ISO 12006-2 AND IFC – PREREQUISITES FOR COORDINATION OF STANDARDS FOR CLASSIFICATION AND INTEROPERABILITY

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SUMMARY: *There are two major candidates for Core Ontologies for the construction and facilities management sector, the ISO 12006-2 Framework for classification of information, and the Industry Foundation Classes, IFC. ISO 12006-2 has been developed to harmonize different national and regional classification systems. It is applied world wide in the development of classification systems for everyday use in the construction industry. The IFCs are intended to enable effective information sharing within the AEC/FM industry, but are still mainly at a prototype stage of development. The standards have similar objectives but show fundamental differences in semantics and structure. This work compares the standards and points out similarities and differences, firstly in order to understand their structure, and secondly to initiate a discussion about the need and the possibility to coordinate them. An integration of IFC with ISO 12006-2 would facilitate and speed up the application in everyday practise of object-based information management. According to the documentation, the starting point of IFC was to reject classification, and therefore integration with ISO 12006-2 would require a major shift of approach. Development of a common meta model, a generic domain model, and a coordinated domain framework are considered necessary tasks.*

KEYWORDS: *ISO 12006-2, IFC, interoperability, construction classification, construction ontology.*

1. ONTOLOGIES FOR CONSTRUCTION AND FACILITIES MANAGEMENT

The demand for standardised concepts and terminology rapidly increases in the construction and facilities management sector. Internationalisation of the industry and an increasing use of information systems are decisive factors in this development. A generally agreed ontology is a prerequisite for effective information exchange and interoperability in any field of knowledge (Lima 2004). The development of the semantic web with agent-based information retrieval is a current example, where interoperability is enabled through ontology development and standardisation (Berners-Lee et al. 2001).

An ontology consists of concepts that describe objects of interest in a domain. The ontology for the construction and facilities management sector comprises concepts for describing construction entities, their design, production, use and management, as well as people using and experiencing the built environment. Internationally agreed ontologies in the sector are scarce, the post-war world wide spread of the SfB building classification system was an exception.

Classification systems are cornerstones in ontology development, they concern both concepts and terminology and have a decisive influence in establishing a common language for actors in a sector. Lately the interest in ontology for the construction and facilities management sector has grown, at first connected with the interest in product modelling and now with the emergence of XML-based information exchange (Tolman 2000).

The construction and facilities management sector is traditionally national and regional in character. Today, there are two major international candidates for core ontologies common to the sector, ISO 12006-2:2001, Building construction - Organization of information about construction works – Part 2: Framework for classification of information (ISO 2002), and Industry Foundation Classes, IFC, developed by the International Alliance for Interoperability, IAI (IAI 2000).

ISO12006-2 defines a framework of generic classes of interest in construction and facilities management. It is intended to be used as a starting point for development of detailed classification tables. Tables that adhere to the principles laid out in the standard are assumed to be similar and possible to translate between. ISO12006-2, with its roots in the SfB-system, has recently been applied in the development of building classification systems like the British UNICLASS (RIBA 1997), The Swedish BSAB 96 (The Swedish Building Centre 1999), the North American OCCS (OCCS 2003) and the Danish DBK-system under development (DBK 2004). The scope of ISO12006-2 is the complete life-cycle of construction works but it is not specifically considering the needs of interoperability of information- and communication technology, ICT, applications. IFC addresses interoperability requirements and has a similar scope concerning both construction and facilities management. IFC consists of a framework of classes and models, intended to be used mainly for translating information between schemata in different object-oriented information systems, but also for development of schemas for such systems. Although its aim is not to develop a generic building classification, its framework of classes is similar to those of ISO 12006-2.

An ontology for the construction and facilities management sector must be common to the worlds of classification and product modelling. Already in the introduction of product modelling research the idea of harmonization with building classification was suggested by Björk in the "Unified Approach Model" (Björk 1992). This model was later integrated into the IRMA model (Luiten et al 1993). Both are compatible with the basic structure of ISO 12006-2.

Both ISO 12006-2 and IFC have as purpose to establish a foundation for development of effective information systems for the construction and facilities management sector. However, there are marked differences in semantics and structure of the systems. The aim of this research is to compare the structure of the standards, to point at similarities and differences, in order firstly to understand why these standards are so different, and secondly to initiate a discussion about the need and the possibility to co-ordinate them.

This author has conducted several studies relevant to the present study, including the development of theoretical foundations for analysing the structure of building classification systems (Ekholm 1996), structuring properties of construction objects (Ekholm 2002), and defining a concept of space for product modelling (Ekholm and Fridqvist 2000). Other work by the author concerning ontologies include a study of the relationship between current ontologies in construction and the process plant and shipbuilding industries (Ekholm 1999), and specifically analysing the possibilities to integrate the Swedish BSAB building classification system with the IFC (Ekholm, Tarandi and Thåström 2001).

Starting with a short introduction to the relation between object-oriented information systems and classification, the following sections analyse and compare the structure of ISO 12006-2 and IFC, discusses information requirements in critical processes, compares with other standards, and reflects on a strategy for harmonizing ISO 12006-2 and IFC.

