Rule driven enhancement of BIM models

Prof. N. Nisbet
AEC3 Ltd, London, UK

Prof. S. Lockley, M. Cerny, Dr. J.Matthews, G.Capper
Univeristy of Northumbria, Newcastle, UK

ABSTRACT: The 2011 UK Government BIM strategy is motivating lead design and construction organizations in the UK to use BIM authoring tools to help prepare information for progressive handover. Acquiring structured handover information is driven by specific purposes (use-cases), management criteria and inputs which are being documented using ISO 29481 (buildingSMART IDM) and ISO 12911 (Framework for BIM Guidance).

Previous work has shown that IFC exports can be transformed into the required COBie format. These transformations can assume compliance to international standards or they can include tolerance of non-standard implementations. These decisions can be driven by market pressure pending the possible adoption of more consistent implementations.

However there remain systematic gaps and weaknesses in the information sets being generated. These gaps may work against the efficient delivery of acceptable datasets by requiring tedious and potentially inaccurate manual attention. Examples of data issues include inaccuracy in the identification of envelope elements, and failures to distinguish functional systems and zones.

The paper examines strategies for applying rule based transformations to highlight and resolve data issues, as a prerequisite to automatically categorizing the facility objects according to local classification systems.

Rule strategies include direct authoring, systematic tabulation, and the RASE (requirements, applicability, selection and exceptions) approach. The strengths and weakness of these approaches will be compared and examples deployed to show how BIM models showing relatively weak completeness and accuracy can still generate valuable deliverables for the client.

1 BACKGROUND

1.1 *UK Government BIM Strategy*

The 2011 UK Government BIM (Cabinet Office, 2011) is motivating lead design and construction organizations in the UK to use BIM authoring tools to help prepare information for progressive handover. It should be noted that the UK Government BIM strategy is not being enforced through legislation, but is being implemented by central government bodies including the Treasury and other Ministries strengthening their role as construction industry client and asset owner/operator.

The initial expectation is that the client body should receive shared structured information in the Construction Operation of Buildings information exchange format (COBie 2012) at key decision points. To support this expectation, the 'Client Information Requirements' are referenced in from the main contract, and the requirements then cite the recently published 'COBie UK 2012' (Cabinet Office 2012). document set. This requirement adopts the US implementation of COBie 2.4 with the substitution of the US classification scheme (Omniclass 1999) with the UK Classification scheme (CPIC 1997). The implementation of COBie in the UK is motivated by specific purposes (use-cases), management criteria and inputs which are being documented using Framework for BIM Guidance (ISO 12911, 2012). In addition to the purposes of FM (such as maintenance and operations), the UK implementation will require detailed data on both cost and environmental carbon impacts (measured in kg CO2e), both from the construction and from the facility in use.

1.2 *Industry response*

The strategy has quite deliberately left open the question of how the industry supply side responds to the challenge of sharing structured data for handover information and for carbon evaluation. It is expected that the lower tiers of the design-chain and supply-chain may provide information upwards using the COBie spread sheet directly. However the lead designers and contractors are now exploring how their tentative use of Building Information Model (BIM) authoring tools can be leveraged to generate substantial parts of the COBie requirement. The initial demand for a 'COBie button' has given way to more serious review of the quality and relevance of data being held in their BIM models. Previous work has shown that IFC exports from all the leading BIM authoring platforms can be transformed into the required COBie format.

2 PROBLEM STATEMENT

2.1 *Current tools*

Most BIM authoring applications have the ability to generate schedules or reports. However these have rarely been used to produce contractually significant documentation. There are currently systematic gaps and weaknesses in the information sets being generated. These gaps may work against the efficient delivery of acceptable datasets by requiring tedious and potentially inaccurate manual attention. The demand for COBie has therefore exposed these issues.

2.2 *Specific COBie requirements*

Some COBie requirements, such as unique names for assets, may be implemented in software enhancements to ensure that a particular BIM authoring tool supports default naming for assets with automatic checks against duplication. In the meantime, strategies can be adopted, such as using the internal 'tag' or 'mark' number as the Component name. This can be effected as part of a report definition, during cut-and-paste from reports into the COBie template or after the BIM has been exported to IFC prior to transformation to COBie.

