Feasibility and Fidelity of Data Exchange through IFC for Building Commissioning

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Abstract

The building commissioning (BC) ensures that the various interacting systems in a building are properly installed and operating. It is a process requiring extensive data exchange among different participants across multiple project phases. The Industry Foundation Classes (IFC), a widely supported data exchange standard in the building industry, can play an important role in building commissioning by enabling interoperability among building commissioning, architectural design and facility management tools. In this paper, we explore whether the current IFC release can meet the requirements of the building commissioning. We consider several BC-related test cases to show how well the IFC can support the BC-related data exchange and discuss what extensions to the current IFC are desired.

1. Data Exchange in Building Commissioning

Building commissioning (BC) is a multi-phase, multi-participant and systematic process of determining that interacting building systems and components perform consistently with design intent and the owners specified performance requirements [ODE 1997]. This process has significant benefits: improved energy efficiency; improved occupant comfort; and reduced operation and maintenance costs. A BC process progresses through several phases: the pre-design phase; the design phase; the construction/installation phase; the acceptance phase; and the post-acceptance/occupancy phase [ASHRAE 1996].

To make it successful, many different parties need to participate in the building commissioning process: commissioning agents; design professionals; contractors; subcontractors; and manufacturer representatives. Thus, a large number of people need to bring information to, and extract information from, this process. As building commissioning is currently practiced, this information is mainly about Heating,

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Ventilation, and Air Conditioning (HVAC) equipment, its related systems and subsystems, their designers' intent, and functional inspection activities. To enable data exchange in the building industry, a number of product and process models such as the Industry Foundation Classes (IFC) [IAI 2003a] are under development. These product and process models are intended to break down barriers that hinder the sharing of data between different software packages and improve interoperability by creating a well-accepted data representation and protocol for its exchange. Current models have focused primarily on traditional representing tasks associated with design, construction and facility management and hence the data exchange needs associated with the BC process may not be well supported.

This paper is part of an on-going research study, sponsored by the National Institute of Standard and Technology, which aims at determining the requirements for process and product models that support the BC process. One of our objectives is to identify the capabilities of the IFC standard in supporting BC-related data exchange. In this paper, we discuss how well the BC requirements are satisfied by Release 2x2 of the Industry Foundation Classes (IFC), which is the latest release of a widely supported data exchange standard in the building industry. Section 2 provides an overview of this release of the IFC standard from the perspective of supporting data exchange in support of BC related activities. Sections 3 and 4 discuss our two main evaluation activities: (a) generating a BC data model that reflects real world BC test cases and matching the IFC to the BC data model; and (b) testing how the IFC are utilized by the commercial CAD software packages to exchange BC-related data. Section 5 presents discussions on what we have done and Section 6 discusses what extensions are desired for the future development of the IFC.

2. IFC support for the BC process

The IFC data exchange standard is an effort initiated by the International Alliance for Interoperability (IAI) to enable interoperability between different software systems in the Architectural/Engineering/Construction and Facilities Management industries [IAI 2003a]. The first IFC release was introduced in 1997. It was built on the technologies developed for the STEP product model specification [ISO 1994]. Initially, the IFC standard mainly focused on exchanging object descriptions, notably their geometric data, through CAD software packages. However, since then, the IAI has continuously expanded the IFC specification, which has grown rapidly, covering areas like building services, codes, architecture, construction, estimating and facility management and specifying substantial amounts of non-geometric data. The IFC specification contains two basic kinds of information elements: ENTITY, which defines on object (e.g. real world object, relationship and property), and TYPE, which defines a simple (e.g. Integer) or complex (e.g. Enumeration) data type. The latest release, IFC R2x2, is a significant update of the IFC standard, especially in the heating, ventilating and air conditioning (HVAC) domain. Not only did the architecture greatly change, but also the covered scope was largely extended, where the number of ENTITYs is almost doubled from 370 in the prior release to 623 in R2x2.

The IFC schema has four layers (i.e. Resource, Core, Interoperability and Domain layers), each of which contains a set of modules (sub schema) that organize related elements. The elements are interrelated through inheritance and peer-to-peer relationships. The BC process usually involves modules of *IfcHvacDomain, IfcSharedBldgServiceElements, IfcFacilitiesMgmtDomain, IfcSharedFacilitiesElements* and other necessary supporting domains. For example, the *IfcHvacDomain* schema defines basic object concepts required for interoperability within the HVAC domain.

