Model Interoperability in Building Information Modelling

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Abstract. The exchange of design models in the design and construction industry is evolving away from 2-dimensional computer-aided design (CAD) and paper towards semantically-rich 3-dimensional digital models. This approach, known as Building Information Modelling (BIM), is anticipated to become the primary means of information exchange between the various parties involved in construction projects. From a technical perspective, the domain represents an interesting study in model-based interoperability, since the models are large and complex, and the industry is one in which collaboration is a vital part of business. In this paper, we present our experiences using the industry standard IFC data modelling format for exchanging design models between various tools, and in implementing tools which consume IFC models. We report on the successes and challenges in these endeavours, as the industry endeavours to move further towards fully digitized information exchange.

1 Introduction

The design and construction industry is undergoing a significant shift away from the use of two-dimensional CAD and paper for design towards three-dimensional, semantically rich, digital models. This trend has reached a point where this technology, generally referred to as Building Information Modelling (BIM), is being used in some form by the majority of the industry. A recent survey by McGraw Hill Construction [1] found that in 2008, 45% of architects, engineers, contractors and building owners surveyed used BIM on 30% or more of their projects. Usage of BIM is forecast to continue growing sharply in coming years.

One of the challenges faced by the industry is the use of BIM not only as a tool in the design process, but as the interface for the exchange of information between the different parties involved in projects. A typical construction project will necessitate collaboration and information exchange between a variety of parties, including the client, architects, engineers, estimators and quantity surveyors, contractors and regulators. Traditionally, information was exchanged in the form of drawings and documents. As each of these parties moves towards the use of BIM tools within their own organisation, there is a significant incentive to instead use digital design models as the medium for exchanging information. However, these parties frequently use different tools, either from different vendors or specific to their business domain, and this diversity of tools poses a challenge for model exchange.

The Industry Foundation Classes (IFC)[2], defined by the buildingSMART alliance, represent the accepted industry standard for design models. Many of the significant BIM tools currently used by industry support import and export of IFC files. We have used IFC as an interoperable format over a number of years, both as a mechanism for exchanging models between tools, and as an input format for software tools that we have built for design analysis and automation. This paper presents our observations of the successes and challenges of IFC as an interoperable standard for building models.

The paper is structured as follows. In section 2, we present a background to BIM and its present and anticipated use in the design and construction industry. Section 3 then presents a brief description of the IFC standard, in terms of its history, structure and role as an interoperable standard. Section 4 presents observations of IFC's present successes and failures as an interoperable standard.

2 Building Information Modelling (BIM)

The construction of a building or group of buildings is a complex endeavour, involving many parties and numerous diverse activities. Even small projects are beyond the scope of any single company to complete in isolation, and larger projects will necessitate the interaction of potentially dozens of organisations including clients, architects, engineers, financiers, builders and subcontractors. The process can be likened to that of co-design in computing, in which the domain knowledge of hardware and software engineers are distinct and successful completion of the project requires intense cooperation during design, manufacture and maintenance/management of the system.

The information models that are used are also large, complex, and highly inter-dependent, and includes architectural drawings, engineering schematics for structural, electrical, HVAC (heating, ventilation and air-conditioning), and mechanical services, as well as details of cross-cutting concerns such as project management, scheduling, and cost planning/estimation.

Traditionally, the dominant medium for exchanging information between parties has been as drawings and other paper documents (e.g. bill of quantities, cost plan, building specification), and this remains the case for many projects today. Although many organisations use some software tools for the definition of their design models, the models are frequently rendered as 2D drawings when they are sent to other organisations.

The information exchanged serves not only to inform the receiving party, but as a record of what information was or was not conveyed, so that, in the event of a dispute or problem, responsibility for a decision may be clearly determined. Companies are comfortable with the use of paper drawings for this purpose, and are still reluctant to sign off on digital information represented in three dimensions, often with additional information compared to the paper equivalent. For example, architects often associate material types with building objects in order to make the building look right for a client presentation, and not necessarily because that is the material to be used in construction. When the model is then given to the engineer or quantity surveyor, it might be unclear whether the material has been selected intentionally, or simply for visual effect. Which parts of the model are definitive, and which are illustrative? This is important from a legal liability perspective.

Understanding of liability implications is also an important reason why the current use of digital models mainly involves exchange of models as files, as opposed to inspection of and linking to models using service-oriented or distributed object technologies.

