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An Assessment of Industry Foundation Classes (IFC) in Representing Contextual Information Required for Production Rate Estimations

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Abstract
Contextual information is needed when estimating the production rates of activities to be occurring in an upcoming project to understand the context under which previous activity production rates were achieved. These information items need to be represented and stored in a structured way as part of project histories to enable estimators to easily query and search for activities that were performed in contextual conditions that are similar to the upcoming project, so as to utilize the production rates of those activities when estimating. Previous research on contextual information showed that there are a large number of items that get to be collected and generated using a variety of hardware and software technologies. In order to enable representation of these information items in a structured way and to share this information with other software systems (such as estimating and scheduling), it is necessary to assess whether it would be possible to exchange contextual information using existing data standards. Various data standards (e.g., CIS/2, IFC, IFD) are currently being utilized in the Architectural/Engineering/Construction and Facilities Management (AEC/FM) domain for enabling interoperability. Industry foundation classes (IFC) is a generic data standard that has the ability to represent a larger set of data items as compared to other data standards, and is being commonly utilized in the AEC/FM industry. Hence, within the context of this paper, the authors have focused on IFC data standard to assess how they are capable of representing historical contextual information required to be stored as part of project histories. Results have shown that IFCs can support most of the design related contextual information items and the current specification needs to be extended to other required contextual information items. It was also observed that, redundancies exist in IFC data representation that might hinder interoperability in the AEC/FM industry applications. These data redundancies in IFC are also highlighted.

Keywords
Project histories, Contextual information, Activity production rates, Production estimation, Data standards, Interoperability

1. Introduction

Contextual information for cost estimators is defined as information items that show conditions under which an activity production rate was achieved in a past project (Kiziltas, 2008; Kiziltas and Akinci, 2009). Such information items are essential for cost estimators while they estimate activity production rates for upcoming bids. Having factual information about past historical projects will positively impact estimators' accuracy in cost estimates, reduce cost overruns and enable having reliable estimates (Paek, 1993; Touran, 1988). These information items need to be represented in a structured way part of project histories for improving access to and usage of historical contextual information and production rates while estimating. In order to enable representation of these information items in a structured way and to share this information with other software systems (such as estimating and scheduling), it is necessary to assess whether it would be possible to exchange contextual information using existing data standards.

The objective of this research study was to evaluate existing IFC data standard utilized within the AEC/FM industry in terms of its capabilities in representing contextual information items. Various data standards (e.g., CIMSteel integration standards -CIS/2, industry foundation classes- IFC, integrated framework for dictionaries- IFDs) are currently being utilized in the AEC/FM domain. The main purpose of these data standards is to improve interoperability between various parties and applications involved in projects. Among these, Industry Foundation Classes (IFC) is a specification that is utilized to share project information in computer interpretable manner to enable interoperability between different systems used by different stakeholders throughout the lifecycles of facilities. Among the available data standards, IFC is a generic one that has the ability to represent a larger set of data items over multiple domains, as compared to other data standards. It is also being commonly utilized in the AEC/FM industry as compared to the other standards. Hence, within the context of this paper, the authors have focused on IFC data standard to assess how it is capable of representing historical contextual information required to be stored in project histories.

For the stated objective, the research method included exploring and assessing the latest IFC specification in terms of what it is capable and limited in representing contextual information items. In this research, alpha IFC 2x4 was explored. This research study builds on findings of another research study performed by the authors. In that previous research study, the authors identified contextual information items required by estimators and to be represented in project histories for cast-in-place (CIP) concrete formwork and concrete pouring activities and bulk excavation (Kiziltas and Akinci, 2009). Using these information items, the authors assessed the existing IFC specification, and identified capabilities and limitations of this data standard. These three construction activities were important as get affected from a wider variety of factors at job sites, executed in various project types (e.g., heavy/civil, commercial), and are more troublesome at job sites. By focusing on these three activities, it was possible to have a wider assessment of IFC representation capability as compared to other activities, such as windows installation, or plastering, which are affected from a smaller set of factors.

Within the context of this paper, the authors first provides a list of contextual information items identified for CIP concrete formwork and concrete pouring and bulk excavation activities and overviews IFC specification. Then this paper details the findings associated with exploring these information items in IFC specification. The result of this exploration task provides the capabilities and limitations of IFC in terms of representing historical contextual information items required by estimators.

2. Background Research

This research study builds on and extends research studies done related to evaluating and extending IFC data standard for domain specific applications, and related to identification of contextual information requirements of estimators from past projects.