2. OBJECT-ORIENTATION AND CLASSIFICATION

2.1 Conceptual models and ontologies

In the construction sector, information systems are developed to support design of products, and communication of information about products. Specifically, object-oriented, model-based or product information systems are based on conceptual representations of products. The conceptual model or schema, also called the Universe of Discourse, UoD, determines the total collection of possible statements about the represented products (SIS 1985 and Eastman 1999).

In order to be effective in communication, it is necessary that product information systems are based on a common understanding of the product in question, and apply a standardised terminology. This requires that the conceptual models and schemas adhere to commonly used and accepted ontologies. Increasingly, ontologies are structured through classification systems to support effective information exchange. This also affects the construction sector where international standards are frequent. One example is the framework standard for building classification systems ISO 12006-2 which has as a purpose to coordinate the structure of national and regional classification systems.

2.2 Objects and classes

Central concepts of information systems theory are "object" and "object-orientation", see e.g. (Rumbaugh et al. 1991). Objects in the domain of interest are modelled as software objects with properties that represent domain object properties. For example, a wall in a building can be represented by a software wall-object with properties that allow a representation of the wall geometry on the computer screen. Cad-systems, e.g., are increasingly object-oriented which allows a more close resemblance between information system objects and domain objects. The advantages of object-orientation are the reason for the development of the IFC standard, which supports object-based information exchange between different information systems.

However, the concept of “class” is just as important as “object” to this field. Rumbaugh et al. ask themselves the question: “if objects are the focus of object modeling, why bother with classes?” Their answer is that abstraction is at the heart of the matter. By abstracting away from idiosyncrasies and understanding a collection of object instances as a class of objects with common properties, a programmer, for example, may use common code, definitions, operations and procedures for the whole collection.

In a general sense an object is an entity, concrete or abstract, towards which our attention is directed (Webster’s 1995). We distinguish between objects by conceptualising their similarities and differences as properties and attributing these to the objects. The concept of property is accordingly called attribute (Bunge 1983:165). The distinction between an object as a whole and its properties is purely conceptual; a property has no separate existence from the object as a whole. However, it is epistemologically useful to separate the object from its properties, e.g. during a process of investigation as we attribute properties to objects, and try out hypotheses by testing whether the objects have the properties or not.

The process of discriminating between objects results in the formation of classes or kinds, e.g. the class of buildings, or ideas. The concept of class, or kind, can be defined using the concepts of scope and property; the scope of a property is the set of objects possessing it. A class is defined as “a set of objects that constitute the scope of a property” (Bunge 1974:15).

2.3 Classification system

To classify means to, for a specific purpose, make a subdivision of a collection of objects into mutually disjoint subsets (Hunter 1988). In order to be able to classify a collection of objects it is at first necessary to define the purpose of the classification. Then the properties of interest to the classification may be distinguished, and finally the objects can be sorted into classes with regard to the chosen properties.

The division into classes can be made with different degrees of fineness. A coarse grouping is based on more generic properties, while a fine-grained grouping is based on more specific properties. For example, the fruits in a basket may, depending on the purpose, in the first grouping be divided into apples and pears. The next grouping may consider different ripeness or different colours.

A classification system must enable a both exhaustive and unambiguous ordering of the objects in the collection. In order for the classification to be exhaustive, every object in the collection must be assigned to a class, and in order to be unambiguous each object may only belong to one class. Without these criteria there are unclassified objects, and objects that belong to more than one class of the same rank.

A classification system has two kinds of relations: the membership relation ($\in$) holding between objects in the collection and the classes of the first rank, and the inclusion relation ($\subseteq$) that relates classes of different rank (Bunge 1985:326). A classification “rank” or “level” is a set of classes with the same fineness, see Fig. 1.

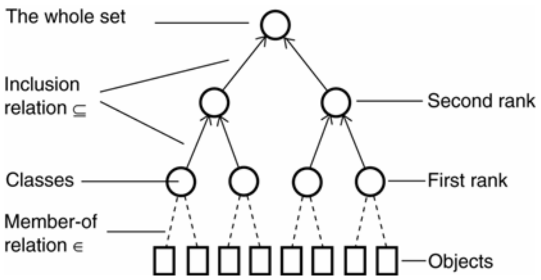

FIG. 1: Classification concepts.

3. THE STRUCTURE OF ISO 12006-2

The ISO 12006-2 standard has been developed as a step in harmonizing different national and regional building classification systems. It is intended to be used as a framework for developing building classification systems by organisations on a national or regional basis. An underlying assumption is that the ISO-standard in the long run will enable the development of common tables at an international level.

ISO 12006-2 ”defines a framework and a set of recommended table titles supported by definitions, but not the detailed content of these tables” (ISO 2002:6). It is based on many years of practical experience, and is also shown to be compatible with scientific ontology and systems theory (Ekholm 1996).

ISO 12006-2 identifies the main classes that are of interest to the construction sector’s building classification for purposes of CAD, specification, product information and cost information systems (ISO 2002:4). The scope of the standard is the complete life cycle of construction works within building and civil engineering. It lists recommended tables according to particular views or principles of specialisation and gives examples of entries that may occur in these tables (ibid:6).