Partially due to the result of the IAI Building Services project BS-8 [IAI 2001], enhancing HVAC interoperability was one of the major objectives of the IFC R2x2 release. The *IfcHvacDomain* module has been significantly modified in IFC R2x2. The number of ENTITYs has increased to 31, compared to 6 in the IFC R2x, and the number of Enumeration TYPEs also was increased from 7 to 31, covering a much wider scope of HVAC equipment. The IFC R2x2 infrastructure is also greatly enhanced by formalizing the usage of new *IfcTypeObject* mechanism, which allows the separation of the attributes and properties related to an object type from those related to specific instances of the object type. In the domains associated with the building commissioning process, where an object type such as an air handler may have a large number of attributes and properties, this new mechanism greatly simplifies the management of data.

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The IFC R2x2 also introduces more pre-defined *PropertySet*s that greatly benefit the BC process. Not only has the number of property sets increased, but each property set also incorporates more attributes that can significantly improve the capability to represent specific HVAC information. Combined with the newly introduced Performance History concept, managing historical commissioning data became much easier in this new release.

As in previous releases, the IFC R2x2 provides a mechanism for implementers to define custom IFC property sets (*IfcPropertySet*) so that IFC-compliant software can exchange data which the IAI has not yet standardized. This extensibility mechanism ensures that a sending system can write out all the data it contains and a receiving system can parse all the data it reads, but the meaning of the extended data cannot be determined using the standard.

3. Experiments through our BC data model

Our first experiment was directed at determining to what extent the most recent IFC data exchange standard can address real-world BC data exchange requirements. These requirements were determined by elaborating the BC process model that was developed in a previous research project [Akin *et al*. 2003]. In our experiment, we studied the commissioning data produced by different sources, such as commissioning companies and organizations that publish commissioning guidelines or regulations, and simultaneously developed a data model for representing this BC data (see Figure 1). Three types of BC inspection activities, *specification, system context inspection* and *functional inspection* are modeled, which represent the most common tasks in the BC process. To simplify the process, this model mainly focuses on construction and post-construction phases in the BC process, covering several typical types of HVAC equipment, from a simple air filter to a complex air handling unit (AHU). These HVAC equipment types represent a wide range of objects inspected in the BC procedure. We attempted to represent the commissioning classes, relationships and attributes by recent IFC releases (i.e. IFC R2.0, IFC R2x and IFC R2x2) and created matching correspondences between objects on both sides of the data exchange. For example, the *BCEvent* class which stands for a general inspection can be expressed by *IfcTask* class in the IFC R2x2.

