concrete Material (IfcMaterial)	**Data structure**	**GUID, Physical properties (color and texture), comments**
	Precast Façade Panels (None)	**Data structure**	**GUID, Location and geometry, concrete material, finishes, reveals, openings**

P-A.32

Level 3: Information Exchanges			
Name	Precast fabricator submittal of final design development for architect approval		
Information Exchange ID	**P-A.32**		
Use Case ID	**PC-1-5**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The precast fabricator must have all the pieces geometry including connections, reveals & openings. No rebar required.		
Metadata	Precast author, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
	Building grid (IfcGrid)	**3D control planes**	**Names, directions, spacings**
	Building (IfCBuilding)	**Data structure**	**GUID, Name, Location Building elements, Approval status**
	Concrete Material (ifcMaterial)	**Data structure**	**GUID, Physical properties, comments, mix design**
	Precast Façade Panels (None)	**Data structure**	**GUID, Location and geometry, location numbers, piece marks, concrete material, finishes, reveals, openings, connection relationships, joint relationships**
	Joints (None)	**Data structure**	**GUID, Location and geometry, jointed elements , loose hardware**
	Connections (None)	**Data structure**	**GUID, Location and geometry, connected elements , loose hardware**

P-GC.32

Level 3: Information Exchanges			
Name	Precast fabricator submission of final design for GC coordination		
Information Exchange ID	**P-GC.32**		
Use Case ID	**PC-1-5**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The precast fabricator must have fully detailed geometry of all the pieces including connections, reveals & openings. Rebar must be fully detailed. Geometry of all parts for the erection data		
Metadata	Precast consultant reviewer, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
	Building grid (IfcGrid)	**3D control planes**	**Names, directions, spacings**
	Building (IfCBuilding)	**Data structure**	**GUID, name, location, building elements , approval status**
	Beams (IfcBeam)	**Data structure**	**GUID, location, polygon, section,**
	Columns (IfcColumn)	**Data structure**	**GUID, Location and geometry**
	Foundation (IfcFooting)	**Data structure**	**GUID, location, polygon, section**
	Slabs (IfcSlabs)	**Data structure**	**GUID, location and geometry**
	Walls (ifcWalls)	**Data structure**	**GUID, location and geometry**
	Concrete Material (ifcMaterial)	**Data structure**	**GUID, physical properties, comments, mix design**
	Precast Façade Panels (None)	**Data structure**	**GUID, location and geometry, location numbers, piece marks, concrete material, finishes, reveals, openings, element quantities and piece marks, reinforcement, embeds, prestressed reinforcement data,**
	Joints (None)	**Data structure**	**GUID, Location and geometry, jointed elements, loose hardware**
	Connections (None)	**Data structure**	**GUID, Location and geometry, connected elements , loose hardware**

P-E.34

Level 3: Information Exchanges			
Name	Precast fabricator submits final design Engineer approval		
Information Exchange ID	**P-E.34**		
Use Case ID	**PC-1-6**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The precast fabricator must have fully detailed all the pieces geometry including connections, reveals & openings, finishes, embeds and reinforcement.		
Metadata	Precast consultant reviewer, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
	Building grid (IfcGrid)	**3D control planes**	**Names, directions, spacings**
	Building (IfCBuilding)	**Data structure**	**GUID, Name, Location,Building elements,Approval status**
	Beams (IfcBeam)	**Data structure**	**GUID, location, polygon, section,**
	Columns (IfcColumn)	**Data structure**	**GUID, Location and geometry**
	Foundation (IfcFooting)	**Data structure**	**GUID, Location and geometry**
	Slabs (IfcSlabs)	**Data structure**	**GUID, Location and geometry**
	Walls (ifcWalls)	**Data structure**	**GUID, Location and geometry**
	Concrete Material (ifcMaterial)	**Data structure**	**GUID, Physical properties, comments, BOQ**
	Precast Façade Panels	**Data structure**	**GUID, Location and geometry, location numbers, piece marks, concrete material, finishes, reveals, openings, concrete properties elements quantity and piece marks, reinforcement, embeds, prestressed reinforcement data,**
	Joints (None)	**Data structure**	**GUID, Location and geometry, connected elements , loose hardware**
	Connections (None)	**Data structure**	**GUID, Location and geometry, connected elements , loose hardware, reinforcement**