Despite these concerns, the use of BIM has reached tipping point in the industry [1]. Use of 3-dimensional CAD tools is commonplace amongst architects, and is also seeing significant uptake in other sectors such as amongst engineers, owners and contractors. In addition to being used in the design process, BIM is also beginning to be used for design analysis, including quantity surveying, cost planning, environmental assessment, acoustic and thermal performance assessment, scheduling/simulation, and checking designs against codes and regulations. As tools for these activities gain in popularity, it is going to become more crucial that software packages manipulating the models are able to interoperate without problems and without necessitating significant human intervention.

3 Industry Foundation Classes (IFC)

The industry standard for exchanging Building Information Models is defined by the Industry Foundation Classes, or IFC[2]. IFC was first specified in 1996 by the International Association for Interoperability (IAI), and has seen a number of minor and major revisions since then (the popularly used versions today are 2x2 and 2x3). The IFC specifications are currently administered by the buildingSMART alliance[1].

From a technical point of view, IFC is defined using the ISO 10303 [3] suite of specifications for data modelling and exchange, otherwise known as STEP (Standard for the Exchange of Product Data). STEP consists of a range of specifications, most notably a language for specifying data schemata (STEP/Express [4], in which the IFC language is defined), a mapping (Part-21 [5])) for text-file representations of models conforming to that schema, a mapping (StepXML [6]) for XML file representation of models, and mappings to APIs for accessing models programmatically (notably Part-22 [7], Standard Data Access Interface, or SDAI). Of these technology mappings, the most significant in terms of interoperability is currently the Part-21 mapping, which effectively defines the IFC's file format[2].

Since the release of version 1.0 in 1996, IFC (the latest version being IFC 2x3) has seen significant takeup by many of the major CAD tool vendors. In the architectural sector in particular, the major vendors all claim support for

[1] http://www.buildingsmartalliance.org
[2] The XML mapping is also defined, as ifcXML, but in the experience of the authors, this is rarely used.

import and export of IFC, including Graphisoft[3], Bentley[4], Nemetschek[5], and Autodesk[6]. Takeup in other sectors is much more variable. The software tools of some, such as structural, mechanical and electrical engineering (including the Revit tools from Autodesk), and steel detailing (notably Tekla Structures[7]), have support for IFC, whereas in others, such as environmental analysis, cost estimation, civil engineering or facilities management, support is less common.

The IFC language is, by any definition, very large and very complex. The language definition of IFC version 2x3TC1 includes 327 data types, 653 entity definitions[8], and 317 property sets.

The language includes constructs for a very wide range of modelling features, including (but not limited to) geometries, to basic building elements (slabs, columns, beams, doors), facilities management, electrical, ventilation and other subsystems, and structural analysis constructs, to identity, organisational, process and cost modelling constructs. The specification is broken up into platform and non-platform domains, but even the core platform constructs include well over 300 classes. The size and scope of IFC mean that few (if any) individual tools implement the entirety of the language.

The complexity of the language is exacerbated by the possibility in many sub-domains for alternative modellings. This can be affected by both software developer implementation decisions and the choice of domain modelling technique by the user. The geometry constructs, in particular, provide myriad ways of modelling the same structure. As a simple example, a block structure may be modelled using a boundary representation with planes for each side, or as an extrusion using a polygon and a vector. A more subtle but more problematic example might be the alternative modelling of a low wall as either a wall object, a thick slab object, an upstand beam, or even a kerb. Each of these objects have different semantic meaning, so although the objects might look no different on a 3D rendering, they will be treated differently by analysis tools.

For cases where the IFC does not provide an particular modelling construct, the language includes a mechanism for the modelling of IfcProxy objects, which serves as a kind of extension mechanism. For example, in the case of landscaping, there is no IFC construct for trees or shrubs, so these are often included (with geometries) as IfcProxy objects.