The ISO standard has not been expressed in a formal data definition language. The standard illustrates objects and relations in an informal schema which for reasons of space is not shown here. The relations between objects are depicted with arrows representing subclass relations and other associations between classes and properties. The schema together with the definitions in the standard are sufficient as a background for representing the standard in a more formal way in EXPRESS-G diagrams, which make a comparison with IFC easier. In the following text the ISO Framework Standard, will be named FST for short, and the classes of the standard will be given short names to fit within the schema boxes.

3.1 The FST Construction Object

The most generic entity in the FST is the “Construction Object”, defined as an object of interest to the construction industry. The FST identifies four main classes of “Construction Object”: “Construction Resource”, “Construction Process”, “Construction Result”, and “Property/Characteristic”. These are related in a generic process model stating that “Construction Resources” are used in “Construction Processes” that will result in “Construction Results”, and all these objects have “Properties/Characteristics”. Every class in the standard is a subclass of one these four. Relations are not treated explicitly in the standard but possible to represent as mutual properties of the related objects. The EXPRESS-G schema in Fig. 2 illustrates these most generic classes.

The FST does not suggest any classification for properties but gives examples from the CIB Master List, e.g. composition, surface and sensory, thermal etc. Generally, building classification systems do not handle geometrical properties, since they are supposed to be used together with drawings or models that contain this information. This identifies a crucial difference between a classification and the ISO-STEP product models, of which IFC is an outlying example.

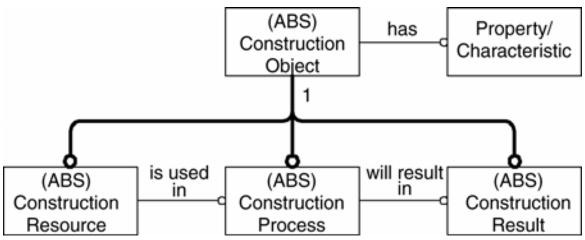

FIG. 2: The high level process model in ISO 12006-2.

3.2 FST Construction Process

A “Construction process” is a “process which transforms construction resources into construction results”. The FST defines “Management process” and “Work process” as the two main kinds of “Construction process”. See Fig. 3. “Management Process” is a planning or administrative process. A “Work Process” leads to a “Work Result” which is a result classified according to process or kind of work. A construction process “occurs during” a “Project stage” or a “Construction entity life-cycle stage”, which according to the FST are the two types of stage of interest to construction information. A ”Construction entity life-cycle stage” is “a period of time in the life-cycle of a construction entity”, e.g. design, production, or maintenance. ”Project stage” is ”a period of time in the duration of a construction project identified by the overall character of the construction processes within it”. Construction processes occur during these different stages and can be named by stage, e.g. broadly as design, production, or maintenance, or more narrowly e.g. as design brief development, structural design, or facilities operation. The relation between these two classes is not quite clear but it seems as if “Construction Entity Life-Cycle Stage” has a wider scope while a “Project Stage” more narrowly focuses on a project organisation and its activities.

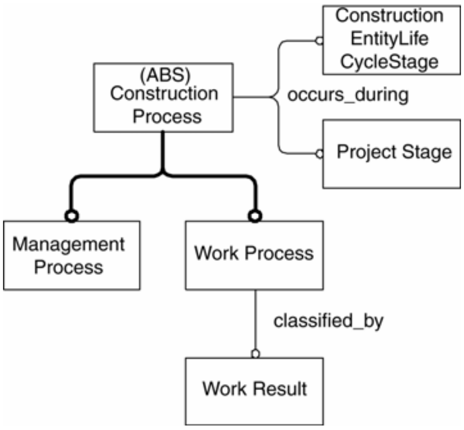

FIG. 3: Processes in ISO 12006-2

3.3 FST Construction Resource

Resources in the FST are shown in Fig. 4. A “Construction Product” is a resource intended for incorporation in a permanent manner in a construction entity. Members of “Construction Aid” are resources like tools and machinery, not intended for incorporation in a permanent manner in a construction entity. The properties of a ”Construction Product” are basic to the properties of the built parts of the construction entity. A “Construction Agent” is a human participant in a construction process, and “Construction information” is information used to support a construction process.

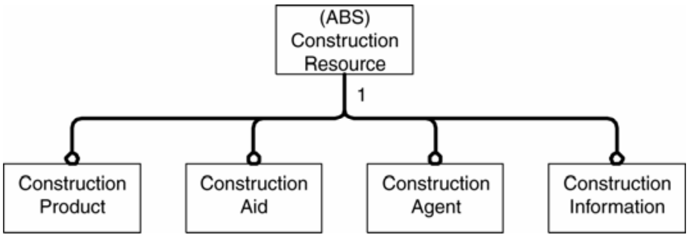

FIG. 4: Resources in ISO 12006-2

3.4 FST Construction Result

The FST identifies four main classes of result: “Construction Complex”, e.g. airport and motorway, which consist of one or more ”Construction Entity”, e.g. building and bridge, and “Construction Entity Part”, e.g. wall and road surface. A “Space”, e.g. a room or roadway, is “contained within or otherwise associated with a building or other construction entity” (ibid:9). See Fig. 5. The result classes identified in the FST seem limited in the sense that they describe material results. However a possible interpretation is that also information like design results, e.g. ideas and abstract models, representing concrete results are possible members of these classes.