This paper focuses on the COBie requirement that all assets shall be classified according to a common classification system. This requirement is justified by the need to identify assets and benchmark their management performance against other assets. The lack of classification information in BIM models is less tolerable than lack of unique names, as it represents a repetitive and knowledge-intensive task to add manually. Moreover it is a manual task that may need to be repeated at several intermediate points either for carbon assessment or for COBie handover.

It is not clear how quickly the application suppliers and users will move towards eliminating these gaps, so the paper will examine strategies for applying rule based transformations to highlight and resolve data issues. Examples of data issues include inaccuracy in the identification of envelope elements, and failures to distinguish functional systems and zones. These are prerequisites to automatically categorising the facility objects according to local classification systems.

3 STRATEGIES

3.1 *Generic solutions*

The above discussion has established the need for tools that automatically classify assets. One approach might be a table of relevant classifications keyed against asset names. However to be generic, a tool needs to be responsive to the information contained against that asset. This implies formulating appropriate rules, representing them in a consistent form and then deploying them efficiently.
Rule strategies include direct authoring, systematic tabulation, and the RASE (requirements, applicability, selection and exceptions) approach. The strengths and weakness of these approaches will be compared and examples deployed to show how BIM models showing relatively weak completeness and accuracy can still generate valuable deliverables for the client.

3.2 *Purpose of adding Classification*

The purpose of using classification on the assets has been given as allowing benchmarking comparisons with other assets. A secondary purpose, which represents the residue of best practice from the last half century, is that classification allows the sorting, ordering, browsing and checking for completeness of documents. Reports generated from BIM may be expected mimic the layout and structure of pre-BIM documents.

A critical characteristic of classification schemes is that they are not normally applied to the actual Component occurrences, but to specific aggregations. The key aggregations are Type, System and Work-package. Table 1 gives UK and US examples. The implementation strategy will need first to tackle aggregation, prior to tackling classification.

Group	Classification	
	UK Uniclass 1999	**US Omniclass 1999**
Intrinsic asset product Type	Table L	Table 23
Elemental functional design intent for Systems	Tables F, G	Table 21 (Uniformat)
Construction task based work Packages	Tables J,K	Table 22 (MasterFormat)

Table 1: Aggregations and Classifications

4 IMPLEMENTATION

4.1 *Aggregation*

Each of the three types of classification identified in Table 1 is dependent on a pre-requisite aggregation. These aggregations exist and can have distinct names prior to classification. For example a Domestic Heating System is an aggregation of Component radiators, boiler, piping and other elements. Table 2 introduces the IFC (ifc2x3) equivalents.

Group	Relationship	Aggregation
Intrinsic asset Type	Ifc Rel Defines By Type	Ifc Type Product (and subtypes)
Elemental functional design intent for Systems	Ifc Rel Assigns To Group	Ifc System (and subtypes)
Construction and task based work Packages	Ifc Rel Assigns To Control	Ifc Work Plan

Table 2: IFC (2x3) representation

In the current usage of B IM authoring tools, the intrinsic asset Type is typically equivalent to the Library or Family resource. In recent years applications have become more rigorous in mapping a library object into a single IFC Type representation, though this is by no means universal, even across an application product line. The Type is the primary vehicle for accumulating design decisions for commodity Components, and their subsequent procurement and management. To date, BIM usage has not made full use of the aggregation of Components to define Systems, either through shared layering or through explicitly named Systems. The idea of a System is better appreciated in M&E (MEP) and structural design than in architectural practice. It does however find a direct equivalent in Cost management, because the System represents the primary justification for the presence of a Component, and hence its benchmarking against systems in similar buildings. The aggregation into Systems is called variously the functional, elemental or design-intent approach. It is increasingly relevant to Specification, where a Systems approach better supports the evolution of requirements compared with Work packages or Types. The assignment of Components to work packages is predominantly the concern of the lead contractor when subletting contracts and planning work.