In addition to the size and complexity of the language itself, individual IFC models tend to be very large. The size and level of complexity present in a model for a large building, including the geometry and semantic information for all building elements, is considerable, even when split into different models according to concern. For example, Figure 1 shows the model of mechanical

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[3] http://www.graphisoft.com
[4] http://www.bentley.com
[5] http://www.nemetschek.net
[6] http://www.autodesk.com
[7] http://www.tekla.com
[8] By way of comparison, the UML2 metamodel [8], often considered by metamodellers to be a large metamodel, defines 260 metaclasses.

services for a 19-storey office building, with an inset showing the precision with which the elements' geometries are defined. The main systems are modelled in full, but the detailed design of individual floors is shown only for two example storeys. The part-21 IFC file for this model is 360Mb, and the model consists of more than 7.3 million objects. Although this is not a small project nor a particularly simple one, it is by no means an extreme case in size or complexity.

The current process for testing the IFC compliance of BIM tools involves the use of a standardized suite of large test models, subject to visual inspection in the tool. There are also a prescribed set of modifications which are then made to the models, which are then rechecked. The procedure does not, at present, include assessment of the tool's handling of semantic information in the model.

4 BIM Interoperability

In this section we provide observations about the issues observed surrounding the use of IFC for exchanging design models between a range of different tools. To do this, we make reference to the KISS classification of interoperability levels, shown in Figure 2, which is taken from the KISS initiative website [9].

4.1 File and syntax levels

There are few problems encountered at the file and syntax levels of interoperability. Over years of using 2-dimensional CAD tools, many organisations in the design & construction industry have developed processes and conventions for managing files, and some of these apply well to BIM, at least during the early stages of uptake. However, in the long term, changes will occur within working methods as organisations attempt to exploit the advantages provided by improved access to 3D object models. At the current level of uptake by industry, the type and extent of these changes in work processes are difficult to predict.

Some problems are observed due to the very large size of the models being used. Some systems have restrictions based on memory consumption or number of objects in a model, which can result in models either not loading, or failing to render in 3D. For example, the mechanical services model shown in Figure 1 is too large for systems built on toolkits such as EDM[9], whereas in a tool like the DDS CAD Viewer[10], it will load but cannot be rendered in 3D.

4.2 Visualisation level

The precursors to digital model exchange in the construction industry were paper drawings, and the models being represented are essentially geometric in nature, so it is not surprising that visualisation has long been the priority for the interoperability of IFC. To date, this has been largely successful. With a few

[9] From Jotne EPM Technology AS, http://www.epmtech.jotne.com
[10] From Data Design System (DDS), http://www.dds-cad.net

