Interdependence between Structural Engineering and Construction Management
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DATA AND PROCESS MODEL FOR ADVANCED INTEGRATION OF MEP INTO BIM PROJECTS

RAINER PARTL[1], STEFAN HAUER[2], and MICHAEL MONSBERGER[1]

[1]*Institute of Construction Management and Economics, Graz University of Technology, Graz, Austria*

[2]*Sustainable Thermal Energy Systems, AIT Austrian Institute of Technology GmbH, Vienna, Austria*

The coordination of mechanical, electrical, plumbing (MEP) and architecture is a most important task in BIM projects. Open data exchange based on BIM formats such as the Industry Foundation Classes (IFC) is an important basis for advanced collaboration in complex project environments. It facilitates performance-based design concepts as multidisciplinary teams can more easily combine task-specific design and simulation tools. An analysis of the IFC4 standard pointed out, that MEP components are not sufficiently specified yet in order to provide such functionality. Moreover, MEP specific guidelines and process models describing the various interactions between architectural and MEP design in a BIM project are still lacking. This paper thus presents a comprehensive MEP data model that complements the current state of IFC. In addition, an associated BIM process model using Business Process Model and Notation (BPMN) that outlines the application of the data model in different design stages of a project is introduced. For this purpose, we take an air-handling unit as example and apply the developed model to an air-handling unit of a campus building at Graz University of Technology. The presented results support architects, MEP engineers, and BIM managers in the project-specific implementation of air-handling unit models and the set-up of a suitable process for the integration into the project.

Keywords: MEP coordination, Air-handling unit, LOG, LOI, IFC, BPMN.

1 INTRODUCTION

The coordination of mechanical, electrical and plumbing (MEP) systems is a key success factor in complex building projects. The knowledge required is usually tacit and seldom documented (Wang and Leite 2016). In complex buildings, (e.g., research laboratories, hospitals, and commercial buildings) the density of MEP systems is typically high resulting in substantial investment costs. The collaboration between different project participants is usually a challenging task in such projects (Riley *et al*. 2005). The changing of architectural design and input requirements from other stakeholders (owner, structural engineer, etc.) are usually a time-consuming factor for the project participants during the project lifecycle (Park and Lee 2017).

Boktor *et al.* (2014) and Park and Lee (2017) reported, that MEP engineering usually dominates the modeling and coordination process in both, traditional 2D-design as well as building information modeling (BIM) projects, due to high rates of information dissemination. Specifically, the interaction and exchange of information between architecture and MEP engineers is a very close process, compared to that of the other project participants (Park and Lee

2017). In future, the parameters of 3D objects in a BIM model will provide a higher quality of the needed information to improve the performance of collaboration (Eastman *et al.* 2011).

The objective of this paper is to introduce five levels of geometry (LOG) of an air-handling unit and to present a parametric data model that complements the current state of industry foundation classes (IFC). In addition, we introduce an associated BIM process model using business process model and notation (BPMN) that outlines the application of the data model in different design stages of a project.

2 METHODOLOGY

In this paper, an air-handling unit is considered as an example. Air-handling units are usually cost-intensive and spatially demanding in MEP equipment rooms. We refer to the planning data of the building PTC 2 (Production Engineering Centre) on the campus of Graz University of Technology. At the time when the building was designed (around 2010), the planning was done with traditional 2D-drawings. For this paper we selected an air-handling unit of this building, which provides the seminar-rooms with supply and exhaust air in the first floor. It is an air-handling unit with a heating function, equipped with a rotary wheel for heat recovery. Thermodynamic air treatment functions such as cooling, dehumidifying and humidifying are not part of this particular air-handling unit.

The geometric representation follows the recommendations of the BIM Forum (2018). Moreover, the LOG design of the air-handling unit was set up in compliance with the existing 2D-drawings of the building's ventilation system. Relevant parametric data for various design stages are mapped with the IFC-standard. In order to investigate the interaction between the MEP engineer and other project participants, we explore the information flow associated with such a unit during the planning phase by using BPMN as a modelling language.

3 RESULTS

The results are grouped into three parts and presented in the following. First, five levels of a geometric model of the air-handling unit are represented. In a next step, the relevant information of the air-handling unit for MEP planning are listed in tabular form as a parametric data model and compared with the IFC data schema. Finally, the collaboration and information data exchange during the various design stages are illustrated in a BPMN-model.