Of these three aggregations, the assignment of Components to Work packages is a decision of the project manager and planners of the lead contractor. To be successful it must be responsive to the state of the market and available commercial relationships. As such it does has not attracted the same pressure for standardisation as the others. The allocation of Assets to Types is already being handled by the BIm authoring tools, and in some cases the libraries come already classified. The most pressing requirement is therefore to create Systems and assign Components to them. For completeness we propose that all Components need to be assigned to at least one System.

Having assigned each Component to a System, we can characterize the System from any common attributes on the Components. For example, if all the Components in a System are of type “Ifc Wall” and/or “Ifc Curtain Wall”, and have the true property “Is External”, then this is indicative that the System is an “External Wall” system. These common properties can be identified and used by a rule engine to decide the nature of the System.

4.2 *Assignment*

The second stage of the process is then to assign the code from a specific classification system, or indeed multiple codes from several classification systems. The assigned code may implicitly suggest a hierarchy or it may be that the classification hierarchy can be explicitly included in the model. The “External wall” may in one System be twinned with “Internal walls” to make a classification “Walling” or it may be paired with “Roof” and “Slabs” to make an “Envelope” System. The common properties identified in the previous stage can be used to drive the rules that will select the appropriate code.

It may seem possible to conflate these two steps: however without first identifying the System, the classification information will instead be associated to the many Components, leading to classic redundancy and inefficiency.

5 EXAMPLES

5.1 *Quantity Take off for cost analysis*

This example is targeted at the UK RICS Standard Form of Cost Analysis (SFCA). This is the cost structure used for shared cost intelligence. It represents a standard set of ‘elemental’ Systems. We wished to show that any BIM developed in the UK can be mapped to a specific report format “CITE4.2” proposed by CITE, part of the buildingSMART UKI chapter.

```
<xsl:when test="(($IfcElement='IfcWall')
  or ($IfcElement ='IfcCurtainWall'))
  and not ($IfcSubType ='Garden'))
  and ($IsExternal='true')">
    <xsl:text>2E1 : External Enclosing Walls</xsl:text>
</xsl:when>
```

Table 3: Fragment of XSLT rule

The rules are embedded in an XSLT to form a concise but evolving definition. Table 3 shows a fragment and Table 4 the outcome. To make the IFC model accessible to the XSLT, we used the AEC3 BimServices TransformX toolkit which uses the University of Northumbria XBIM toolkit to map between the IFC STEP file representation and IFCXML representation. The XSLT then generated a CITE42 report.

```
1 2 : SUPERSTRUCTURE
2 2E : External Walls
3 2E1 : External Enclosing Walls
4 External Enclosing Walls System
5 Wall Standard Case, Wall Type, standard
6 Basic Wall: Generic Ext - 150mm
  Element Type = L384 : Structural walls
  Asset Accounting Type = Fixed
7 L0-01A Cell 1
  Interior Or Exterior Space = internal
   Object Type = D376 : Secure facilities
   Net Floor Area = 7.615 m2
   Net Perimeter = 11546. mm
9 Basic Wall: Generic Ext - 150mm:211794
   Is External = true
   Load Bearing = true
   Structural = true
   Phase Created = New Construction
   Volume = 0.090 m3
   Area = 0.647 m2
   Length = 220. mm
   Width = 150. mm
   Item= 1.000 nr                       0.090 m3
```

Table 4: CITE4.2 Bill of Quantity output (reformatted)

5.2 *Automated Carbon Embodiment Costing (iCIM)*

The interoperable Carbon Information Modelling project (iCIM) was a UK Technology Strategy Board funded research initiative with the objective

“to enable the construction supply chain to calculate carbon embodied at any stage in the design, build, and operate cycle of a building using BIM tools in an interoperable framework.”

The BuildingSmart data model was used as the core representation, from which the carbon content was calculated and industry standard BIM software was employed as the primary BIM content authoring tools.