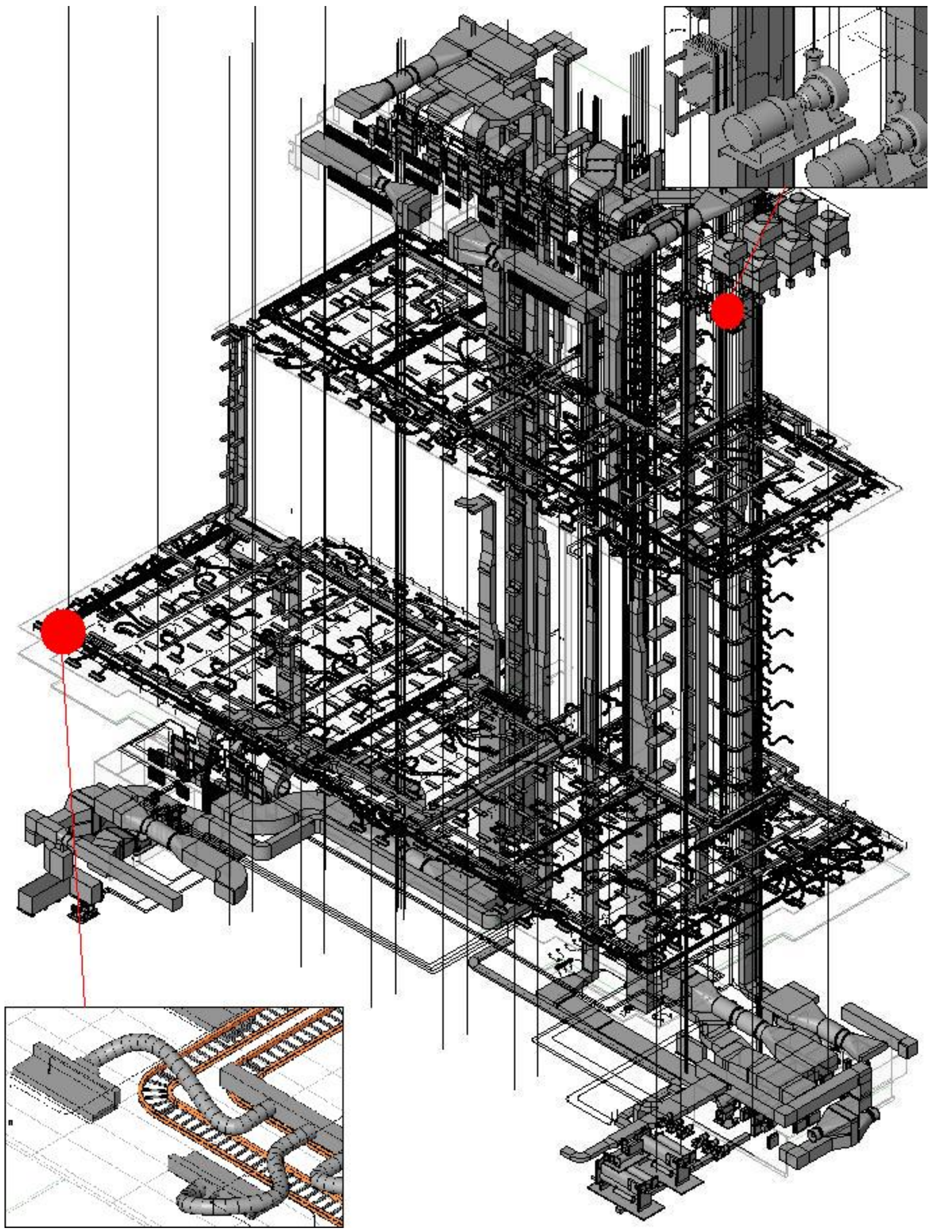

Fig. 1. Model of mechanical services for a 19-storey office building

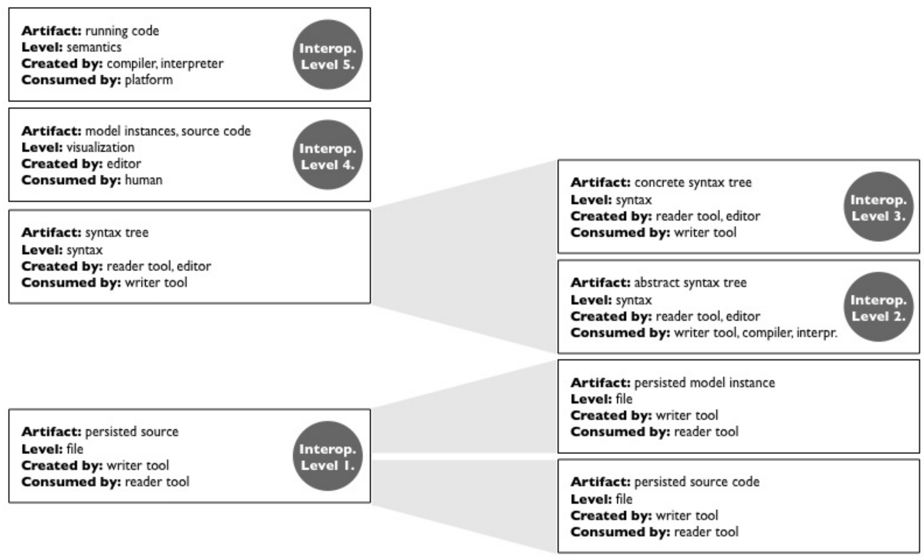

Fig. 2. The KISS classification of interoperability levels

exceptions, models produced in one tool are generally able to be visualised in another.

One such exception, mentioned in the previous section, is when the size of the model precludes its visualisation in a given tool. Another issue is the use and reuse of geometries. Models from Revit Structure, for example, can sometimes have IfcOpening or other objects appear out of position in other tools, due to the way that position and dimension information is modelled in the case of objects that are copied or reused.

Another outstanding issue is that of alternative visualisations. An architect will choose colours and textures for their model that reflect its actual appearance, whereas a quantity surveyor or someone checking the model against a regulatory code will frequently opt for a colour scheme that best distinguishes building objects based on semantic information, such as their type (e.g. having a slab and its supporting beam be different colours, despite both being concrete) or material (using different colours for different grades of concrete, or for concrete vs plasterboard, even if they are to be painted the same colour). Because of the different objectives in play, the model can appear different in different tools. IFC includes language support for the definition of different representations for objects, but to date there is no concensus on how to manage these. For example, there is no tool-independent way of grouping or labelling different representations into, for example, zoom levels or visual-versus-symbolic viewpoints.