The generic result classes “Construction Complex”, ”Construction Entity” and “Construction Entity Part” are related by a part-of relationship in a compositional hierarchy. The result classes are “abstract” and only intended to be instantiated after a first division into subclasses based on different views on the physical reality they represent. According to the FST, a “Construction Complex” is classified by function-or-user activity. A “Construction Entity” is classified either by form or by function-and-user activity. “Construction Entity Part” is classified by function as “Element”, by type of work as “Work Result” and as “Designed Element” by subdividing “Element” by “Work Result”. “Space” can be classified by enclosure, e.g. outdoors or indoors, by user function-or-activity or by a combination of these. “Space” in the FST has no relation with “Construction Entity Part”. A relation like “enclose” or “composed of” would seem relevant according to (Ekholm and Fridqvist 2000). The subclasses based on separate views are included in Fig. 5.

From the example of Designed Element it is easy to imagine the need for other combined classes e.g. "Designed Construction Entity" and "Designed Space". The Swedish BSAB 96 has a classification table for construction entities that could best be described as "Designed Construction Entity". It is a combination of "Construction Entity by Form", e.g. tunnels, bridges and buildings, and "Construction Entity by Function" (The Swedish Building Centre 1999). The difference in view is motivated by the purpose of the classification, if it is of importance to identify Construction Entities by the main construction method, e.g. girder bridge, arch bridge, or truss bridge, or by function-or-user activity as railroad bridge, motor vehicle bridge or pedestrian bridge. A similar subdivision is possible for "Space", e.g. indoors or outdoors specify form, e.g. kind of enclosure, and living room or kitchen specify function-or-user activity.

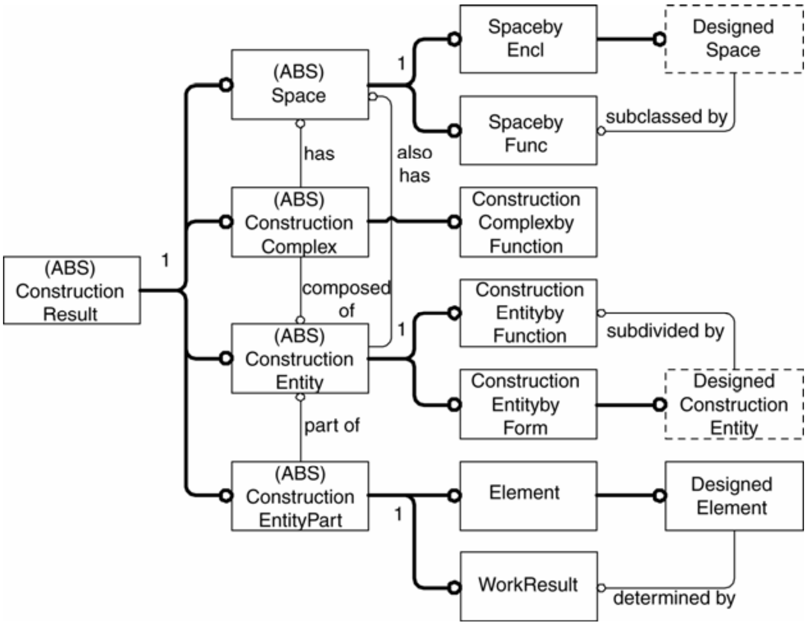

FIG. 5: Construction Result according to ISO 12006-2

4. IFC AND THEIR RELATION TO ISO 12006-2

4.1 The objective of IFC

The IFC constitute a framework for sharing information between different disciplines within the AEC/FM industry throughout the project lifecycle (IAI 2000:2). The main purpose of the IFC is to enable effective information exchange between information systems, so called interoperability. This concerns both semantic definitions and object exchange formats. The semantic definitions of the IFC concern, just as ISO 12006-2, objects of interest in construction and facilities management. However, IFC does not adhere to the ISO-standard and has different definitions and general structure. The documentation of IFC does not present a theoretical background for its structure or choice of model classes. It was built following the general EXPRESS modelling conceptual framework, see section 4.3.

IFC has gone through several practical tests that confirm its applicability and it is integrated in an increasing number of applications. However, with the exception of two earlier studies, one by the present author (Ekholm 1999), and one by Howard (2002), IFC has never been subject of a detailed critical analysis concerning its relation to building classification.

4.2 Conceptual layers

The organization principle for the IFC framework provides for a modular structure of models (ibid:5). The models are structured into conceptual layers of different scope. There are four conceptual layers where sets of model schemata are defined (ibid:5):

1. Resource classes.
2. Kernel and Core Extension classes.
3. The Interoperability classes.

4. The Domain classes.

The Resource layer contains classes that are applicable to most of the classes in other layers, e.g. geometry, date and time, material and cost. Resources could be understood as representing generic properties of domain objects.

The Core layer consists of the Kernel and the Core Extensions. The Kernel provides all the basic concepts required for IFC models. In an early version of the standard the Kernel is explained as ”a kind of Meta Model that provides the platform for all model extensions” (IAI 1997:6). In a later version the Kernel is explained as a “template model that defines the form in which all other schema within the model are developed…The Kernel is the foundation of the Core Model” (IAI 2000:8). The Kernel is independent of the AEC/FM domain.