E-P.34

Level 3: Information Exchanges			
Name	Engineer to precast fabricator approval and mark ups		
Information Exchange ID	**E-P.34**		
Use Case ID	**PC-1-6**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The engineer must have added comments and/or corrections into the model for pieces, connections or joints.		
Metadata	Engineer reviewer, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
	Building grid *(IfcGrid)*	***3D control planes***	***Names, directions, spacings***
	Building (IfCBuilding)	**Data structure**	**GUID, Name, Location building elements, approval status**
	Concrete Material *(ifcMaterial)*	***Data structure***	***GUID, physical properties, comments, BOQ***
	Precast Façade Panels (None)	**Data structure**	**GUID, Location and geometry, location numbers, piece marks,** ***concrete material, finishes, reveals, openings, connections*****, review status and comments**
	Joints (None)	**Data structure**	**GUID, Location and geometry, review status and comments**
	Connections (None)	**Data structure**	**GUID, Location and geometry, review status and comments**

P-GC.22

Level 3: Information Exchanges			
Name	Initial precast schematic design for general contractor review		
Information Exchange ID	**P-GC.22**		
Use Case ID	**PC-2-1**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The precast fabricator must present the model at the preliminary design stage and at a level of detail allowing early design collaboration.		
Metadata	Precast fabricator author, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
	Building grid (*IfcGrid)*	***3D control planes***	**Names, directions, spacings**
	Building (IfCBuilding)	***Data structure***	**GUID, Name, Location** **Building elements** **Approval status**
	Façades *(IfcCurtainWall)*	***Panelization Grid***	**GUID, x-spacing, y-spacing, sections ,reveals**
	Storeys (IfcBuildingStorey)	**Zone**	**Elevation, plan, thickness**
	Floor *(None)*	***Data structure***	***GUID, location, polygon, section,***
	Beams *(IfcBeam)*	***Data structure***	***GUID, Location and geometry***
	Columns *(IfcColumn)*	***Data structure***	***GUID, location, polygon, section***
	Foundation *(IfcFooting)*	***Data structure***	***GUID, Location and geometry***
	Slabs *(IfcSlab)*	***Data structure***	***GUID, Location and geometry***
	Walls *(IfcWall)*	***Data structure***	***GUID, Location and geometry***
	Precast Façade Panels (None)	***Data structure***	**GUID, Location and geometry, location numbers, piece marks, reveals, windows, typical connections, connected elements**

GC-P-A.22

Level 3: Information Exchanges			
Name	General contractor approval and review status.		
Information Exchange ID	**GC-P-A.22**		
Use Case ID	**PC-2-1**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The GC has to check and approve the designs for the architect and precast fabricator		
Metadata	GC reviewer, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
	Building grid *(IfcGrid)*	***3D control planes***	**Names, directions, spacings**
	Building (IfcBuilding)	**Data structure**	**GUID, Name, Location** **Building elements** **Approval status**
	Beams *(IfcBeam)*	***Data structure***	***GUID, location, polygon, section,***
	Columns *(IfcColumn)*	***Data structure***	***GUID, Location and geometry***
	Foundation *(IfcFooting)*	***Data structure***	***GUID, location, polygon, section***
	Slabs *(IfcSlabs)*	***Data structure***	***GUID, Location and geometry***
	Walls *(IfcWalls)*	***Data structure***	***GUID, Location and geometry***
	Precast Façade Panels (None)	***Data structure***	**GUID, Location and geometry, location numbers, piece marks, review status.**

A-E.22

Level 3: Information Exchanges			
Name	Initial architect design for engineer of record		
Information Exchange ID	**A-E.22**		
Use Case ID	**PC-2-2**		
History	10/29/2007 –Created, – Chuck Eastman, Rafael Sacks, Yeon-suk Jeong, Israel Kaner		
Preconditions	The architect must have modeled the building to a level of detail positioning floor slabs, column positions, and approximate size and placement of window and other openings. The structural system must be known (although more than one alternative may be considered in separate exchanges). Precast architectural panels are being considered for the façade system.		
Metadata	Architect author, version or timestamp, status		
Information passed	Name	Data Type	Included Attributes
	Building grid (IfcGrid)	**3D control planes**	**Names, directions, spacings**
	Building(IfCBuilding)	**Data structure**	**GUID, Name, location, building elements approval status**
	Façades*(IfcCurtainWall)*	***Panelization Grid***	***GUID, x-spacing, y-spacing, sections ,reveals***
	Storeys (IfcBuildingStorey)	**Zone**	**GUID, geometry**
	Floors	**Data structure**	**Elevation, plan, thickness**
	Columns (IfcColumn)	**Data structure**	**GUID, location, polygon, section,**
	Slabs (IfcSlab)	**Data structure**	**GUID, location, polygon, section**
	Walls (IfcWall)	**Data structure**	**GUID, Location and geometry**
	Precast Façade Panels *(None)*	***Data structure***	***GUID, Location and geometry, location number***