IFC (ISO 16739 standard) is a standardization effort for product (such as building components), process (operations, cost, time, relationships) and control model specification in the AEC industry. Data schemas define how different applications will talk to each other and how information will be represented. It is an effort led by International Alliance of Interoperability (IAI) since 1996 and now IAI broadened the issues they deal with under the name of buildingSMART. IFC is capable of representing product, process and control related data on components (e.g., building elements, facilities elements) from nine domains (e.g., architectural, construction management, electrical, HVAC) and at four layers (i.e., domain, interoperability, core and resource layers). Represented components (called entities) consist of both tangible concepts (e.g., walls, beams), and abstract concepts (e.g., costs, spaces). With layered representation, hierarchical structure between entities is maintained. Domain layer includes entities and definitions of these entities specific to nine domains, interoperability layer includes entities that are commonly shared between AEC/FM applications, core layer includes abstract concepts (e.g., space, annotation, site, task, schedule) that are related to entities defined in other layers, and resource layer includes entities to define basic properties (e.g., geometry, material, cost, quantity) of entities defined in other layers (Lachmi, 2004). Objects, properties, relationships are three main categories of entities in the domain layer, where each object has properties (using entity types in interoperability layer, property sets) assignments (using relationships entities), associations (using resources layer entities) and decompositions. Given this data structure, IFC compliant (i.e., can import export IFC files) software applications are developed to share and exchange project information throughout its life cycle.

There have been studies in the literature that evaluate capabilities of IFC in representing various information items exchanged in the AEC/FM industry. These studies resulted in suggested extensions to the existing IFC schema. Examples of such studies include, inclusion of domain specific objects required for precast concrete component representation and information exchange (Eastman *et al.,* 2006), for building commissioning data exchange (Wang *et al.,* 2005), for structural design (Serror *et al.,* 2008), and for facilities management (Yu *et al.*, 2000). These examples are various and each example focuses on a domain specific data exchange and provides requirements for extending the IFC schema on the version with which the studies were conducted.

In order to understand how capable IFC in representing contextual information items, the authors used a list of contextual information items identified in a previous study for the construction activities: cast in place concrete column and wall formwork installation and bulk excavation. The authors identified a set of contextual information items by brainstorming with sixteen estimators from various construction companies. Findings of this previous study are detailed in Kiziltas and Akinci (2009). In that study, a set of information items were identified as necessary for estimators related to these construction activities. These information items were related to design features of components (e.g., size, shape, openings), construction processes utilized at the job site of a past project (e.g., equipment types, capacities, material properties), construction job site properties (e.g., soil type, ground conditions), and project characteristics (e.g., project type, size, location). Using the findings of that study, the authors evaluated to what extent existing schema of IFC is capable to represent construction estimating related information items required from past projects.

3. Research Method and Findings

This research included exploring and assessing the latest IFC specification to identify capabilities and limitations in representing contextual information items. In this research, open source alpha IFC 2x4 schema was explored. Findings of this exploratory study are provided in groups below.

3.1 Assessment of IFC in Representing Design Related Contextual Information Items

The results of exploration of identified contextual information items in IFC are summarized in Table 1. Table 1 shows the list of contextual data related to identified information items that are represented in IFC, and IFC classes that need to be used to navigate to the required data item. In the explorations, the starting point has been taken as ifcTask, which represents a construction activity. The reason for starting from ifcTask was that contextual information items were identified specific to construction activities; hence associated with activities.

Table 1 proves that IFC is quite comprehensive in representing geometry related information items. Majority of the design related information items could be represented using the classes represented in the IFC schema. As can be seen from the first column of Table 1, majority of the data items are related to finding lengths, widths, areas, volumes, openings, shape and shape features (e.g., steps on components, constant height) of components on which activities act. These groups of information items are possible to represent with wide alternatives provided in IFC. IFC utilizes ifcGeometricRepresentationItem group to represent geometry related information items. Under this class, a geometry of any product can be represented with (a)curve segments, (b) curves, (c) surfaces and surface models (e.g., face based, shell based), (d) vectors, (e) solid models, (f) bounding boxes, and (g) geometric sets, such as sets of points, curves and surfaces (IAI, 2008).

IFC is quite extended in representing geometry, however, there are limitations that make IFC representation incapable and complex as: (a) navigating through reified relationships that make the representation complex and hard to follow, (b) flexibility of IFC schema in representing geometry in multiple possible ways that result in interoperability problems, and (c) incapability of IFC in representing some of the information items.