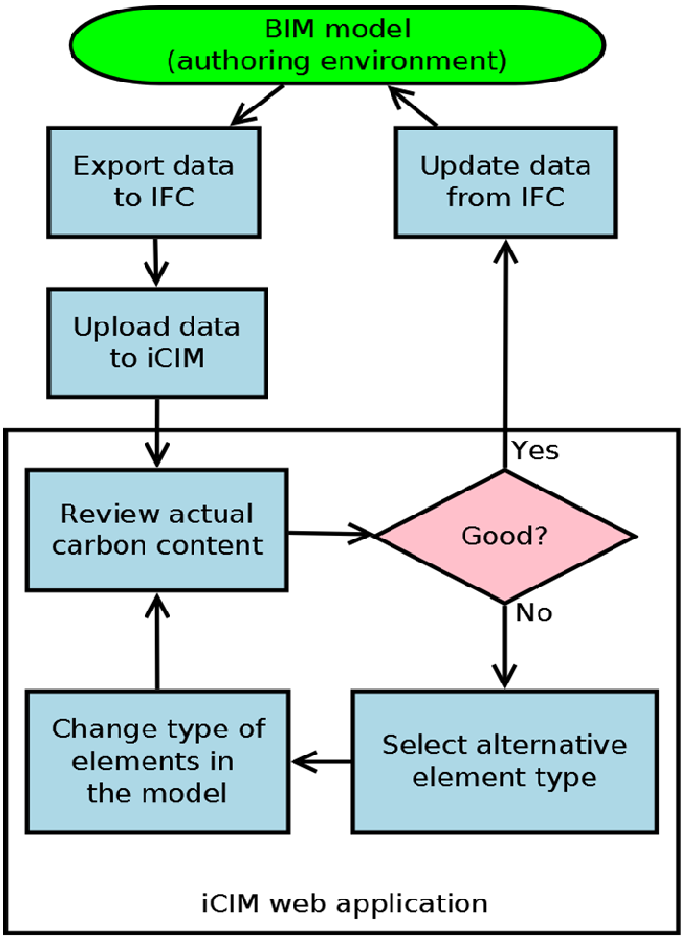


Figure 1 iCIM workflow

Industry standard data libraries were also adopted to ensure relevance to UK working practice. Figure 1 outlines the general workflow implemented.

The initial data requirements analysis for the project highlighted several inadequacies in the data sets available for carbon embodiment calculation. These included

- Inadequate data representation in the BIM models authored by the design team
- A lack of agreed material and material property definitions
- Multiple and incompatible classification systems
- Industry BIM libraries unsuitable for UK practice

An analysis of model content was carried out (see Model Enhancement Metrics) to identify the key entities that required enhancement, these included

- Materials
- Element Types
- Classification
- Building Element Volumes and Areas

It was clear that the amount of effort required for the construction user to add this missing information to their models would have precluded effective use of the iCIM assessment tool. Therefore the BIMs produced as part of the normal design and construction process needed to be automatically enhanced to contain this additional data.

A simple rule driven approach was adopted to add ontologies and enhance material, element and classification definitions in the existing BIM models. In addition a UK National BIM library (NBS, 2012) of construction types and materials was authored to support reuse and industry uptake.

The term ontology is used rather than classification as the purpose is to enable knowledge sharing and reuse in addition to structured reporting of content, which is the normal use of classification in the construction industry. There are many formal and informal definitions of ontology (Turk, 2006) and how one should be constructed; this project has not adopted formal representations such as OWL (Consortia, 2009) but future work will investigate this in more detail. The ontology classes used have been based on the existing UK classification standards, the New Rules of Measurement for cost estimating (RICS, 2010) and UniClass (CPIC, 1997).

The relationships in the ontology have been defined between the IFC 2x3 Schema (buildingSMART, 2010) and the two classification systems. The ontology rules are defined in a simple XML representation and the content is populated automatically using an extension of the open source xBIM toolkit (Lockley, 2012). The rule enhancement process reads arbitrary BIM models in IFC2x3 format and enhances these with the new data generated by executing the iCIM rule set; the resulting output is a content enhanced IFC data model.

