BIM-based Information Exchange for Functional AEC Design and Ordering Processes

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Abstract

In Architecture, Engineering and Construction (AEC) industry the exchange of information and knowledge between the participating disciplines is crucial for the success of a building project. We develop a BIM based functional design an ordering process (FDOP) to shorten the latency in collaboration between architects, engineers and contractors and perform rapid information and knowledge exchange in early project design phases. The executable information delivery manual (xIDM) is extended based on previous work to host the FDOP and to enable automated filtering and checking processes. A practical use case is developed and studied to explain the concept in details.

Keywords: executable information delivery manual, functional design and ordering, BIM-based information exchange, model flow management, exchange requirements.

1 Introduction

In the AEC industry the exchange of information and knowledge between the participating disciplines is crucial for the success of a building project. With lack of accuracy and tedious procedures these exchanges can introduce serious collaboration problems, which result in both monetary and temporal costs. Accordingly, there is a need to enable better AEC information exchange and management.

Our project is based on a process-model, slightly different from conventional design processes used in architecture and in the construction industry, but comparable with procurement-processes in the manufacturing sector. The basic notion is to take maximum advantage of the specific know-how provided by all participants in the design and manufacturing process. Interdisciplinary teams commonly perform design and engineering, while contractors are responsible for the construction process. Architects and designers stand for the conceptual ideas in a project, engineers and other specialists guarantee the technical feasibility. Contractors are usually kept out of the design process up to the bidding stage, although they have very detailed knowledge in fields like aligning construction with manufacturing and assembly, use of materials and machinery etc.

In order to ensure maximum control of their design-ideas designers hand over the result of the design-work to contractors on a very high level of detail in the bidding-process. Despite their specific know-how, contractors have little room to optimize their work on the design-level. In our project we propose not only a more effective and more reliable data exchange between designers, engineers, contractors and manufacturers, but also an adapted design-method suitable for gathering and integrating know-how into design-processes. It is based on the principle of minimal necessary specification. In every stage of the design- and manufacturing-process as much room and responsibility for optimization is to be delegated to the person or organization with the best know-how in the respective field. Delegating tasks and responsibilities to others requires exact definitions of interfaces and specifications of boundary conditions, goals and requirements. As a result design- and engineering-tasks split up into two to parts, a core task to be performed within the core-competence of the instance involved and a reliable definition of tasks handed over to others.

Conventional file-based information exchange could hardly solve this problem, because it does not address the task and role specific information exchange requirements and may lead to severe management problems for repeated task sequences (e.g. design and review cycles). It is necessary to develop a more effective approach which is able to shorten the latency in collaboration between architects, engineers and contractors and perform rapid information and knowledge exchange in early project design phases.

To solve these issues and to enable performance competition instead of price competition in the AEC design and ordering processes and to reduce waste in the design processes by eliminating multiple uncoordinated design work, preventing to design too much detail too early and introducing construction knowledge already in the early design phases, we developed a BIM-based functional design and ordering process (FDOP) (Breit et al., 2010) and the executable information delivery manual (xIDM) that hosts the FDOP. Based on the concept of the information delivery manual (IDM) (Wix and Karlshoej, 2010) the xIDM is developed to maintain AEC processes and control the information and knowledge exchange, which are considered as model flow. The xIDM also aims to standardize the design and ordering processes using BIM technology while providing the means to easily create, modify and adjust procedures, which are essential for the project organization in AEC and allow developing best practices and continuous improvement efforts. The BIM model server technologies are used to provide a central information repository, which handles reliable and comfortable process dependent information exchanges and management with customizable verification and validation, while maintaining the whole information structure of the project including all versions of design and offering sub models.

2 Methodology

We identify that information management and inter-disciplinary knowledge exchange in the early design phase between AEC professionals is a severe problem and that file-based BIM exchange based on IFCs has major problems to serve as a common basis for interoperability in AEC. We propose a process orientated solution, the FDOP and we state that extending the concept of the IDM to a computer executable version in conjunction with BIM model server technologies can improve significantly the information management process and enable rapid access to project information and knowledge to all participating professionals in real time. We develop use cases and the concept for the xIDM platform and verify it through the process of partial implementation into a software prototype. We study and learn if the concept can be implemented to a workable solution and to what extend automated process-related information exchange can be achieved. We use the xIDM prototype on two real-world practice cases. One is using the FDOP for façade element of multi-story residential building with the collaboration of architects and engineers and fabricator of a timber construction company, where information exchange used a manual file-based IDM-IFC approach. We study if and to what extend the IT-based process-oriented information exchange works and identify problems and introduce enhancements. The other is deploy the xIDM prototype on a project, that tries to enhance the design process of steel-concrete composite office buildings by providing rapid structural feed-back to architectural design iterations by computer generated and optimized structural systems. To study the interaction of the new project delivery processes and xIDM platform, we plan a design and delivery charrette, consisting of two groups of the AEC professionals and students, one using the conventional procedure and the other working with the new approach. In this paper we are presenting the work for developing the concept of the FDOP and the xIDM, while the real-world use cases will be presented in later work.