Reified relationships, which represent relationships between objects as separate and standalone objects, are quite widely used in the IFC schema. This representation is used to make the representation more flexible and to enable defining some semantics associated with relationships. However, at the same time, these reified relationships make the representation schema complex. For example, if building element heights, widths, lengths are to be represented in IFC, it takes at least 10 classes to move from the class representing the building element (e.g., ifcWall) to the geometric representation classes (i.e., ifcGeometricRepresentationItem). From this class on, depending on the contextual data to be represented, the number of IFC classes to be navigated changes, as detailed in Table 1. Such large number of class representation can be complex and hard to follow, but is essential to keep the data model traceable and easy to implement reasoning mechanisms on.

Table 1: Representation of Design Related Contextual Information Items in IFC

Contextual Data		IFC class representation
Element_height, Width, Length		ifcTask→ ifcRelAssigns →ifcRelAssignsToProduct→ifcProduct→ ifcProductRepresentation→ ifcProductDefinitionShape→ifcShapeAspect→ifcShapeModel→ifcShapeRepresentation→ ifcRepresentationItem→ ifcGeometricRepresentationItem (applicable to all six alternatives)
	1.	ifcBoundingBox
	2.	ifcFaceBasedSurfaceModel→ifcConnectedFaceSet→ ifcFace→ ifcFaceBound→ifcLoop→ ifcEdgeLoop→ ifcEdge→ *calculations needed**
	3.	ifcShellBasedSurfaceModel→ifcShell→ifcOpenShell→ifcConnectedFaceSet→ifcFace→ifcFaceBound→ifcLoop→ifcEdgeLoop→ifcEdge→*calculations needed*
	4.	ifcGeometricSet→ifcCurve→ifcBoundedCurve→ifcPolyline→ifcCartesianPoint→*calculations needed*
	5.	ifcGeometricSet→ifcCurve→ifcLine→ifcVector→ifcCartesionPoint→*calculations needed*
	6.	ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement Component(e.g.,ifcWall,ifcColumn)→ifcRelDefines→ifcRelDefinesByProperties→ ifc ElementQuantity→ifcPhysicalQuantity→ifcSimplePhysicalQuantity→ifcQuantityLength
Formwork_area		ifcTask→ ifcRelAssigns →ifcRelAssignsToProduct→ifcProduct→ ifcProductRepresentation→ ifcProductDefinitionShape→ifcShapeAspect→ifcShapeModel→ifcShapeRepresentation→ ifcRepresentationItem→ ifcGeometricRepresentationItem (applicable to the first four alternatives)
	1.	ifcBoundingBox→ *calculations needed*
	2.	ifcFaceBasedSurfaceModel→ifcConnectedFaceSet→ifcFace→ *calculations needed*
	3.	ifcShellBasedSurfaceModel→ifcShell→ifcOpenShell→ ifcConnectedFaceSet→ifcFace→ *calculations needed*
	4.	ifcGeometricSet→ifcCurve→ifcLine→*calculations needed*
	5.	ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement → Component (e.g., ifcWall, ifcColumn→ifcRelDefines→ifcRelDefinesByProperties→ ifcElementQuantity→ifcPhysicalQuantity→ifcSimplePhysicalQuantity→ifcQuantityArea

