Information Exchange Requirements to Support Commissioning of HVAC and Building Envelope Components During an Energy Retrofit Project - A Comparative Case Study

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ABSTRACT

In order to support a variety of commissioning processes in an automated way, differences and commonalities regarding information exchanges and data flows associated with the commissioning of different types of systems and components should be identified and formalized. In relation to this, we investigated the construction phase of an energy retrofit project in Philadelphia, PA. Specifically, we studied two systems that directly affect the energy consumption, occupant comfort and the operation costs of a facility: the Heating Ventilation and Air Conditioning (HVAC) system and the building envelope. First we identified tasks, stakeholders and required information exchanges. Then, comparing these information exchanges with the Model View Definition of the Industry Foundation Class schema, we analyzed whether these exchanges exist or have to be created to support the use of computational tools during commissioning processes. This paper summarizes our findings.

INTRODUCTION

The commissioning process during construction is used to ensure the completion of the construction tasks within the project specifications and requirements, satisfying the defined quality standards and meeting the Owner's Project Requirements (OPR). This process can be initiated and applied during all phases of a facility life-cycle (pre-design, design, construction, occupancy or operation phase) with many stakeholders and different tasks involved in it (ASHRAE, 2005). In order to support the commissioning process in an automated way, the information requirements (processes, communication channels, data collection, and information exchanges) among the different tasks, stakeholders and processes needs to be formalized. As a contribution towards this large-scale goal, this paper describes a study that targets the inspection and testing processes during the construction phase of an energy retrofit project. Specifically, components of the Heating, Ventilation and Air Conditioning (HVAC) system and the building envelope are analyzed in order to propose a formalization of their information requirements during the commissioning processes.

PROBLEM DEFINITION AND RESEARCH APPROACH

Every year, lack of interoperability in construction projects leads to $15.8 billion in losses in the US construction industry (NIST, 2004). In order to overcome this scenario, several standards have been developed to support the formalization of information exchanges and data flows in construction projects (Eastman et al., 2011). Pursuing the assessment of how current standards support the commissioning process and for identifying additional elements that need to be added to the standards, the HVAC system and the building envelope during the inspection and testing phases of the commissioning process of an energy retrofit are studied. The selected case study is the Building 661, located in Philadelphia, PA, US. It is part of the Department of Energy's Efficient Buildings HUB (EEB Hub). Through the energy retrofit, it seeks to achieve LEED Gold Certification (Kieran Timberlake and consultants, 2013).

Given the focus towards energy efficiency and the large scope of the commissioning process, only some of the components that have a high impact on energy consumption during occupancy and operation phase of buildings have been targeted to be investigated. After a literature review, the research team concluded that the components to analyze initially are: insulation of ducts of the HVAC system, and the roof of the building envelope. The insulation of ducts was chosen because duct leakage leads to an increase of fan power consumption (Diamond et al., 2003), then retrofitting the insulation of ducts can lead to energy savings between 16% and 18% with a low investment (Jump et al., 1996) and (Proctor Engineering Group, Ltd, 1995). Additionally, the roof was chosen because in heating-dominated climates roof is the primary heating loss component (Hootman, 2013). Also, as it has been stated by several authors (Balaras et al., 2007), (Mohsen & Akash, 2001), its proper insulation can lead to energy savings between 2% and 14%. In this case, Philadelphia, PA has a heating dominated climate (BizEE, 2013).

Pursuing the definition of a set of formalized information exchanges to use when completing activities within the specifications and OPR, an analysis of the components based on form, function and behavior was done. Processes, information exchanges and data flows were identified and analyzed in order to develop Model View Definitions (MVDs). Finally, these MVDs were compared with the information exchanges existing in one of the current standardized schemas for product modeling: Industry Foundation Classes version 4 (IFC4) (BuildingSmart, 2013).

Other researchers have extended IFC to model specific HVAC components. For example, Bazjanac et al. (Bazjanac et al., 2002) developed MVDs including static information of HVAC components (type, placement and connections) and dynamic information related to performance values. However, although such models are very useful, it did not include the information about insulation of ducts.

RESEARCH METHODS

Use cases were developed in order to define the information exchanges related to the inspection and testing phases during the commissioning process. They identified target users, goals, current state and ideal state, expected impacts of the standardization and standards and codes used. Then, based on the use cases, standards (ASTM, 2012), guidelines (AABC Commissioning Group, 2005) (ASHRAE, 2005), building specifications (Kieran Timberlake and consultants, 2013) and reports (ARAMARK, 2013) gathered from the Commissioning Agency (CA) and the research team involved in the project, process models were formalized to understand the data flow and the information exchanges involved.

The process models were divided in three phases that the CA and the research team of the EEB HUB agreed: planning, implementation and documentation. The first two are based on the Associated Air Balance Council Commissioning Guideline (AABC Commissioning Group, 2005) and the last one on the ASHRAE guideline 0-2005 (ASHRAE, 2005). At the this level of detail, the key tasks are the same for inspection and testing processes and also for both components as it can be seen in Figure 1.