3 BIM-based FDOP

We propose a BIM-based information exchange mechanism for the FDOP that enables to give architects early industry responses to design proposals regarding building performances, constructability and costs. It uses "reduced" architectural design models from architects as functional ordering models with specifications, functional performance requirements and 3D bounding spaces describing constraints or special ranges of components' positions, e.g. an allowed position with tolerance for a window. From the EC-side engineering and fabrication offering models are provided as response to the architectural order with different levels of performance and price ratios allowing to choose and to compare the offers and to run model based performance simulations such as energy consumption, sustainability, Life circle assessment (LCA) etc.

To support the FDOP, we use the technology of the industry foundation class (IFC) standard building model schema and the IDM. Building models themselves are defined in IFC models/sub-models comprising of standard IFC's and extensions and stored in a BIM model server. We use BIMServer (Beetz et al., 2010) in our research. Based on the IDM we develop the concept of the xIDM which defines process- and role-based information exchange with specified requirements and validation rules. It helps the FDOP with secure task and role specific information exchange, which supports the management of typical iterative review and coordination task sequences and levers the use of BIM.

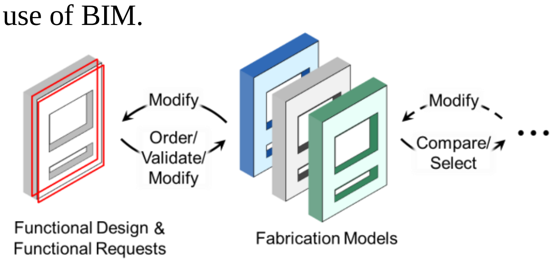


Figure 1. Functional Design and Ordering: a façade element with two windows is shown as a functional design model - the red rectangles indicate the functional requests. Three different fabrication models are offered – the different colours represent different qualities and prices.

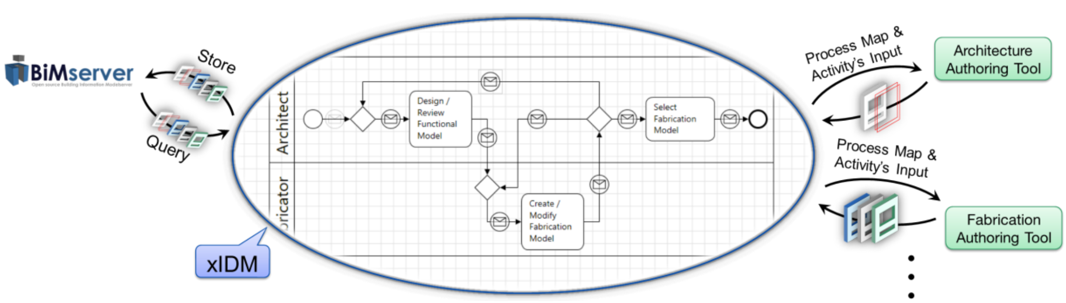


Figure 2. System Architecture

3.1 *Functional Design (FD) & Functional Requests (FR)*

A functional ordering model contains two parts, a functional design of architectural artefacts and related functional requests (see figure 1). The functional design presents an architectural design of building elements with geometry information and predefined functional performance such as "Fire Rating", while the functional requests contain extra requirements, e.g. valid value range for "Fire Rating" or size constrains of a façade element, indented to be used for validating or checking the fabrication models. Fabrication models are then offered, validated and modified based on the FD and the FR. And the fabrication model can also be used to give feedback to the architect to modify the initial functional ordering model that is the FD and the FR.

3.2 Communication

There are communications between the xIDM platform and the model server as well as between the xIDM platform and different AEC authoring tools (see figure 2). The latter is controlled by an activity a certain role has to perform and usually means that a user will download the partial IFC model with all the information needed, perform the required task and produce and upload an enhanced IFC model. This will trigger the control mechanism of the xIDM platform to manage and control the work flow by upload/query the necessary model/s to/from the server automatically and maintain the whole project model and its related sub-models and its versions.

4 The xIDM Implementation

4.1 From the IFC to the IDM

The IFC is a computer language used to describe building elements digitally, thus the same building models can be created, used and analysed directly by different computer software for different purposes maintaining the information and knowledge exchanging consistently (Eastman et al., 2011).