Contextual Data	IFC class representation
Volume_of_ work	1. Same as formwork_area representation (4 different alternative sets) and 2. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →Component(e.g.,ifcWall, ifcColumn)→ifcRelDefines→ifcRelDefinesByProperties→ ifcElementQuantity→ifcPhysicalQuantity→ifcSimplePhysicalQuantity→ifcQuantityVolume
Form_factor (i.e., Area of formwork/volume of concrete)	1. Same as formwork_area representation, *calculations needed*
Steps_on_components	1. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →Component (e.g., ifcWall, ifcColumn)→ifcProductRepresentation→ ifcProductDefinitionShape→ifcShapeAspect→ifcShapeModel→ifcShapeRepresentation→ ifcRepresentationItem→ifcGeometricRepresentationItem→ifcBooleanResult→ifcBooleanClippingResult→1st operand: ifcSweptAreaSolid→ 2nd operand: ifcHalfSpaceSolid
Constant_width	1. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →Component(e.g.,ifcWall,ifcColumn)→ifcProductRepresentation→ ifcProductDefinitionShape→ifcShapeAspect→ifcShapeModel→ifcShapeRepresentation→ ifcRepresentationItem→IfcGeometricRepresentationItem→ifcSolidModel→ifcSweptAreaSolid 2. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →ifcWall→ifcWallStandardCase→ then it has always a regular shape and geometry.
Constant_height	1. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →Component (e.g., ifcWall, ifcColumn)→ifcProductRepresentation→ ifcProductDefinitionShape→ifcShapeAspect→ifcShapeModel→ifcShapeRepresentation→ifcRepresentationItem→IfcGeometricRepresentationItem→ifcSolidModel→ifcSweptAreaSolid 2. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →ifcWall→ifcWallStandardCase→ then it has always a regular shape and geometry.
Shape	1. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →Component (e.g., ifcWall, ifcColumn)→ifcProductRepresentation→ ifcProductDefinitionShape→ifcShapeAspect→ifcShapeModel→ifcShapeRepresentation→ ifcRepresentationItem→IfcGeometricRepresentationItem→ifcSolidModel→ifcSweptAreaSolid (with sweptArea attribute)→ ifcProfileDef→ifcArbitraryClosedProfileDef→ifcCurve 2. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →Component (e.g., ifcWallStandardCase, ifcColumnStandardCase)→ ifcProductRepresentation→ifcProductDefinitionShape→ifcShapeAspect→ifcShapeModel→ifcShapeRepresentation→ifcRepresentationItem→ifcGeometricRepresentationItem→ifcBoundingBox 3. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →ifcWall→ifcWallStandardCase→ifcRelDefinesByType→ifcWallType→ifcWallTypeEnum →(standard, polygonal,shear)
Pilaster, bulkhead, overhang, anchor blocks	1. Same as shape identification 2. If modeled as separate components, geometric reasoning is required 3. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →Component (e.g., ifcWall, ifcColumn)→ifcRelVoidsElement→ ifcFeatureElement→ifcFeatureElementAddition/Subtraction
Waterproofing	1. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →ifcWall →ifcWallStandardCase→ifcRelDefinesByType→ifcWallType→ ifcWallTypeEnum (i.e., elementedwall)
Openings, opening area, Incidental_items/embeds, expansion joints	1. ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →Component (e.g., ifcWall, ifcColumn)→ifcRelVoidsElement→ifcOpeningElement→ ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →Component(e.g.,ifcWall,ifcColumn)→ ifcRelDefinesByProperties→ ifcElementQuantity →ifcPhysicalQuantity→ifcSimplePhysicalQuantity→ ifcQuantityVolume

*calculations needed: IFC cannot directly represent the value required for a contextual data, but some calculations or geometric reasoning steps are required

In addition, the flexibility of IFC schema in representing geometry in more than one possible way can be considered as a limitation. Table 1 shows that IFC schema provides flexibility to represent the same information item in multiple possible ways. A building element can be represented in IFC with bounding boxes and face based surfaces (i.e., boundary representation-bRep), swept solids or constructive solids geometry (CSG), which builds solid models from primitives (e.g., lines, points) with Boolean operands (Eastman *et al.*, 2008). For example, height of a building element can be found in various ways, as a building element can be represented with ifcBoundingBox, ifcFaceBeasedSurfaceModel, ifcShellBasedSurfaceModel or ifcGeometricSet. In addition to this flexibility in geometry representation, there are multiple ways to reach the same data value in multiple ways. For example, length of a building element can be the Ydim attribute of an ifcBoundingBox, length of ifcEdge, distance between two ifcCartesianPoints, or; if properties of the building element is tracked, it can be the ifcQuantityLength (see Table 1 first row).

Though IFC is broad in representing various information items, it should be extended to include the information items that are not represented in IFC schema yet. Though such unrepresented information items are quite rare for design related information items within IFC, two of the information items that estimators would be interested in were “existence of formliners on the building components” and “an activity executed continuously or work was on discrete multiple locations.” There is no notion of temporary structures, such as formwork or shoring in IFC, as well as explicit representations for pilasters, bulkheads or overhangs. Therefore, formwork area and form factor values had to be calculated from their geometric representations within the current specification. Similarly, existence of boxouts, such as pilasters, bulkheads should be derived from associated building element’s geometry via geometric reasoning. In addition, among the alternative ways of representation, some of them cannot directly represent the value required for a contextual data, but some calculations or geometric reasoning steps are required. These alternatives are marked with “calculations needed” note at the step where value can be obtained, as shown in Table 1.