4.3 The IFC Kernel

IFC uses EXPRESS as data definition language. The basic data units in EXPRESS are entities, relationships and attributes (Schenck and Wilson 1992:26). The IFC apply these units as a starting point to define the Kernel objects consisting of “IfcRoot” with the subclasses “IfcObject”, “IfcRelationship”, and “IfcPropertyDefinition” (IAI 2000:12). See Fig. 6.

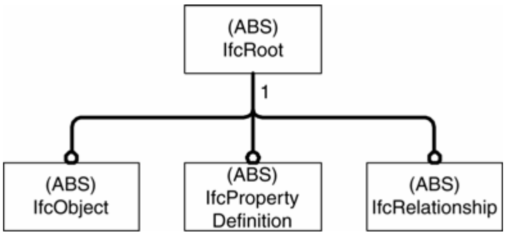

FIG. 6: The IFC “template model”

“IfcRoot” is the most generic entity, it has name, ID, description and history. “IfcObject” represents concrete and conceptual objects in the domain. Among examples are wall, space, grid, work task, cost item, labour resource, actor, and person. “IfcPropertyDefinition” represents different properties of domain objects. “IfcRelationship” has a double role in that it both represents relations between members of “IfcObject”, and relations between model classes. The fact that the former relationships are treated separate from properties is odd from an ontological point of view, since relations are mutual properties, e.g. “position” and “before” are properties based on relations between two or more things. The reason for using IfcRelationship to represent relations between classes is in accordance with the tradition of Entity-Relationship modelling, where “Relationship” is a linguistic entity that refers to a relationship between modelling concepts, and not to a relationship between domain objects.

The immediate subclasses of the “template model” constitute a second level in the Kernel. Subclasses of “IfcObject” are shown in Fig. 7.

In contrast with the FST, the IFC classes are not related in an explicit definition or model and one may wonder whether the selection is complete or if the classes are mutually exclusive, disjoint, as they would be in a classification system.

To compare, for example the “IfcResource” is not equivalent to the FST Resource. An “IfcResource” is defined as “information needed to represent the costs, schedule, and other impacts from the use of a thing in a process…It is not intended to use “IfcResource” to model the general properties of the things themselves”. This is radically different from the standpoint of the FST where a Resource like FST “Construction Product” is defined as “a commodity that may be incorporated into a construction entity in a permanent manner”. The “IfcResource” is an attribute, representing properties of resources, while the FST “Resource” is a class concept referring to a concrete thing seen as a resource. The FST “Resource” class may be used independently of other classes while the “IfcResource” requires an instance of “IfcProduct” to be applied. An “IfcProduct” is defined as a physical item incorporated into an AEC/FM project either directly as supplied or through construction/assembly of other products.

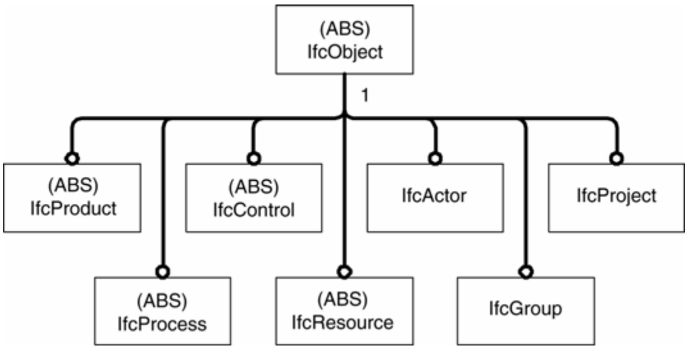

FIG. 7: IfcObject

An argument for the IFC standpoint is given by Froese and Yu who explain that “things as resources, products, etc. can be very dependent upon the perspective of the user of the information” and “it is difficult to design representational structures that satisfy all these different perspectives” (Froese and Yu 1999:2832). The FST takes a different standpoint and identifies two main perspectives of particular relevance to design and production, the “Construction entity part” and the “Construction product”. The former is a part of the construction entity, e.g. an FST “Element” or a FST “Work Result”, and the latter is a product seen from the point of view of acquisition into a construction process. These views are used as complements, e.g. in applications for specification and cost calculation.

Within the second level of the Kernel, the “IfcRelationship” class is specialised into five categories, “IfcRelAssigns”, “IfcRelConnects”, “IfcRelDecomposes”, “IfcRelAssociates”, and “IfcRelDefines”. These relate “IfcObject” to different other “IfcObject”, e.g. “IfcRelAssigns” may be used for an arbitrary relation between objects, “IfcRelConnects” may represent a physical coupling, “IfcRelDecomposes” represents the part-of relation and “IfcRelDefines” is used for relating Property Sets or Type objects with an object instance. Each relationship is further specialised according to the specific object that it relates, e.g. “IfcRelAssignsToResource”.

The same reflections as for the “IfcObject” subclasses are relevant to make for the “IfcRelationship” classes: are the different kinds of relationship theoretically well-founded, is the selection exhaustive?

4.4 The Core Extensions

The classes described above constitute the IFC Kernel. The next level is the Core Extensions layer, which consists of specialisations of the Kernel classes “IfcControl”, “IfcProcess” and “IfcProduct”. The subclasses of “IfcProduct” are “IfcElement”, “IfcSpatialStructureElement”, “IfcAnnotation”, “IfcGrid” and “IfcPort”. Fig. 8 shows the subclasses of “IfcElement” and “IfcSpatialStructureElement”.