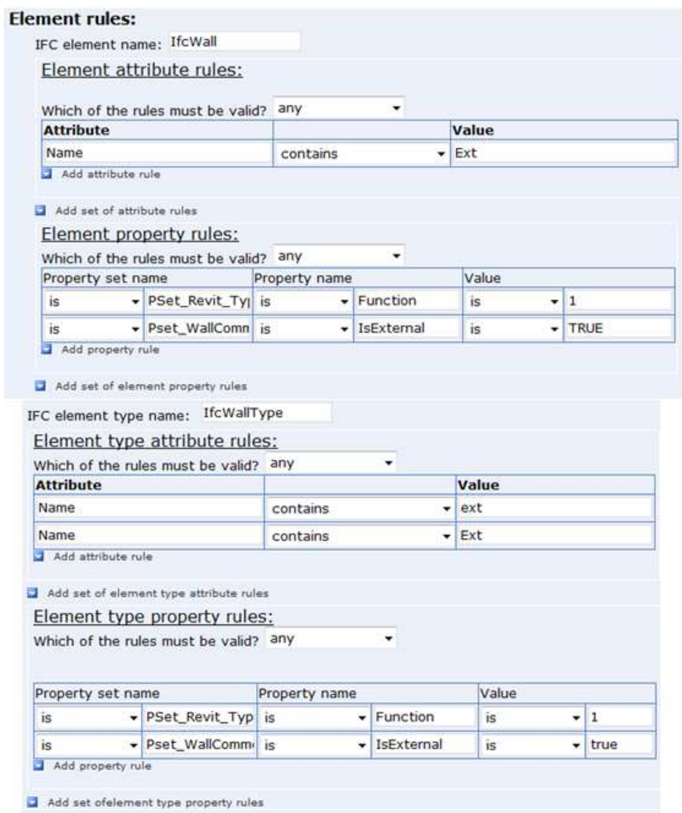


Figure 2 Rule authoring interface

Figure 2 Rule authoring interface illustrates the data input screen for building the rule set. The example shown is for assigning entities to the NRM classification "External Wall". The rule defines the conditions that must be met in terms of the IFC Schema for an instance in the model to be identified as an "External Wall". Rules are structured in XML format (see **Error! Reference source not found.**) using Microsoft InfoPath for data entry. Classification structure is separated from the classification rules to support multiple classification rules for the same classification structure. The parts of the rule are executed in order of the following precedence checking

Instance characteristic	Example
1. Type	IfcWall
2. Attribute	IfcWall.Name
3. Property	IfcWall.PsetWallCommon.IsExternal
4. Element Type	IfcWallType
5. Element Type Attribute	IfcWallType.Name
6. Element Type Property	IfcWallType.PropertySet.PropertyValue

Table 5 Precedence of rule execution

If an instance satisfies the rule it is then classified into the appropriate classification facet. We examined several candidate entities to represent the classification structure in the IFC schema. The main candidates are IfcClassification, IfcSystem and IfcGroup. IfcClassification is the obvious solution; however in the Ifc2x3 definition it was unnecessarily sophisticated for our purpose and led to complicated data structures, it should be noted that this has changed in the Ifc2x4 edition to a simpler implementation. To retain compatibility with current BIM software tools it was not practical to move to this latest definition in Ifc2x4. As discussed previously, IfcSystem is a candidate however for the iCIM purpose we are operating on entities that have a wider scope than servicing buildings, it was therefore decide to use the more generalized form of IfcSystem which is IfcGroup.

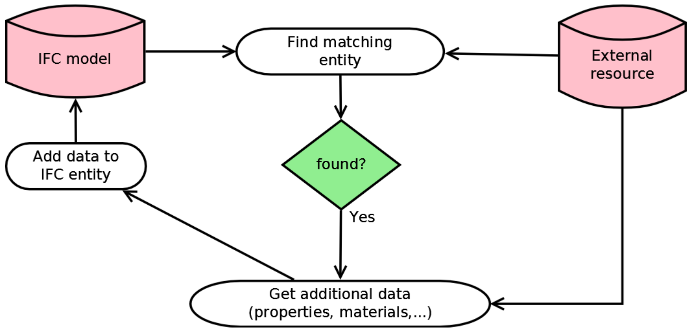
IfcGroup represents "a logical collection of objects" and allows for nesting of sub-groups. Each group of instances can then be classified in accordance with NRM classes. An investigation of BIM software vendors IFC implementations showed they each are taking slightly different approaches to mapping their proprietary data into IFC models. If the origin of the data is known then platform specific rules can be created to improve the quality of the resulting model. A good example of this are the proprietary property sets used by vendors to save properties of elements which are not mapped to property sets defined in the IFC schema.