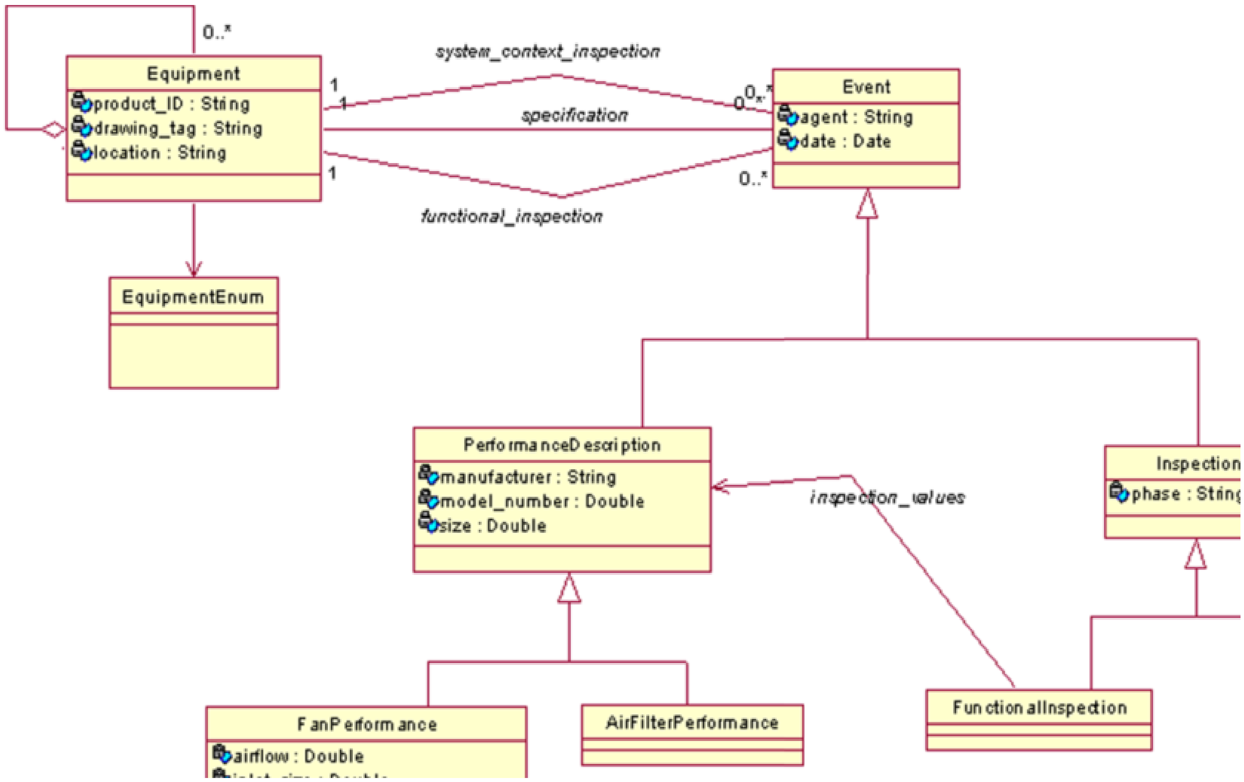

Figure 1 UML Class Diagram of Building Commissioning Data Model (Partial)

Based on these correspondences, BC data instances were translated into IFC data instances. Table 1 shows example of the correspondences between BC attributes and the IFC R2x2 attributes. Also, we incorporated other BC-related data models as alternatives to evaluate the capability of the IFC to exchange BC data. For example, we explored some commercial BC software and created data models that represented their information requirements. Translating these data models into the IFC R2x2 representation gave results similar to those already discussed for the BC data model.

Table 1. Partial result of matching BC data model to IFC R2x2

BC Object	**Fully Matched**	**Partially Matched (different representations)**	**Not Matched (NO proper counterpart in IFC)**
BCFanPerformance	• Agent • Date • AirFlow	• Inlet_Size • Model_Number	• Outlet_Size • Current_Phase_A • Current_Phase_B • Current_Phase_C • Voltage_Phase_A • Voltage_Phase_B • Voltage_Phase_C

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BCEquipment - AHU-1	• Product_ID • Drawing_Tag • Specification • System_Context_Inspection • Functional_Inspection	• Location	
BCFunctionalInspection	• Agent • Date • Inspection_Values		• Phase
BCCentrifugalFanContext	• Agent • Date	• Is_Unit_Supported • Is_Inlet_Ductwork_Attached • Is_Outlet_Ductwork_Attached • Is_Proper_Fan_Rotation • Is_Control_Wiring_Connected • Is_Power_Wiring_Connected	• Phase

4. Exchanging data using the IFCs among commercial CAD software

A number of major CAD software companies now claim that their products support the IFC exchange standard. We tested how well several CAD software systems that are "IFC-Compatible" are able to support IFC-based data exchange for BC tasks. A series of tests were performed to investigate the interoperability among mainstream CAD software packages currently used in practice by using the IFC data exchange standard.

We created several tests to evaluate IFC usage by commercial CAD packages. First, we generated an IFC output (e.g. gas heater and pipes) in one particular CAD package and re-opened it in the same package. As expected, those packages we tested could successfully restore information from the IFC output they produced. Then, we tested the compatibility of data exchange between two different packages through the IFC data exchange standard. In the test shown in Figure 2, CAD System 1, with support of a third-party IFC translator, was able to import an IFC output from CAD System 2. CAD System 1 was able to retrieve and understand all geometric information correctly, but unfortunately, almost all the HVAC-related specific attributes were lost due to the fact that CAD System 2 put them in implementer-defined IFC property sets (*IfcPropertySet*), which CAD System 1 did not understand. Finally, we followed the same procedure as the second test with CAD System 2, but using the BC data model discussed in Section 3. We translated the BC data instances into an IFC data file, which CAD System 2 failed to read, although it was deemed a legal IFC file by the IFC file checker software.