An “IfcElement” is defined as components that make up an AEC product (IAI 2004). The names indicate that they are identified by function and thus similar to the different FST Elements. However, this is not the intention as shown below in section 6.1.

“IfcSpatialStructureElement” classes are only spatially defined. In the technical documentation of IFC 2x2, a spatial enclosure hierarchy shows “IfcSite”, “IfcBuilding”, “IfcBuilding” seen as section of a building, and “IfcBuildingStorey” related through “IfcRelAggregates”, a subclass of “IfcRelDecomposes” (IAI 2003:102).

In FST, “Construction Complexes”, “Construction Entities” and “Construction Entity Parts” are related in a compositional hierarchy, as illustrated in Fig. 5. A spatial hierarchy of enclosure similar to IFC’s could be developed in parallel to the compositional hierarchy. The FST does not mention the concept of construction site explicitly, but in principle it could be seen as a construction complex consisting of related construction entities like roads, buildings, pavements etc. The other kinds of space would be derived from a spatial view on construction entities and construction entity parts.

The FST does not specify how relations between different kinds of spaces are handled. For example, the relation between a room and a building storey is not covered by the FST. IFC needs to support this kind of specification but could be improved by applying a more generic view of the concept of space and how it is related to buildings and parts of buildings. Examples of relevant analyses of the concept of space are presented in (Ekholm and Fridqvist 2000) together with a proposed definition of space relevant for both classification and product modelling. Here, the concept of space is included in a theoretical framework that also considers other aspect views on the building, e.g. functional systems and their parts.

Although "IfcGroup" is not an "IfcProduct", it has two subclasses in IFC Product Extension, "IfcSystem" and "IfcZone". "IfcGroup" could be understood as a generic class describing an arbitrary aggregate of members of "IfcObject". Functionally related parts of a collection may be represented together as "IfcSystem". Similarly if the collection consists of adjacent spaces the collection may be represented as "IfcZone".

The seemingly ad hoc based position of these classes in the Core Extension may be explained as a consequence of the lack of theoretical foundation for the development of the IFC framework. The generic concept of system should be defined already in the most generic, ontological level, of the framework e.g. stating that any object may be a system composed of parts.

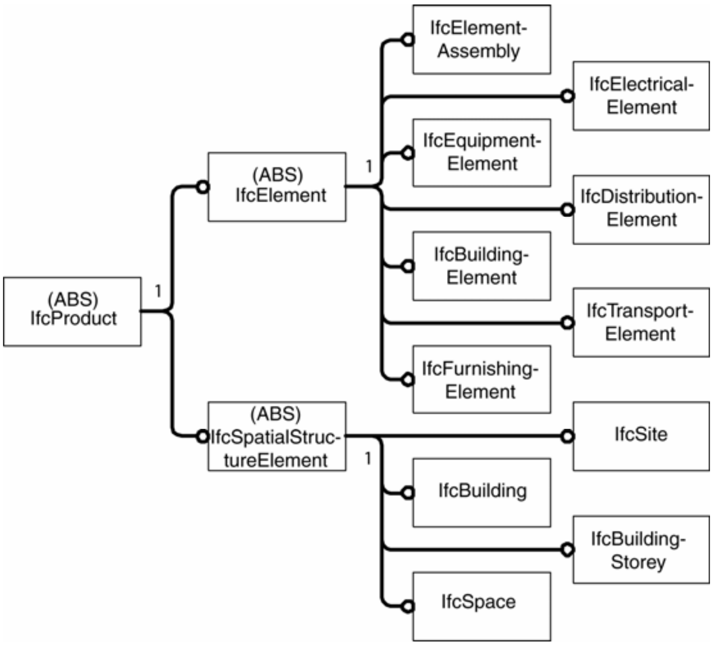

FIG. 8: IfcElement and IfcSpatialStructureElement

4.5 The Interoperability Layer

The next lower level is called the Interoperability Layer. It contains classes common to different actors and disciplines in the construction and facilities management sectors. Here one may find, for example, "IfcWall", "IfcBeam", and "IfcElectricalAppliance". The classes of the interoperability layer are intended to be generic in scope. One example is the class "IfcWindow" which is a "leaf node" in IFC, i.e. it is not subclassed in the standard. Further detailing is achieved through assigning Property Sets, e.g. that assign different numbers of glazing panes, opening types, framing arrangements etc.

The classes in this level are similar to those in classification tables of national and regional classification systems. However, the classes are not intended to be equivalent to those in classification as will be discussed in section 6.1.

5. VIEWS IN CONSTRUCTION AND FACILITIES MANAGEMENT

5.1 Views on Construction Entities

The separation of classes from spatial, functional, and compositional views and the possibilities to combine these is characteristic to several processes in construction and facilities management. The difference of view is motivated by the purpose of using the information, for example, whether it is of importance to identify a construction entity by main construction method or by function-or-user activity.

The example given above in relation to the FST described a bridge as a girder bridge, arch bridge, or truss bridge, and as a railroad bridge, motor vehicle bridge or pedestrian bridge, respectively. The functional-or-user activity view on the "Construction Entity" may be of specific interest in the brief stage or in the facilities management stage. Similarly, the compositional view may be of interest during systems design, detailed design, production and maintenance, where knowledge of composition and constituent materials are necessary.