3.2 Capabilities and Limitations of IFC in Representing Construction Process Related Information Items

Identified construction process related contextual information items were related to properties of equipment, labor, material and temporary items used in construction processes. Table 2 provides a list of these information items that could be represented in IFC, and IFC classes that should be used to represent such information items.

Table 2: Representation of Construction Process Related Contextual Information Items in IFC

Contextual Data	IFC Class Representation
Equipment_type	ifcTask→ifcRelAssigns→ifcRelAssignsToProcess→ifcRelAssignsToResource→ifcConstructionResource→ifcConstructionEquipmentResource (attribute: identifier, no enum of eq types) no property sets
Equipment_condition	ifcTask→ifcRelAssigns→ifcRelAssignsToProcess→ifcRelAssignsToResource→ifcConstructionResource→ifcConstructionEquipmentResource→ifcControl→ifcPerformanceHistory (phase: construction)
#_of_equipment used	ifcTask→ifcRelAssigns→ifcRelAssignsToProcess→ifcRelAssignsToResource→ifcConstructionResource→ifcConstructionEquipmentResource (attribute: base quantity with unit)
Crew_composition	ifcTask→ifcRelAssigns→ifcRelAssignsToProcess→ifcConstructionResource→ ifcCrewResource→ifcLaborResource→(attribute: base quantity)
Availability_of_crew	ifcTask→ifcRelAssigns→ifcRelAssignsToProcess→ifcConstructionResource→ ifcCrewResource→ifcLaborResource→(attribute: resourceconsumptionEnum: occupied)
Crew_skill	ifcTask→ifcRelAssigns→ifcRelAssignsToProcess→ifcConstructionResource→ifcCrewResource→ifcLaborResource→(optional attrib skill set: string)
Daily_shift	ifcWorkControl→ifcSchedule→ifcRelAssignsToTasks→ifcScheduleTimeControl→(attribute: ActualStart)→ifcDateTimeSelect→ifcHourInDay
Overtime	ifcTask→ifcRelAssigns→ifcRelAssignsToControl→ifcRelAssignsTasks→ifcScheduleTimeControl→(attribute: ActualDuration)→ifcTimeMeasure
Strength_of_concrete	ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcBuildingElement →ifcRelAssociatesMaterial→ifcMaterialSelect→ifcMaterial→ifcMaterialProperties→ifcMechanicalConcreteMaterialProperties (attribute: compressiveStrength)
Concrete_yield_percent	ifcTask→ifcRelAssigns→ifcRelAssignsToProcess→ifcConstructionResource→ifcConstructionMaterialResource→(attribute: usageRatio)
Formwork_type	ifcTask→ifcRelAssigns→ifcRelAssignsToProcess→ifcConstructionResource→ifcConstructionMaterialResource→(attribute: resourceIdentifier: string)
Formwork_brand	ifcTask→ifcRelAssigns→ifcRelAssignsToProduct→ifcProduct→ifcElement→ifcManufacturerTypeInformation (attribute: manufacturer; attribute:modellabel)

IFC represent majority of the construction activity, construction method, schedule and work plan related information items under the ifcProcess group. An activity is represented using ifcTask, and resources utilized for activities are represented under ifcConstructionResource class (e.g., for materials ifcConstructionMaterialResource). Properties related to these tasks and resources are important to estimators and could be represented in IFC schema via navigating from ifcTask to the required information item. For example, skill set of labors utilized in an activity is represented as an optional attribute ifcLaborResource. This optional attribute however is not customized with enumerated values but is represented with strings.

Another important point about how IFC represents construction process related information items is that, IFC schema does not provide alternative representation paths for such information items, as compared to geometry related information items. This one way of representing information items provides consistency in representing information items. This is evident from comparison of Table 1 and Table 2, where Table 2 only shows one to two alternative ways of representing information items.

In addition to the information items listed in Table 2, there were information items that were identified as important to know about a past activity, but could not be represented using the current IFC schema. They were much larger as compared to design related contextual information items. These information items included: (a) size of the equipment used for an activity, (b) number of hours an equipment failed at site for an activity, (c) concrete pouring rate for concrete operations, (d) condition of formworks used in formwork activities, (e) forming context (e.g., one sided vs. two sided forming), (f) sizes of individual forms and assembly obtained by ganging forms together, (g) whether a used assembly is a new one or a reuse, (h) number of pours per component, and (i) whether bracing, winter protection, temporary support are used for concrete and formwork activities. IFC schema can be extended in property sets to incorporate these information items.