4.3 Semantic level

As discussed in the previous section, the principal goal for IFC was originally that of visual model exchange between tools, and thus far, this has met with a degree of success. However, as the construction and digital design industry moves further into BIM, the opportunities for leveraging models depend increasingly on models that can be reliably interchanged and interoperated on a semantic level. Semantic interoperability poses more issues, ranging from relatively simple technical problems, to deeper problems tied to modelling style within the community that exchanges models.

Some of the simple problems include a loose approach to the use of object identifiers. For example, some tools do not preserve object identifiers (GUIDs) when editing models, which causes problems for tools which provide more sophisticated versioning and change-tracking functionality, such as Jotne's EDM Model Server[11]. These tools depend on GUIDs to version models at the individual object level, rather than for the whole model, and to permit intelligent merging of models pertaining to different stakeholder viewpoints.

Modelling style The potential of these semantic model exchange opportunities has been made visible in a number of projects. For example, Ecquate's LCA Design [10] tool allows the designer to evaluate the short-, medium- and long-term emmissions of a building, by inspecting the materials and other information about a building in combination with databases of emmissions data. The Automated Estimator tool [11] allows a quantity surveyor or cost engineer to automate large parts of the time-consuming quantity takeoff process, by using a rule engine that categorises and itemises building objects based on material, relative position and other properties. Projects such as Solibri's model checker[12], and Jotne's EDMrulechecker[13], allow for the checking of models against codes such as accessibility or fire regulations.

One of the keys to the uptake of these kinds of analysis tools is the reliability of the models that are provided to them. If the objects (in particular materials and object types) being used in a model are not consistent with those expected by the analysis tools, then the analyst will need to spend time "'fixing"' the model, which reduces the value of the tools. For example, some models will encode structural steel members as being of material "'Structural Steel"' with the grade of steel (e.g. C350, C450) encoded in the object description, whereas others will have the grade of steel as the material type. If a quantity takeoff tool anticipates one encoding but encounters the other, it will not compute the correct quantity of steel.

There are efforts underway to address these issues of modelling style. The IFD (International Framework for Dictionaries) specification [12] and library[14]

[11] http://www.epmtech.jotne.com
[12] http://www.solibri.com
[13] http://www.epmtech.jotne.com
[14] http://www.ifd-library.org

provides an ontology for the definition and storage of building model objects that can be reused on different projects, and has been used in a number of jurisdictions (typically national) to encourage consistent use of modelling constructs. Technical solutions such as this require the involvement of stakeholders in order to define the disciplines and conventions that should be used when modelling, e.g. in Australia the ongoing National Guidelines and Case Studies project within the CRC for Construction Innovation[15].

Coverage Issues There are a number of interoperability problems that arise because of coverage issues, either coverage of the IFC language by implementing tools, or coverage of the domain by the IFC language.

Cases do arise where a tool fails to produce a correct visual rendering because it encounters an IFC construct that it does not understand, but these are rare, since the geometric and visualisation constructs are shared across IFC, and these constructs are typically well covered by tools. More common, though, is the situation where an alternative modelling is chosen due to a shortcoming of the designer's tool palette. For example, if the designer wishes to place a low kerb or upstand beam in front of a wire closet, but the tool's palette does not provide such a construct, the designer might insert a slab or wall element instead. This will look correct, but will pose problems for analyses such as quantity takeoff.

The other situation where coverage is an issue is where IFC does not provide a modelling construct. For example, if a designer wishes to place a water tank, IFC has no construct to represent that. The designer has the choice of either representing the tank using curved walls and slabs, or of using an IFC proxy object. Both of these solutions pose challenges for analysis, since the construct/s will not be understood by the analysis tool, but judicious use of one of the IfcProxy constructs is the most robust method of handling this issue. The most important way to address this latter problem lies, like that above, in the development and adoption of modelling conventions and guidelines for these cases. However, implementation of the proxy mechanism within tools also needs to make it as easy for a user to add a new proxy object as it is to use a semanticaly misleading construct that presents the same visual appearance.