Once a set of rules have been authored they are executed in order of precedence on any IFC model using the meta-model functionality of xBIM.

```xml
<group name="External Walls">
    <element name="IfcWall">
        <attributes select="any">
            <attribute>
                <name>Name</name>
                <value type="contains">Ext</value>
            </attribute></attributes>
            <properties select="any">
                <propertySet name="PSet_Revit_Type_Construction" type="is">
                    <property name="Function" type="is">
                        <value type="is">1</value>
                    </property>
```

Figure 3 XML Rule set

In addition to enhancing the content based on rules that derive new information from the existing model it has also been necessary to enrich the content by importing data from external sources. This requires a rule set to be developed which matches content from source A with source B. In the simplest case this may be matching an entities name or identifier and substituting. This is the case with IfcMaterial where additional property data is required for carbon calculations and this data is maintained externally to the BIM authoring environment. In more complex scenarios it is necessary to swap or substitute entire building elements or types. This is the case where a user wishes to update their BIM design with complex changes such as substitute wall type A and its constituent parts for wall Type B and its constituent parts. This occurs in design time "round tripping" where the output of one BIM tool needs to update the model in another BIM tool.



The IFC schema provided some basic support for these operations using IfcOwnerHistory but does not explicitly support "round tripping" at the moment in the widely used "Coordination View".

5.3 *RASE*

The RASE (requirements, applicability, selection and exception) methodology has been previously used to explore the capture of regulations and other requirements (Eilif Hjelseth & Nick Nisbet, 2011). Whilst the majority of the normative documentation has been successfully captured using a four colour markup tool, there have been specific examples where the text is not normative by declarative. The first examples encountered were in Energy and environmental regulation where introductory sections would classify geographic regions and off-shore dependencies into specific climate zones. These zones thereafter determine which normative requirements apply. The initial response was to say that these Codes were data that should pre-exist in the BIM model to allow checking to proceed. The RASE approach would then check this value and a mismatch would lead to a failure, prior to considering any actual requirements. Whilst successful, it created a disappointing user experience.

To overcome this, RASE was modified to allow a specialized Requirement. This indicated that the Requirement (that a building be assigned to a certain Climate Zone) could be taken as a Declaration. The interpretation of this was specific rule engine. If the clause would otherwise fail, it could revisit the requirement and note the revised value, in memory for the duration of the rule check or update the revised value back into the source facility BIM model. The third option was that the engine could ignore the specialized requirement and generate an immediate 'Fail' condition. In any of these cases the reporting and trace-back mechanisms should inform the user.

Taking the first example, the classification system can be marked up and rules deduced. Table 5 shows the markup, shown as tags instead of the usual colour, applied to the classification document.

```
<r*>2E1</r*> :
<a>External</a>
not <e>garden</e>
<s>Enclosing Walls</s>
```

Table 6: Example of classification markup

Table 6 shows this text parsed to create a logical statement. An entire classification table is a set of such statements, joined by 'and' operators as all of the clauses must be true.

(SFCA == '2E1') or not (Is External) or not (Wall or Curtain Wall …) or (Garden Wall)

Table 6: Example of the checkable statement

The actual checking process then uses a data dictionary to relate these terms to specific calls to the BIM model. The dictionary is in general independent of the topic of the regulation.

6 CONCLUSIONS

This paper has sought to create a clearer relationship between classification and BIM and show that automatic classification processes can be applied to produce useful results. By separating the grouping and the classification stages, we have shown how multiple classifications can be supported, and how in particular, System/Group definition is crucial to relate design intent with cost management. Investment in full rule sets for grouping and for classification will benefit both the industry and its clients.

6.1 *For classification authors*

Classification authors can be challenged to produce tables with explicit and consistent rules, based on a controlled number of deciding attributes.

6.2 *For BIM authoring tools*

BIM authoring tools should be challenged to support the identification of Systems, even for architectural aspects such as substructure or external envelope.

6.3 *For users*

The use of classification is more closely related to the downstream purposes of using the BIM models. It is primarily these downstream applications, including code-checking, cost assessment and such like, which should be supporting automatic and semi-automatic classification tools.