3.1 LOG Layout for an Air-Handling Unit

The relevant parts of the considered air-handling unit are represented as 3D model. In addition, peripheral equipment such as routes for supply and return systems as well as space for installation and maintenance are considered. The first two levels of geometry (LOG 100 and LOG 200) are shown in Figure 1. Subsequently, the progression to LOG 300, LOG 350 and LOG 400 is illustrated in Figure 2. The typical characteristics of every LOG stage are explained in the following:

LOG 100: In an early design stage, the air-handling unit is ashlar-formed. In the context of structural requirements, the approximate size of the plinth is illustrated for static load calculation. The space requirements for duct connection, maintenance and installation of supply lines are indicated in yellow coloring. These space requirements would usually be depicted as volumes, but for the sake of better illustration they are reduced to areas in the figures.

LOG 200: For LOG 200 the conceptual design of the air-handling unit is refined. Based on functional requirements set by the client, the basic subcomponents of the unit (e.g. heat exchangers, fans, filters etc.) are defined. Compared to the previous LOG, level 200 thus shows the individual components of the unit and indicates the function of each with an appropriate symbol. The preliminary size of the single components is for example important to determine the total length of the air-handling unit. The rough size of the components and their location are relevant to specify wall openings and transportation routes required to bring the assembled unit into the MEP equipment room. Furthermore, the duct connections of the air distribution systems are shown in rudimentary form.

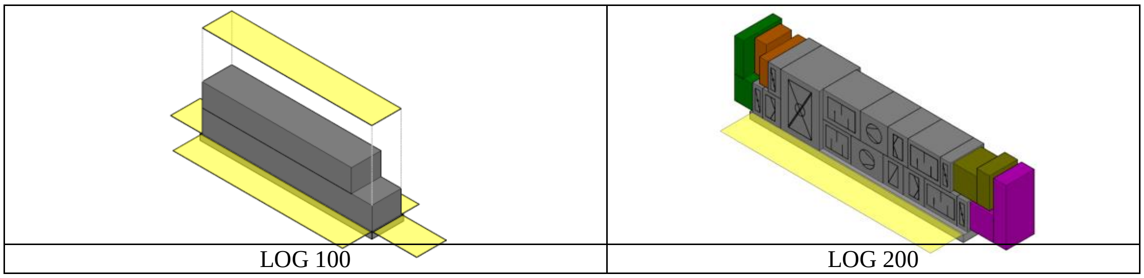

Figure 1. Geometric models for LOG 100 and LOG 200 of an air-handling unit.

LOG 300: Level 300 corresponds with the design development phase in the overall planning process. It is important to provide all relevant information for the bidding process and the award of contract and to provide other disciplines with required information. For this purpose it is necessary to prepare a detailed geometric design including information about associated electrical equipment such as frequency converters (FC), motors (M), pressure difference sensors (Δp) etc. required by the electrical engineering and building automation. In contrast to the previous representation, the duct connections are shown in detail now. Additionally, the ports of the waterside connection of the air heater are introduced.

LOG 350: This LOG refers to the construction phase. The unit is thus modeled with real dimensions obtained from product data by manufactures. It shows the specified geometry of a certain product, which differs from the design representation of LOG 300. In Figure 2 (middle), the heat recovery system of the chosen product is for example split up into the rotary wheel and non-specific (empty) sections for maintenance, which are connected by a damper. Moreover, the number of individual components differs. For example, two components (e.g. ventilator and silencer) are combined in a single unit.

LOG 400: Level 400 represents the status of an as-build model. The illustration of the components is basically equal to that of the previous level. The main difference is that components requiring maintenance are highlighted in yellow. In addition, the revision doors are also shown.

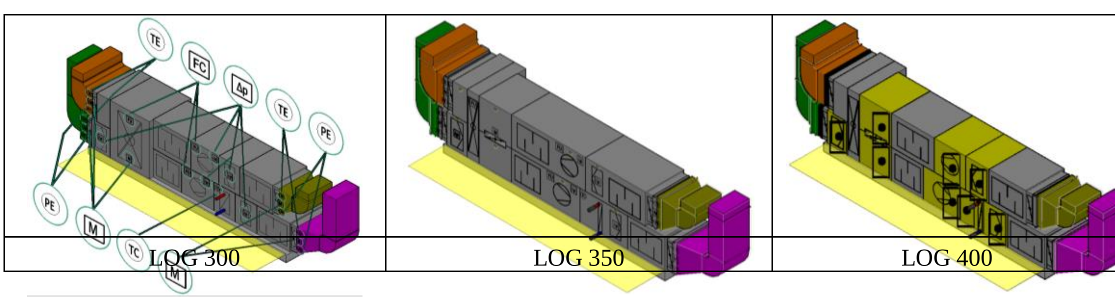

Figure 2. Geometric models for LOG 300, LOG 350 and LOG 400 of an air-handling unit.