4.4 Alternative Representations

Beyond the lack of agreed mechanisms for managing different geometric representations (as discussed in the previous section), there are often much more complex problems of different representation paradigms. For example, in modelling roads, it is common to begin with a string-based representations of roads and associated elements (signage, markings, drainage and electrical information), using vectors for edges instead of surface models. Switching to a surface-based model requires complex transformations of the model. This idea of mapping between representation paradigms will become a more significant problem as BIM is expanded to

[15] http://www.construction-innovation.info

include more disciplines, particularly models beyond a single building, including urban planning models. Examples of this include ongoing buildingSMART projects investigatint the use of IFC for Bridges and for GIS.

5 Conclusion

The transition from paper-based exchange of design models to processes based around the use of digital models represents an important shift in the design and construction industry. Using digital models opens the posibility of automating a number of the analyses done during design, with important consequences for the speed and efficiency of the design process, and for the quality of the resultant designs. In an industry so heavily dependent on collaboration, challenges of interoperability must be addressed in order to maximise these benefits.

The IFC is an ambitious example of model-based interoperability, covering a wide range of modelling information, and across a wide range of sub-domains. When evaluated against the KISS hierarchy[9] of interoperability levels, it has thus far met with relative success in providing file- and visualisation-level interoperability within a subset of domains, most notably in architecture and structural design. However, it faces challenges as it moves into more situations demanding semantic interoperability, and as its use is broadened to include more sub-domains, both anticipated and unanticipated.

The principal semantic interoperability challenges revolve around the quality and consistency of the models produced. Efforts are underway to provide for consistent modelling both through technical solutions and through the engagement of stakeholders to determine what constitutes good modelling practice. The success or failure of these efforts will go a long way towards determining the extent to which BIM succeeds in transforming the industry.

From a technical perspective, IFC and its use in the design and construction industries represents an interesting study for a number of reasons. The domain is challenging because of its breadth, and because of the size of its models. As an industry heavily based on paper for information exchange and analysis, the opportunity is significant for digital techniques to automate and streamline processes. Being a highly collaborative environment makes interoperability a key issue, and the industry finds itself in a situation similar to some parts of software engineering (with the UML language being the most obvious example), where visualisation-level interoperability has reached some level of maturity, and semantic interoperability is developing.

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References

1. : Building Information Modeling (BIM): Transforming Design and Construction to Achieve Greater Industry Productivity. Technical report, McGraw Hill Construction (2008)
2. buildingSMART: Industry Foundation Classes, Edition 3, Technical Corrigendum 1. http://www.buildingsmart.com (July 2007)
3. International Standards Organisation (ISO): Industrial automation systems and integration – product data representation and exchange – part 1: Overview and fundamental principles. ISO Standard 10303-1:1994 (1994)
4. International Standards Organisation (ISO): Industrial automation systems and integration – product data representation and exchange – part 11: Description methods: The express language reference manual. ISO Standard 10303-11:2004 (2004)
5. International Standards Organisation (ISO): Industrial automation systems and integration – product data representation and exchange – part 21: Implementation methods: Clear text encoding of the exchange structure. ISO Standard 10303-21:2002 (2002)
6. International Standards Organisation (ISO): Industrial automation systems and integration – product data representation and exchange – part 28: Implementation methods: Xml representations of express schemas and data, using xml schemas. ISO Standard 10303-28:2007 (2007)
7. International Standards Organisation (ISO): Industrial automation systems and integration – product data representation and exchange – part 22: Implementation methods: Standard data access interface. ISO Standard 10303-22:1998 (1998)
8. Object Management Group (OMG): Unified modeling language superstructure, version 2.1.2. OMG Document number formal/07-11-02 (November 2007)
9. Bettin, J.: Knowledge Industry Survival Strategy Initiative. http://www.industrialized-software.org/kiss-initiative (January 2009)
10. Tucker, S., Ambrose, M., Johnston, D., Newton, P., Seo, S., Jones, D.: LCADesign: An integrated approach to automatic eco-efficiency assessment of commercial buildings. CIB REPORT **284** (2003) 403
11. Drogemuller, R.: Model based estimating system for civil concrete structures. Final Report 2005-0008-C-01, CRC For Construction Innovation (2005)
12. International Standards Organisation (ISO): Building construction – organization of information about construction works – part 3: Framework for object-oriented information. ISO Standard 12006-3:2007 (2007)