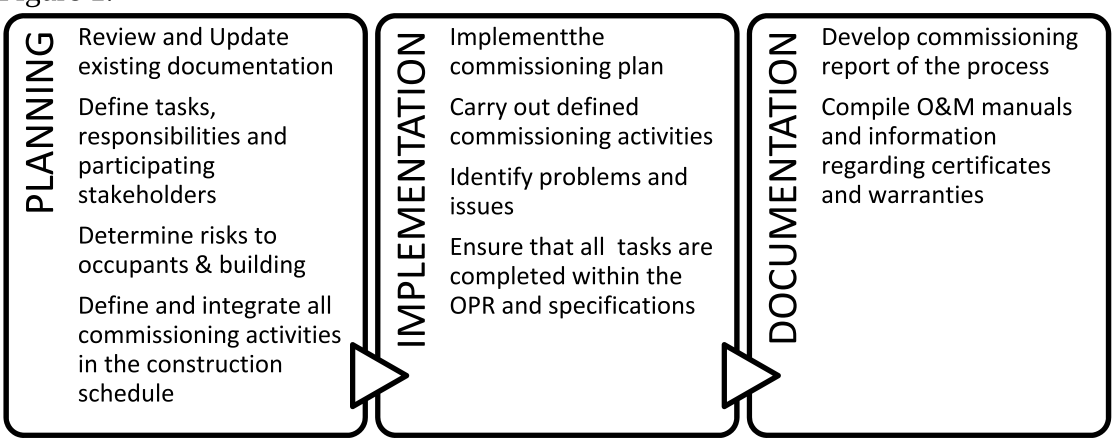

Figure 1. Phases and key tasks involved for inspection and testing

In order to break up the process models, each one of the identified tasks was divided in subtasks, which were assigned to its corresponding responsible stakeholders (designers, general contractor, HVAC system/Building Envelope subcontractor, HVAC system/Building Envelope testing company and Commissioning Authority) based on the use cases. Following this, and according to the collected information, information exchanges for the tasks (input and outputs) and the documents containing such information were identified. A unique ID number was assigned to the documents in order to highlight their usage over the entire construction process (see Table 1). Later, the information contained in these documents was used to create MVDs, with the goal of comparing the information exchanges with the existing IFC4 definitions for the selected components. These definitions with its corresponding property sets (see Table 2) were collected from building smart website (BuildingSmart, 2013).

Table 1. Information exchanges required between the tasks

ID	DOCUMENT NAME
1	Owner's Project Requirements (OPR)
2	Basis of Design (BOD)
3	Information generated during bidding phase to update OPR and BOD
4	Coordination and shop drawings
5	Technical Submittals defined in design phase
6	Project specifications (Kieran Timberlake and consultants, 2013)
7	RFI generated from stakeholders reviews
8	Commissioning plan (ARAMARK, 2013)
9	Risks to occupants and building according each activity
10	Environmental control of systems of particles to be released into occupied areas and conditions that can affect the building
11	Activities schedule generated by the GC
12	Inspection and Special Inspection report defined in project specifications (Kieran Timberlake and consultants, 2013)
13	Manufacturer's technical representative's field report
14	Factory's Authorized Service Representative's reports
15	Inspection log defined in project specifications (Kieran Timberlake and consultants, 2013)
16	As-built record drawings generated during construction phase
17	LEED submittals defined in the project specifications (Kieran Timberlake and consultants, 2013)
18	Construction Indoor Air Quality Management Plan defined by LEED requirements
19	Construction checklists defined for inspection and testing
20	Safety Plan during activities completion
21	Sampling report of documents generated for inspection/testing during construction phase
22	Report from inspection/testing site visits
23	Issues report from inspection/testing
24	Request for information generated from construction phase
25	Installation completion report
26	Inspection/testing commissioning progress report
27	Construction progress report defined in project specifications (Kieran Timberlake and consultants, 2013)
28	Lesson Learnt from installation, inspection and testing report
29	OandM manuals of HVAC systems
30	HVAC system / Building Envelope inspection/testing final report
31	Owner construction approval
32	Means and Methods to complete defined tests
33	Verification procedures for each test
34	Personnel Safety plans during inspection/testing activities
35	Equipment/assembly safety plans during installation/inspection/testing
36	Construction checklist final report
37	Records of data from testing activities
38	Report of analysis of testing records

Table 2. IFC4 MVD entities related to HVAC ducts and roof

IFC4 MVD: HVAC DUCTS	IFC4 MVD: ROOF
IfcDuctFitting	IfcRoof
IfcDuctFittingType	IfcRoofType
IfcDuctSegment	IfcRoofTypeEnum
IfcDuctSegmentType	
IfcDuctSilencer	
IfcDuctSilencerType	

RESULTS

At the level shown in Figure 1 for the inspection and testing process models during the commissioning process, the only difference that exists between the HVAC system and the building envelope is that for the latter, mock-ups might be needed prior starting the process. They have to be inspected and tested in order to “verify selections made under sample submittals and to demonstrate aesthetic effects and set quality standards for fabrication and installation” (Kieran Timberlake and consultants, 2013). When the process is analyzed in detail, the similarities between the information exchanges of the HVAC system and roofing components are: the LEED certification requirements (Material and Volatile Organic Compound (VOC) reports), the codes that (the component) complies, material, warranty, and location. However, when comparing these information exchanges with the existing IFC4 entities, the information associated with first two does not exist. Table 3 summarizes the information requirements and its value type (string, Boolean or double) that have to be created in the IFC4 specifications to support the LEED Gold certification.