7 FUTURE WORK

7.1.1 *Automated Exchange Compliance*

The iCIM project demonstrated the feasibility of rule based model enhancement, however the methodology adopted can provide a general ontology based solution for other domains of knowledge. This increases the likelihood that in future BIMs may contain multiple ontologies for a range of knowledge domains giving rise to the need to determine whether a given model is adequately populated for a specific application. The approach currently pursued by buildingSMART is to use MVDs (buildingSMART, Model View Definitions, 2010). These define constraints on the IFC schema that specify which subset of a model can be exchanged. Whilst they do inform exchange requirements they do not enhance the model content to meet the exchange purpose. For example, a MVD may state that a classification is required for a COBie handover exchange, but it will not provide the rules to automate the derivation of the required COBie information from an arbitrary model. MVDs could however be used to confirm that a model that has had an ontology added now meets the requirements of an exchange process.

Further work is required to determine if the quality and fitness for purpose of an ontology resulting from a rule based enhancement can be automatically determined.

7.1.2 *Model Enhancement Metrics*

The first steps towards assessment of quality and fitness for purpose of BIMs is to define measurement metrics. As part of the iCIM project simple metrics were identified to understand the scope of the arbitrary model out from industry standard BIM tools. This work is at a very preliminary stage but reveals some interesting insights into the current generation of BIM models.

Four metrics were defined for simple assessment of model population

Metric	Definition
Content	Number of IFC instances
Complexity	Number of ontologies supported
Completeness	Average percentage of specified attributes per IfcProduct
Semantic	Percentage of non-geometric or shape related instances

Initial application of these metrics to a range of models produced by the current generation of BIM tools reveals that shape representation dominates the content and that building semantic data is a relative small percentage of the model and sparsely populated (incomplete). Typically models analysed contain less than 10% semantic data and over 90% geometry related data, of the 10% semantic data typically 50% is Relationships between entities.

Further inspection of Relationship entities in the models gives an insight into the impact of the "Coordination View" (buildingSMART, 2010).

8 REFERENCES

buildingSMART. (2010). Retrieved 2012, from Coordination View: http://buildingsmart-tech.org/specifications/ifc-view-definition/coordination-view-v2.0/summary

buildingSMART. (2010, Jan). *Model View Definitions*. Retrieved from buildingSMART: http://buildingsmart-tech.org/specifications/ifc-view-definition

buildingSMART. (2010). *The buildingSMART data model*. Retrieved 2012, from buildingSMART: http://buildingsmart.com/standards/ifc

Cabinet Office (2011) "*UK Government Construction Strategy*" accessed April 2012 from http://www.bimtaskgroup.org/wp-content/uploads/2012/03/Government-Construction-Strategy.pdf

COBie (2012) "*COBie*" Retrieved April 2012 from http://www.buildingsmartalliance.org/index.php/projects/activeprojects/25

Consortia, W. (2009, October 27). *OWL 2 Web Ontology Language*. Retrieved 3 1, 2012, from W3C Recommendation: http://www.w3.org/TR/owl2-overview/

CPIC. (1997). *Uniclass (Unified Classification for the Construction Industry).* RIBA Publications.

Eilif Hjelseth, Nick Nisbet (2011) "Capturing normative constraints by use of the semantic mark-up (RASE) methodology" in CIB W78 2011 28th International Conference - Applications of IT in the AEC Industry.

ISO 12911 (2012). "Framework for BIM Guidance" http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=52155

Lockley, S. (2012, January). *The xBIM Toolkit*. Retrieved April 2012, from The xBIM Toolkit: www.codeplex.com/xBIM

NBS. (2012, March). *The National BIM Library*. Retrieved April 2012, from National Building Specification: http://www.thenbs.com/topics/BIM/articles/nationalBimLibrary.asp

Omniclass (1999) "*Omniclass*" Retrieved April 2012 from http://www.omniclass.org/

RICS. (2010). *New Rules of Measurement – Order of Cost Estimating and Elemental Cost Planning*. London: RICS.

Turk, Z. (2006, April). Construction informatics: Definition and ontology. *Advanced Engineering Informatics, 20*(2), 187-199.