3.3 Capabilities and Limitations of IFC in Representing Construction Site Related Information Items and Project Characteristics

Identified construction site related contextual information items were related to soil conditions, site access conditions (e.g., access, traffic around the site location, hauling location) and ground conditions. Project characteristics identified by estimators contained information about project in general, such as weather conditions, project location, owners. Table 3 provides a list of these information items that could be represented in IFC, and IFC classes that could be used to represent such information items. Represented classes for this group are not shown beginning from ifcTask, as the information items in this group are generally represented closer to the root element, and not specific to individual construction activities but general to multiple activities.

Table 3: Representation of Site Related Contextual Information Items and Project Characteristics in IFC

Contextual Data	IFC Class Representation
Component_ location	*Calculations needed between:* ifcSite→(attribute refElevation) and Component (e.g., ifcWall) → ifcObjectPlacement→ifcLocalPlacement→ifcAxis2Placement→ifcAxis2Placement3D→ ifcCartesianPoint
Time_of_year	ifcProject→ifcOwnerHistory→ (attribute creationDate)
Project_owner	ifcProject→ifcOwnerHistory→(attribute owningUser)
Project_ manager	ifcProject→ifcOwnerHistory→ifcOwnerHistory→ (attribute owningApplication)
Project_ location	ifcSite→ifcPostalAddress→ (attribute: region)

Similar to representation of construction process related information items, IFC schema does not provide alternative ways of representation to the site related contextual information items. Actually, among representation of all the identified information items, IFC schema was quite limited in representing construction site related information items. For instance, estimators would like to know (a) type of construction site (i.e., brown or green site), (b) ground conditions (e.g., hard, even, slushy), (c) soil type in excavation activities (e.g., sand, gravel), its rock ratio, and moisture content. However, IFC schema does not provide specific classes to represent these requirements of estimators. In addition to these, IFC schema is limited in representing hauling information for excavation activities, such as hauling distance, grade, direction and width, and conditions of traffic around site, and site access. Weather conditions, such as average daily temperature and existence of rain/snow are also not possible to represent in IFC. For representation of these information items that are related to geography, IFC schema is being extended to IFG (IFC for Geographic Information Systems-GIS) to represent geographic information with building information in a single data model.

ifcProject that is the root of an IFC based project model, and ifcSite classes can provide information required within the project characteristics group of information items. General information about a project, such as who was the owner, when the project started, where the project was located, can be represented in IFC schema.

4. Conclusions

This paper provided an overview of identified contextual information requirements of cost estimators from past projects and an analysis of IFC schema in terms of representing the identified information items. Results of the analysis showed that IFC schema is comprehensive to represent majority of the identified information items, though sometimes problematically. The reasons identified related to IFC representation were (a) providing multiple ways of representing the same information item (as in the case of design related information items), (b) resulting in complex navigation from the activity of interest to the class or attribute that represents the required information item, and (c) being insufficient to represent some contextual information items required by estimators.

IFC schema is comprehensive and flexible in representing majority of the contextual information items. Especially, IFC schema is quite extended in representing design related contextual information items that were mainly related to geometry, shape and geometrical features of building elements. However, it was also observed that IFC schema provides alternative ways of representing geometry (such as b-rep, CSG and swept surfaces) which might be a limitation in terms of interoperability when identified information items are shared among multiple applications. It was also identified that redundancies exist in obtaining the same information item from multiple ways, such as obtaining length of a building element from its geometric representation or from element properties. In case of the other groups of information items, IFC is capable to represent information items consistently in one way (such as construction process information with ifcProcess group) without putting the burden on the users to select among alternative ways of representing the same concept.

Another finding of this study was that IFC schema requires complex data representation to reach even a simple information item such as length of a wall. It is because IFC schema uses reified relationships to make the data model transparent and traceable. However, this results in following a chain of classes and attributes to move from an activity or component of interest to the information item required. Though it might make the data model more complex and result in a long path of classes to represent, keeping reified relationships is essential also for deriving new information from the represented information in a transparent way.

There were cases in which it was identified that IFC schema was limited and had to be extended to incorporate required information items. For example, for the groups of construction process, site and project characteristics related contextual information items, IFC schema was not comprehensive especially in representing construction site related information items, such as soil types, ground conditions, access conditions to the site, etc. In order to incorporate these information items in the IFC schema, the schema need to be extended.

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