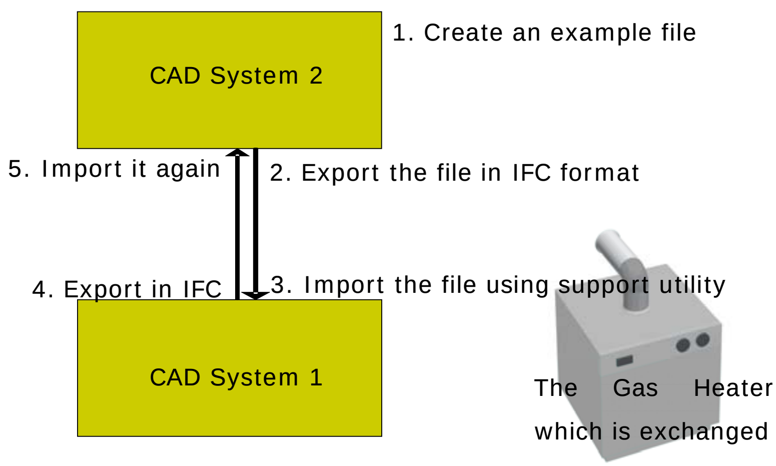

Figure 2 Procedure to exchange data between CAD System 1 and CAD System 2

5. Lessons learned

During this project, we identified entities and activities involved in the BC process and tried to represent them with the latest IFC specification. Through our experience, we can highlight a number of findings:

- Commissioning activities (e.g. functional inspection event) are well represented, as are basic descriptions of the associated HVAC equipment (e.g. location, manufacture information and identification etc.) and the relationships between these activities and the HVAC equipment.
- About 1/3 of the specific attributes for HVAC equipment (e.g. Airflow) are covered by the IFC R2x2, represented by pre-defined *PropertySet*s or the attributes of specific ENTITYs.

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- The IFC R2x2 has a flexible infrastructure that is suitable to support BC-related data exchange, which involves a large number of specific HVAC attributes. It is well understood that it is not possible to cover all required attributes in a model; however, the IFC data exchange standard provides a proper mechanism to extend its coverage when necessary, although it may result in some other issues that are discussed in the following paragraph.
- The IFC do not limit how applications utilize its representations. An IFC file whose syntax is correct may not use the IFC representations as expected. We studied the IFC data files generated by several CAD packages. Most of the BC-related attributes are stored in the generic *IfcPropertySet* discussed earlier, even though the IFC specification already provides a better solution (e.g. pre-defined *ProeprtySet* or attributes in a specific Entity). This will cause a loss of interoperability because no other applications can identify those attributes. For example, in an IFC file generated to exchange properties of a gas heater as shown in Figure 2, 1/3 of all HVAC attributes that are in the *IfcPropertySet* could possibly be represented by the IFC R2x2's pre-defined *PropertySet*s.
- The IFC specification may have more than one way to represent a concept; however, IFC-compatible software usually does not implement all possible presentations, which results in additional difficulty when sharing data between different software packages. For example, *IfcPropertySet* can organize data directly, but it is also possible to use it to organize data represented as instances of *IfcPropertyListValue.*. Both implementations can achieve similar functions, but if specific software only expects one implementation, it will lose data represented in the other format.
- Not all commercial software systems have caught up with the latest developments of the IFC [Steinmann 2004]. Only a few applications implement the latest IFC R2x2 specification, even though it was released almost two years ago. This limits the application and utilization of some of the desirable new features of the IFC standard.

6. Potential extension to IFC

During this project, we identified entities and activities widely involved in the Building Commissioning process. Based on our model matching experiments, we found the recent IFC release has significant potential capability to support BC data exchange. Tests conducted with both the BC data model and other data models showed that the IFC R2x2 provides a strong support infrastructure for representing the high-level classes and their attributes identified as important for BC data exchange, e.g. *Equipment*, *Event* and their direct subclasses. The IFC R2x2 simplifies the infrastructure of the HVAC-related domain to make it more general, by eliminating a number of specific sub-classes and introducing a series of pre-defined *PropertySet*s.

With the introduction of new, enhanced, pre-defined *PropertySet*s associated with generic IFC entities (i.e., *IfcTypeObject*), the IFC also improves its capability in exchanging specific attributes. In our experiments, nearly 1/3 of the specific attributes of the BC data being exchanged have their direct IFC counterparts declared in pre-defined *PropertySets*.

However, the latest IFC release still does not cover all necessary BC data items. As a general purpose schema, extensions to IFC classes seem necessary to provide better support for BC data exchange, which will be part of our future.