3.2 Parametric Data Model of an Air-Handling Unit

In the following, the design stages from the conceptual design until the bidding and award of contract are considered. The most important parameters of the first three levels of information (LOI) are explained and compared with the IFC4 Add 2 standard. IFC is a neutral and software independent data format providing interoperability among project participants working with different software tools. In order to provide this basic functionality and additional features such as quality assurance based on model checking, it is essential that IFC data models including MEP component models are as complete as possible. For this reason, relevant parameters of the considered air-handling unit were identified and compared with the IFC data schema in order to evaluate the completeness of the IFC4 standard. The investigated parameters are grouped into parameters specifying the entire air-handling unit (Table 1) and into parameters describing specific sub-components of the unit (Table 2).

Table 1. Mapping of parameters of an air-handling unit for different LOIs and compared with IFC.

Parameters of the entire air-handling unit	Specific parameter	LOI 100	LOI 200	LOI 300	IFC data schema	
					Exist	Missing
Air volume flow		x	x	x	x	
Space requirements		x			x	
Material			x	x	x	
Geometry	Length, wide, height	x	x	x	x	
Weight		x	x	x	x	
Building automation control system	Number of switch cabinets	x				x
	Measurement equipment (sensor)		x	x	x	
	Digital information - Analog in- and output - Digital in- and output			x		x
Electrical parameters	Electric load estimate	x			x	
	Electric power (current, voltage)		x	x	x	
Internal pressure loss			x	x	x	

Table 2. Mapping of parameters of sub-components of an air-handling unit and compared with IFC.

Sub-components of the air-handling unit	Specific parameter	LOI 100	LOI 200	LOI 300	IFC data schema	
					Exist	Missing
Filter	Filter type		x	x	x	
	Filter grade			x		x
Heat recovery system	Type specification (e.g. rotating heat recovery system)		x	x	x	
	Exhaust and outlet temperature		x	x	x	
	Heat and humidity efficiency		x	x	x	
Air heater	Outlet temperature of the heat recovery system and supply air temperature		x	x	x	
	Thermal power		x	x	x	
	Proportion glycol / water		x	x	x	
	Return and flow temperature		x	x	x	
	Dimension of waterside connection			x		x
Duct silencer	Insertion loss (octave band)		x	x	x	
	Number of scenery			x		x
Fan	Sound power level (octave band)		x	x	x	
	External pressure loss (total pressure)		x	x	x	

The parameters in Table 1 are considered to be particularly relevant for the entire planning team whereas the parameters in Table 2 are considered to be mainly relevant for MEP planners.

As an example, the space requirements are essential for the early architectural design stages (LOI 100). In addition, load estimates for electrical engineers and building automation (BA) engineers are required. This information is relevant in the following design stages (LOI 200, LOI 300). Parameters such as geometry, weight, and the air volume flow are important in all design stages. In the building automation domain of IFC, the switch cabinet is not defined. Furthermore, detailed information on sensors and other parameters (filter grade, dimension of water side connections, number of scenery) are still lacking. The detailed specification of the sub-components takes mainly place in the full conceptual design phase (cf. Figure 3). The corresponding parameters are thus primarily relevant for LOI 200 and LOI 300 as shown in Table 2. The identified parameters are well covered by the IFC standard.