There is no equivalent in IFC to the FST classes "Construction Entity by form" and "Construction Entity by function-or-user activity". The only IFC class in this level is the "IfcBuilding", a subclass of "IfcSpatialStructureElement", a semantically spatial concept.

5.2 Views in design

The FST reflects the idea of design as a process where functional requirements are met with technical solutions and concrete work results. There is a need for separate classes for these views, since they concern different stages and actors in the construction process. The FST classes for construction entity parts are "Element", "Designed Element" and "Work Result".

During design, building classification supports the incremental determination of properties of the designed object. At first the designed object is identified through a spatial view, location and geometry are determined. Next, the object is functionally determined and can be classified as "Element". When the technical solution of a part has been determined it may be classified as "Designed Element" and "Work Result". See Fig. 9.

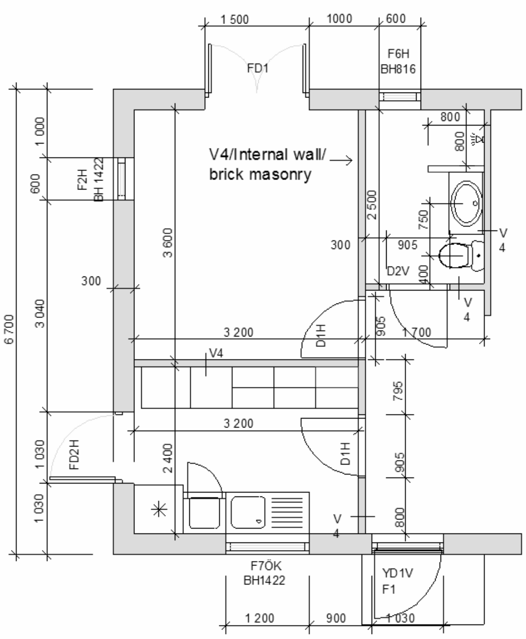

FIG. 9: Identification of a designed object with location and geometry through a spatial view

In principle the sequence is the same in drawing-based design and 3D-model-based CAD, the designer starts by defining design objects, representing e.g. building parts by geometry, and incrementally determines function and technical solution. However, the main 3D-modelling CAD-applications integrate the first two steps and require a designer to instantiate a design object from an "Element" class with predefined geometry parameters, e.g. a wall as a vertical plate. In this case the instantiated object is already determined by function according to the definition of the "Element" class. It could be argued that object-oriented CAD-software would better suit the design process if these two steps were not conflated.

5.3 Views in specification and cost calculation

In order to develop a specification or cost calculation using the FST each Element is specified by "Work Results" including used resources, e.g. labour and material. Tab. 1 illustrates a specification using the Swedish classification system BSAB 96 from a prototype test of information transfer from product model to cost calculation using IFC and BSAB 96 (Nilsson & Eriksson 2002).

The IFC cannot handle cost calculation in this way since it does not identify classes based on different views. Instead, cost calculation is enabled by associating instances of “IfcProduct”, e.g. “IfcBuildingElement”, with “IfcConstructionResource” and related “IfcCostItem” (IAI 2003). It would seem less cumbersome to use predefined classes like FST “Work Result” to handle this. The latest version of IFC comes close to including a work result entity through the definition of “IfcTask”: “An “IfcTask” is an identifiable unit of work to be carried out independently of any other units of work in a construction project”; it may be classified by a Work Breakdown Structure code (IAI 2004). A project Work Breakdown Structure, WBS, is a hierarchical structure of the results of a process, e.g. a project or a production process (MIL-HDBK-881 1998). In practice, this means that “IfcTask” will be considered equivalent to the FST “Work Result” and used for the same purpose. But a result is not the same as a process, therefore, “IfcTask” should not be a subclass of “IfcProcess” but rather of “IfcProduct”.

Applications for design, specification, and cost calculation might require that attributes of objects emanating from different views are inherited by a new object during the processes. This requires support for multiple inheritance in the database structure and is a problem for IFC since it only allows single inheritance (IAI 2000:39). There is perhaps a connection between this fact and the rejection of IFC developers to define different classes representing different views on the same thing.

TABLE 1: The structure of a specification based on BSAB 96

E-code	Element (E)		
27.G	Roof carcass		
	WR-code	Work Result (WR)	Unit
	HSD.113	Beam framework	length (m)
	HSD.2	Glue-laminated wood beam	length (m)
	GSN.17	Roof truss	amount (no)
	ZSE	Angular fittings	amount (no)

5.4 Views in other standards

The recognition of the relevance of distinguishing classes from different views is not unique to the FST, rather, it is common in other standards. For example, STEP AP 221 “EPISTLE”, used for Product Data Management separates between a “functional physical object”, which represents a functional view on an object in the domain, while the “materialized physical object” includes both a functional and a compositional view (EPISTLE 2004).

Another industry standard, IEC 61346 “Industrial systems, installations and equipment and industrial products“, developed for classification of “technical objects”, for similar reasons as the FST, distinguishes between objects identified from three different views, the functional: “function”, the compositional: “product” and the spatial: “location” (IEC 2000).