Although with the help of the IFC we can define a common model that could be understand by different software, we still cannot use the IFC correctly in a multi-software project, since "IFC is a weak- (or loosely) typed system and provides multiple ways to type objects" (Venugopal, 2012) and the process-specified content exchange is not clearly defined (Eastman et al., 2010). This is the fundamental reason of the establishment of the IDM, to guide software tools dealing with the usage and exchange of the IFC models. To use the IDM practically in customized AEC processes with customizable verification and validation, the xIDM is introduced and is used in a collaboration platform for managing the model flow.

4.2 Model Flow

The information and knowledge exchange in xIDM are based on IFC models, thus we use the term model flow to indicate the information exchanges between different activities. We divide the model flow from one activity to another into two steps. The first step is to filter out the partial model needed for the following activities, while the second is to check whether the selected sub-model fulfills a predefined set of constrains and/or requirements. After these two steps, the model can be considered as a valid input model for the following activities and will be delivered. If the constraints and requirements are not met by the model the connecting arrows in the PM can be colored differently, indicating the faulty conditions of the model. The procedure is illustrated in Figure 3. The model flow's status is updated automatically when any updating on the model server is performed, e.g. user uploads a functional design model or an engineering/fabrication offer model to the server via the xIDM tool.

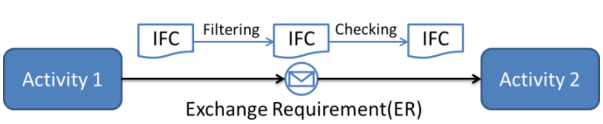


Figure 3. The model flow from one activity to the next.

4.3 xIDM Components

Similar to the IDM, the xIDM comprises of three components, Process Map (PM), Exchange Requirements (ERs) and Functional Parts (FPs). The xIDM can be formalized in xml format including the xIDM core content and additional information for visualization and illustration of the PM.

4.3.1 Process Map (PM)

On the xIDM platform the FDOP can be planned, designed and modified in the process map component (see figure 5) while the management component controls the execution. The PM defines an AEC process flow. A FDOP example is shown in figure 6a and consists of only two activities: *Design/Review Functional Model* and *Create/Modify Fabrication Model* and four other constituting components of the PM, *business role*, *gateway*, *start event* and *end event*. The gateway indicates possible model flow bifurcations and does not direct the model flow. This is done by the Exchange Requirements, which are described next.

4.3.2 Exchange Requirements (ERs)

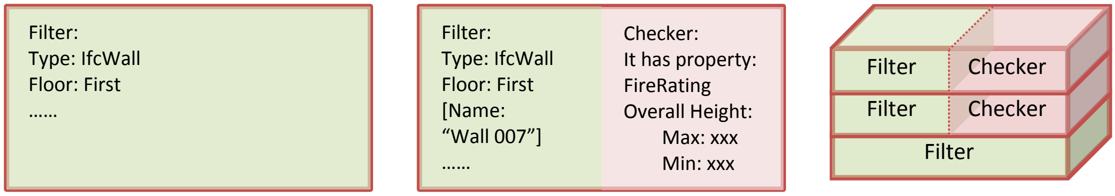
ERs specify what information should be considered as input or output for the different activities, i.e. which IFC entities or extensions should be used and what actual information should be passed from an activity to another, or technically from one software to another software. This follows the idea of model view definition (MVD) (Hietanen, 2006b) that uses document-based use case specifications for the instruction of AEC software developers implementing IFC (Berard and Karlshoej, 2011). More MVD related research can be found for example in these works, Weise et al., 2003, Katranuschkov et al., 2010 and Liebich et al., 2011. In our approach we will use ER's potential to automate the exchange process directly which enables the end user to specify content and control requirements for the model flow on the xIDM platform. In this way, we specify the ER differently from the ER or the exchange object descried for example in *BIM Handbook* and the exchange requirement model descried for example in *mvdXML* by binding the model schema and the actual necessary information together, which leads to more customized and process specific usage.

ERs can be used to filter out a partial IFC model, e.g. to query only the IFCWalls in the first floor. If necessary, the range of the actual values of specified IFC properties or extension properties may be defined as global constraints in ERs. They are defined at the planning phase and can be used and applied to models regardless of the design's details. An example is a value range for the "FireRating" property which is applied to all elements required to provide this property. Different to the global constrain a local constraint is provided within the functional request by the architect and will be used subsequently to check the offered fabrication models. The allowable location's range of the window placement in a façade element is an example. ERs control the model exchange between activities by filtering and checking of models and can work together with the gateway elements to control the model flow as an automated decision making process. For example, a gateway links to two different ERs, one indicating certain constraints are fulfilled while the others are not, thus different models will result in different model flow directions in the PM.