Table 3. Information requirements for LEED Gold certification

INFORMATION REQUIREMENTS: MATERIALS	INFORMATION REQUIREMENTS: VOC
Product [string]	Contractor [string]
Manufacturer [string]	Specification section [string]
Total Material cost (excluding labor) [double]	Submittal number [string]
Is this salvaged and reused material? [Boolean]	Product type or application [string]
Recycled content	Product Name [string]
Post-consumer % [double] (include letter) [string]	Manufacturer [string]
Pre-consumer % [double] (include letter) [string]	VOC content (g/l) [double]
Raw Material Extraction	Backup documentation? [string]
Location of manufacturer (city, state) [string]	Authorized representative [string]
Distance to manufacture location [double]	Date [string]
Backup documentation included? [string]	Represented Company [string]
Authorized representative [string]	
Date [string]	

Represented Company [string]	

Afterwards, analyzing the specific information exchanges for the insulation of the ducts of the HVAC in the IFC4 MVD, it is found that insulation is only defined for: IfcDuctFitting and IfcDuctSegment. In these entities, the insulation is defined as "insulation" in the Material Layer Set (IfcMaterialLayerSet). Herein, the insulation is defined by LayerSetName, which defines the *name* ("insulation"), *description* (description of the defined layer). Also, MaterialLayers (IfcMaterialLayer) allows the attribute definition of: *material, thickness* (LayerThickness), indication if the material layer represents an *air layer* (IsVentilated), *name, description, category* (of the thermal insulation) and *priority* (in relation to connected elements). Table 4 summarizes the identified information exchanges that are needed to define the insulation of the ducts of the HVAC system and do not exist in the current IFC4.

Table 4. Attributes needed in IFC4 MVD for insulation of HVAC ducts

GENERAL DESCRIPTION	STRING	DOUBLE	BOOLEAN
Insulation Materials	Make, model, codes that complies, ASTM standard designation, type and grade	VOC content, Thermal conductivity, water-vapor permeance thickness,	Indoor application, factory-jacket or field-jacket,
Insulation installed indoor		Flame-spread index, smoke-develop index, maximum use temperature, clearance requirements for installation, space required for maintenance	
Factory-applied jacket			Self-sealing
Tapes	Make, model, Color, type, material, codes that complies	Width, thickness, adhesion, elongation, tensile strength	
Securements	Type, make, model, material, seal type	Thickness, diameter, length to suit depth of insulation	
Mastics	Make, model, codes that complies, color	VOC content, permeance, service temperature range (minimum and maximum), solids content(% by volume and weight)	Water-based, indoor and outdoor use
Sealants	Type, make, model, color	VOC content, service temperature range (minimum and maximum)	Indoor application?

Finally, analyzing the specific information exchanges of the roof component of the building (metal panels) in the IFC4, we found that roof is defined by: IfcRoof, IfcRoofType and IfcRoofTypeEnum. Within these entities, the main definitions of the roof are in the property set Pset_RoofCommon. It has some of the required definitions for a retrofit as: *status* of the element (new, existing, etc.), *acoustic rating, fire rating* and *thermal transmittance*. However, as in the HVAC system, the insulation details (sealants and auxiliary roofing materials) are not defined (only the U-value is defined in the Thermal transmittance). Table 5 summarizes the missed details regarding insulation and quality standards of the roof in the current IFC4.

Table 5. Attributes needed in IFC4 MVD for Roof (metal panels)

GENERAL DESCRIPTION	STRING	DOUBLE	BOOLEAN
FM Global certificates for all roofing materials	Fire/windstorm classification, Hail Resistance (MH)	Thermal Movements (ambient temperature, material surface temperature)	FM approval
Auxiliary roofing materials	Type, name	Thickness	Complies with VOC content
Roof insulation	Codes that complies		
Sealants	Type, material, grade, class, use	Width, thickness	

CONCLUSIONS

The objective of the research described in this paper was to identify the required information exchanges that support the commissioning process of the HVAC system and building envelope in an energy retrofit and compare them with the current IFC4 specifications. The initial analyses of the results highlighted that the information exchanges for the ducts of the HVAC system and roof required to achieve the LEED Gold certification do not exist in the current IFC4 specifications. Adding the required information exchanges of the studied components to the IFC4 MVDs, will allow supporting the achievement the LEED Gold certification in an automated way.

Also, several identified information exchanges regarding the insulation of ducts of the HVAC system and roof were not found in the current IFC4. Special attention should be paid to these information exchanges during the commissioning process because significant energy consumption improvements can be gained from these elements (Diamond et al., 2003), (Hootman, 2013) (Balaras et al., 2007) and (Jump et al., 1996). Hence, adding them to the IFC4 will be beneficial during the operation of a facility.

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