3.3 BPMN Model of an Air-Handling Unit for the Design Stages

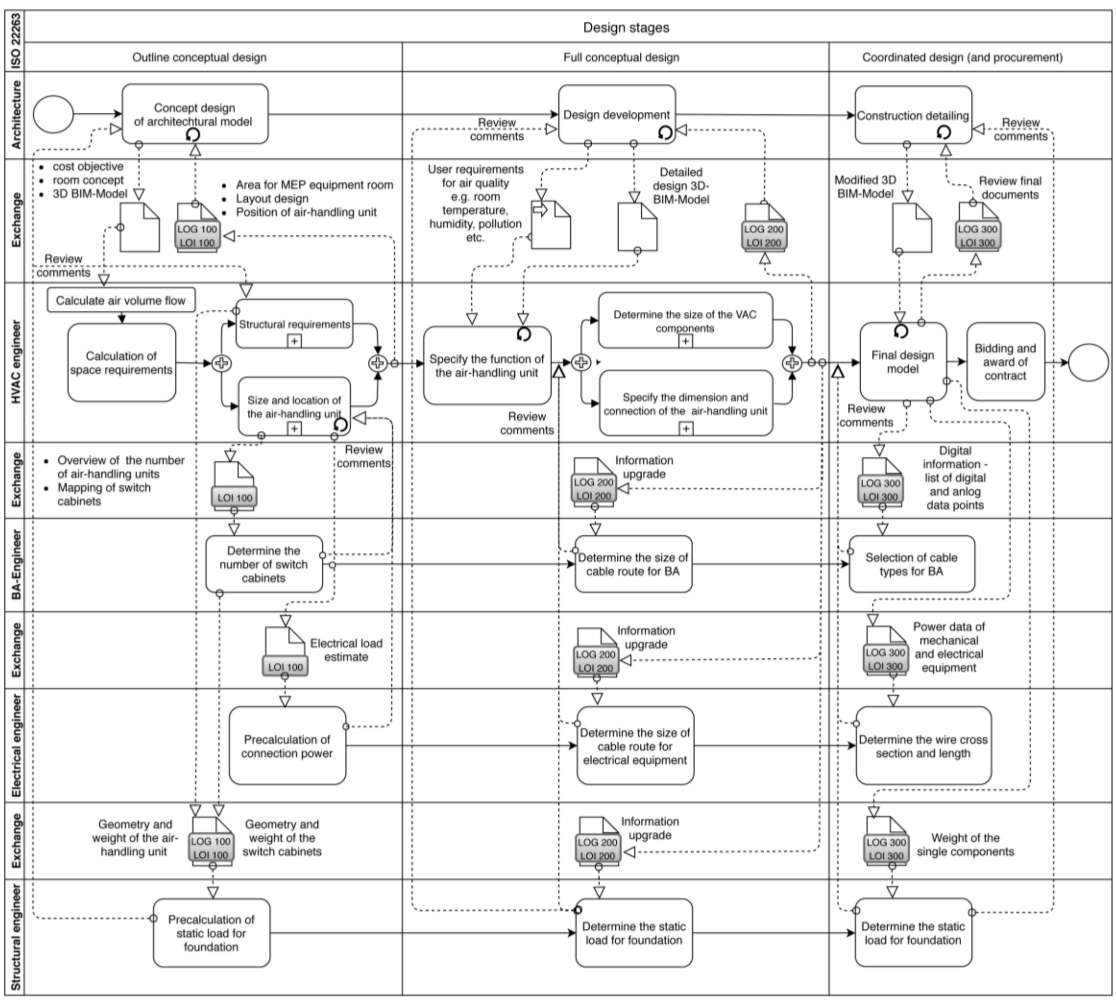

Figure 3. BPMN model of the interaction and workflow between the project participants for different design stages of an air-handling unit.

The information flow for the air-handling unit during the planning phase is explored in Figure 3 using the BPMN methodology in order to investigate the interaction between MEP engineering and the other project participants.

The structuring of the design stages is done according to the ISO 22263 (2008) standard. Figure 3 shows that even the design of a single component such as an air-handling unit requires the interaction of many different project participants. It illustrates the different disciplines and the required information exchange between individual project tasks. The iterative information exchange leads to a higher information level and more detailed geometric model. The requirements for the LOI and the LOG can be different for project participants. As an example, the building automation (BA) engineer and the electrical engineer primarily need alphanumeric information from the heating ventilation and air conditioning (HVAC) engineer in early design stages. The figure shows that the rate of information exchange between the HVAC engineer and the architect is high.

4 CONCLUSION

The paper discusses a generic BIM model of an air-handling unit. For this purpose, different levels of geometry and relevant parameters for designing an air-handling unit are explored. The LOG illustrations consider the requirements of MEP engineers as well as other project participants in different project phases. An evaluation of IFC4 Add 2 shows that most of the relevant parameters are covered by this standard. However, parameters in the building automation domain and some parameters required for the bidding and award of contract are lacking in the IFC data schema. The geometric and the parametric model are an integral part of the information exchange flow in the BPMN model. The interdisciplinary work flow during the design stages demonstrates that many project participants are involved in the planning process of an air-handling unit. The described approach could be applied to further components in order to map complete systems.

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