4.3.3 Functional Parts (FPs)

ERs are abstract containers containing a number of FPs that serve a specific AEC use case, while FPs bind series of functional rules into reusable sets. The actual definition of filtering and checking rules constitute a functional rule. It can contain filters to filter out a partial building model and/or contain filters and checkers to perform the validating on a partial model (see figure 4).

The actual implementation happens in defining the functional rule. For the user, there are two ways to define a functional rule, one is to use existed template and provide custom-make values, while the other is for advanced user to define it manually by providing filtering and validating code in programming languages, e.g. Java. For the developer, he/she need to define the filtering and validating template according to the MVD or customising requirements.



a. Functional Rule for filtering b. Functional Rule for checking c. Functional Part

Figure 4. Functional Rule and Functional Part

4.4 *The xIDM Application*

To use the xIDM for information management, we develop an application, which mainly comprises two components, a process designer and a process manager. The xIDM's process map is designed and exchange requirements are defined with the designer as well as filters and checkers that are embedded in functional parts. And the xIDM is executed and managed in the manager with interfaces to a BIM model server and the IFC compliant authoring tools used by architects, engineers and fabricators. When manage an xIDM, the ER links can be colored differently indicating different status, e.g. an ER is passed or not, to give the user an overview of the model flow and the process.

4.5 *Plugin for AEC Authoring Tools*

To enable AEC authoring tools understand the process and deliver correct models containing sufficient required information, plugins need to be developed. These plugins can reuse the functional parts created in the xIDM and will help the user to provide suitable model with necessary information by providing possibility for the user to add specified information.

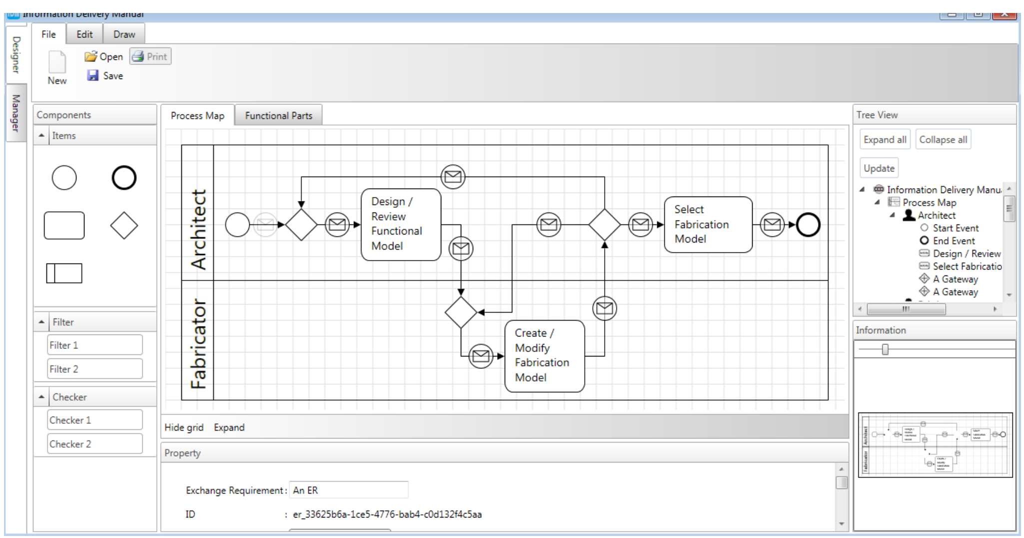


Figure 5. xIDM Client.

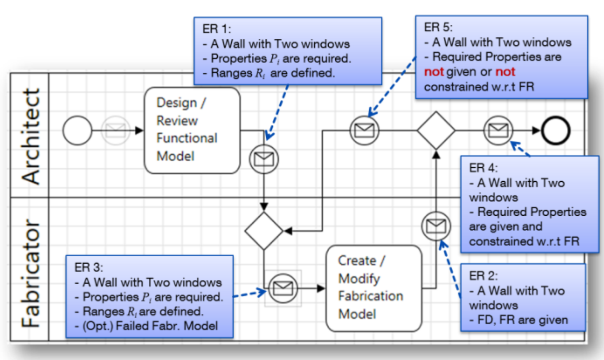
4.6 *Collaboration and Synchronization*

Two essential problems for a multi-party project are collaboration and synchronization. The xIDM platform is designed in the following way to handle them. The xIDM platform can be implemented as a desktop application connected with a BIM model server, which stores all the models remotely on the server and the xIDM formated in an xml structure as well. At the planning phase, the xIDM can be downloaded into any xIDM client installed in different local machines and uploaded after modification by project planners and/or managers, while the others will notice this modification and synchronize the xIDM. At the executing phase, the xIDM becomes static, although the user has the possibility to switch to the planning phase, modify the project's xIDM and resynchronize it with all local clients). The user works with the models that are stored only in a model server, the synchronization automatically happens in the server, and the local xIDM platform will be notified for any updating and synchronize the local model flow. It is similar to have a web application which can be directly accessed by different user simultaneously.