There is no principle problem to integrate different views in the same model or schema. An example has been developed by Ekholm and Fridqvist (Ekholm and Fridqvist 2000). This shows a possible solution that integrates a functional or spatial view with a compositional view (ibid:324). An aspectual view regards a certain subset of the total composition of the modelled object, while the compositional view includes the object’s composition, i.e. the assembly units or work results that the object is made from.

6. CONCLUSION OF THE STUDY

6.1 Classification and product modelling

As a starting point for the development of IFC, the relevance of building classification for product modelling was questioned since “it only allows a user to categorize elements according to primary functional role or as part of a system” (IAI 1997:2-15). The developers of IFC intended to ”avoid this by defining model elements, functional roles, and systems separately so that an element can assume multiple roles and/or be a member of multiple systems”.

The development of IFC has been guided by these principles. As a consequence the IFC Core Extension and Interoperability classes are not intended to be equivalent to classification classes, but should be seen as some kind of placeholders for information about the modelled instance. The properties of the instance are determined through associations with "GeometryResources", "PropertySets" and other classes in IFC. Accordingly, in order for an IFC instance to be classified e.g. as an FST Element it would need to be assigned a Property Set equivalent to that of the "Element" definition.

In prototype tests of IFC this has not been tried out, but instead the IFC class names have guided the interpretation of the IFC classes as functional elements. Where such IFC classes have been missing the "IfcProxy" class has been applied to represent among others "Work Result" classes (Tarandi 2003).

One problem with the IFC approach is the idea that "model elements" may be identified independent of e.g. a spatial, functional, or compositional view. This approach is supported by Froese and Yu who claim that generally, things should be modelled as "what they are" rather than as "the role they play". This contradicts the general understanding among philosophers and scientists that we only know the world "as we see it", not "as it is". Popper, e.g., says that "If we wish to study a thing, we are bound to select certain aspects of it" (Popper 2002:71). We see the world through our concepts, and these are by definition classes (Bunge 1983:169). It is impossible to focus on an object without at the same time assigning it to a class. For example, when we call something a "wall" we immediately include the thing into the functionally defined class of enclosing/dividing things.

Another problem with the IFC approach is that it seems to abandon the basic ideas of object-oriented modelling as presented by e.g. Rumbaugh et al., see above Section 2.2. The idea of abstraction requires that the modeller shifts focus from instance to class. If IFC had applied its own espoused principles it would enable a model element to be instantiated in a generic level independent of functional, compositional, or spatial definition. But this is not supported, e.g. all classes from "IfcRoot" down to "IfcBuildingElement" are abstract and cannot be instantiated (IAI 2003:114).

In practice IFC has not succeeded in establishing the intended separation between model elements and classification. The IFC classes have, to a large extent, similar names as those used in classification systems. An example is the "IfcWall", which also in IFC is defined by its functional role as "enclosing". Instances of this are not independent of functional role. This would not have been problematic if IFC had acknowledged the fact and adhered to FST or any other classification framework.

In fact building classification supports precisely the process which IFC strives for. As explained above, classification classes must be seen as part of the information that is determined in the process alongside the geometry information expressed by drawing objects. This fact is an important argument for revising the IFC class structure in adherence to the FST.

6.2 Integrating the FST and the IFC

Recently, based on the experiences of the Workshop on eConstruction, the need for a strategy for development of a unified building construction model has been stressed (Wix 2004:32). The analysis presented here suggests that the harmonization of building classification represented by ISO 12006-2, and product modelling, represented by the IFC, should be an essential part of the work.

What would be the reason for harmonising FST and IFC? Classification systems adherent to the FST are used in daily practise in several countries for both manual and computer-based information structuring. IFC specifically addresses questions of interoperability and represents a considerable investment of time and money. If IFC and the FST were harmonized it would facilitate and speed up the integration of everyday practise with object-based information management.

Would it be possible to integrate these standards? The FST and IFC both lack an explicit theoretical foundation, and establishing a common ground would effectively support an integration process. The FST follows the basic rules of classification systems, i.e. to be exhaustive and unambiguous. Compared with FST, the IFC's framework is more ad hoc which makes it harder to understand, apply and develop. A framework for information systems in the construction and facilities management sector should be both theoretically well founded and practically applicable. The former will increase versatility and life span of the standard.

The FST and IFC support slightly different processes, but, as shown, there is a significant overlap between the frameworks. The FST is developed to support specification, cost calculation, CAD-layering, PDM-systems, brief development, etc. for the construction and facilities management processes. IFC has a similar scope, but the needs of CAD-systems and the definition of CAD objects were initially in focus.

How could the harmonisation be accomplished? A starting point would be to abandon the IFC strategy of "defining model elements, functional roles, and systems separately" and acknowledge the need for a framework based on views and classification. Then, it would be necessary to define a "meta model" based on generic principles for modelling domain objects starting, not from the basic entities of the EXPRESS language, but from very generic ontological theories, e.g. a general theory of systems and properties. This would include the definition of objects from different views. An attempt in this direction may be found in (Ekholm and Fridqvist 2000). A next consideration would be to build a generic domain model similar to that of FST or the IRMA that defines the main classes, including objectified relationships, needed to build the model schemas. The overall aim would be to develop a framework for object-oriented information exchange for construction and facilities management that would be both scientifically well founded, and applicable and acceptable for the processes that are to be supported.

7. REFERENCES

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