Following the development roadmap of the IFC R2x2, we agree with the IFC development direction to incorporate more pre-defined *PropertySets* to represent HVAC attributes. Our tests show that certain kinds of properties, such as boundary limitations and installation information, are not well supported by the current IFC release. Such information could be deduced in some cases, but is hard to implement. One outcome of our future work will be the recommendation of specific new pre-defined *PropertySets* to support building commissioning.

Besides extending the IFC schema, we believe it is more important to instruct software developers in the proper use of the existing IFC exchange standards. The IFC provides several choices to implement the same concept, but it does not limit how CAD software utilizes these implementations. For instance, although there are pre-defined *PropertySet*s available, their existence does not guarantee software packages will use them as intended. Instead, software developers adopt the general purpose *IfcPropertySet*, which is easy to operate and can represent almost any kind of data in similar way. This limits the ability to use the IFC as a BC data exchange standard between two commercial packages. Three suggestions may partially address this limitation. First, the IAI might release a much clearer guide or more examples than it currently does [IAI 2003c], to help developers understand how to use the IFC efficiently and encourage software companies to implement the latest IFC release in proper ways. Alternatively, more implementer agreements could be developed that address the specific issues identified here. Second, the IAI might introduce a stricter IFC compatibility certification. Generating a legal IFC output, for which the syntax is correct, is not enough. Every IFC object must be used correctly according to its intended purpose. Third, the IAI or some other organizations such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) might recommend a glossary for the HVAC domain and the building commissioning process that will also improve interoperability. For example, unifying terms “Air_Flow”, “AirFlow” and “Air Flow” to a single form will eliminate many data exchange barriers. Developing such a glossary, while extremely hard, will be a constructive step to take towards developing IFC-compatible software packages.

7. Summary

Building Commissioning is a process that has extremely high demands for data exchange through multiple phases of building design and construction. Data exchange standards, like the IFC, can benefit the BC process by smoothing the data exchange task. In this paper, we evaluated the support for the Building Commissioning process provided by the latest IFC release. The IFC have evolved to be able to support a considerable part of BC tasks, however, further extensions are still necessary to bring this support to a better level.

Reference

[Akin et. al 2003] Akin, O., Turkaslan-Bulbul, T., Brown, S., Kim, E., Akinci, B., Garrett, J., *Comparison of ASHRAE Guidelines with Building Commissioning Practice*, National Conference on Building Commissioning, California

[ASHRAE 1996] ASHRAE (1996) The HVAC Commissioning Process. ASHRAE Guideline 1-1996.

[EuroSTEP 2001] EuroSTEP Inc. (2001) 4D Application Development: MS Project – IFC Mapping Specification. Released on Jun 29, 2001.

[EXPRESS-X 1999] EXPRESS-X Reference Manual, ISO 10303, WG11, N088 (1999) Last Accessed Dec 2004. http://www.steptools.com/library/express-x/n088.pdf.

[FIATECH 2004] FIATECH (2004) Automating Equipment Information Exchange. Last accessed Nov 2004. http://www.fiatech.org/projects/idim/aex.htm

[IAI 2001] International Alliance for Interoperability (2001) Project BS-8. Last accessed May 2005. http://eande.lbl.gov/BTP/iai/bs8/

[IAI 2003a] International Alliance for Interoperability (2003) *Industry Foundation Classes*, Last accessed Nov 2004. http://www.iai-international.org

[IAI 2003b] International Alliance for Interoperability (2003) ifcXML Project. Last accessed Nov 2004. http://www.iai-na.org/

[IAI 2003c] International Alliance for Interoperability (2003). IFC 2x Edition 2 Model Implementation Guide.

[ISO 1994] International Standard Organization (1994) ISO 10303: Standard for the Exchange of Product model data.

[ODE 1997] Oregon Department of Energy (1997) Commissioning for Better Buildings in Oregon. Accessed Nov 2004. http://www.energy.state.or.us/bus/comm/commintr.pdf

[Steinmann 2004] Steinmann, R. (2004) International Overview of IFC-Implementation Activities. Last accessed Nov 2004. http://www.iai.fhm.edu/ImplementationOverview.htm.

[Wang et al. 2004] Wang, H., Akinci, B. Garrett, J. H. et al. (2004). Towards Domain-Oriented Semi-Automated Model Matching for Supporting Data Exchange. In Proc: The 10th International Conference on Computing in Civil and Building Engineering, Weimar, Germany.