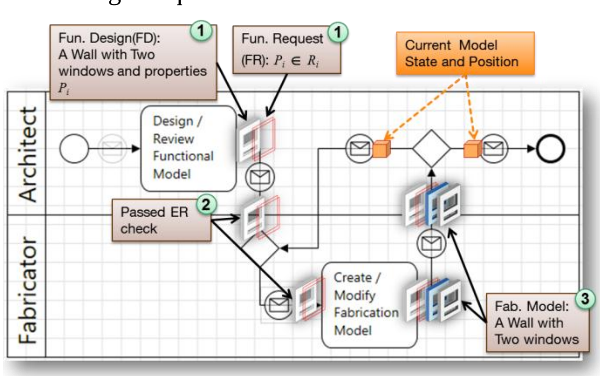
5 FDOP for Façade Elements

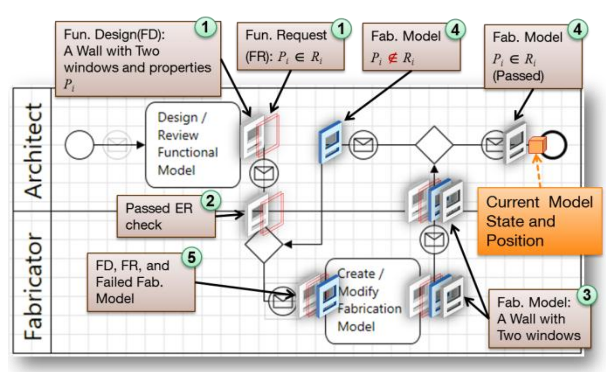
We demonstrate the concept of our approach in a practical case for the FDOP of façade elements. Figure 6a shows the process map of the FDOP, which contains two activities, "Design/Review Functional Model" and "Create/Modify Fabrication Model", five exchange requirements and two gateways. The model flow of this example could be divided into five stages (see Figure 6c).

In the first stage, the functional ordering model, which is a FD containing the architecture design and the required properties and a FR containing required constrains for the properties and the geometry is created in the first activity by the architect. In the second stage, they will be filtered and checked by "ER 1" and "ER 3", and then they can be considered as valid input information for the next activity. Based on this, the fabricator can create one/several fabrication offering model/s, which will be validated by "ER 2". The current model position and stage 3 is shown by the two colored cubes in Figure 6b. After the validation by "ER 2" the process meets a gateway that leads to two different ERs, "ER 4" and "ER 5" (see Figure 6c). This is stage 4 and "ER 4" leads to valid fabrication model, while "ER 5" leads to a failed model. The failed model can be bind into the model flow together with the FD and the FR at the first gateway. This will make the second activity change its behavior from *create* to *modify*, which then processes a modification task based on the failed one.



a. Exchange Requirements





b. The model flow at stage 1, 2, 3

c. The model flow at stage 4, 5

Figure 6. The model flow of a FDOP for Façade Elements

Based on this PM In figure 5 for manual selection of offered fabrication models a selection activity has been added as well as an ER after the obtaining of valid models and a new gateway with two ERs to enable feedback from the fabricator to the architect. The last ER is defined to check the *select* action. Thus until the architect does not perform the selection action, the model flow will not end.

6 Conclusions and Outlook

In this paper we present a concept to use BIM-based information exchange to support Functional Design and Ordering Processes in AEC industry. We extend the concept of the IDM to an executable version we call xIDM and present a practical use case. We are developing a desktop application as local client to create and use the xIDM for information management in a platform, where BIMServer is used to maintain the models and the xIDM. The communication of them is tested and the model query and updating functionality is being developed. The xIDM platform can also be connected directly with different AEC authoring tools, which can use the already defined ERs and FPs to automate the exchange process in a certain degree with the help of plugins. A concept is provided for the developer and the end user to handle the ERs either using template or customized content. Moreover, further work includes the development of the plugin, ERs, FPs and use cases and the implementation of the automated filtering checking concept we have developed as well.

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