Research on Information Models for the Construction Schedule Management Based on the IFC Standard

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Abstract:

Purpose: The purpose of this article is to study the description and extension of the Industry Foundation Classes (IFC) standard in the construction schedule management, which achieves the information exchange and sharing among the different information systems and stakeholders, and facilitates the collaborative construction in construction projects.

Design/methodology/approach: The schedule information processing and coordination are difficult in complex construction projects. However, Building Information Modeling (BIM) provides a platform for exchanging and sharing information among information systems and stakeholders based on the IFC standard.

Through analyzing the plan, implementing, check and control, the information flow in the schedule management is reflected based on the IDEF0. According to the IFC4, the information models for the schedule management are established, which not only includes the each aspect of the schedule management, but also includes the cost management, the resource management, the quality management, the risk management and so on.

Findings: The information requirement for the construction schedule management can be summarized into three aspects: the schedule plan information, the implementing information and the check and control information, and three aspects can be described through the existing

and extended entities of the IFC4, and different information models are established respectively.

Originality/value: The main contribution of the article is to establish construction schedule management information models, which achieve the information exchange and sharing in the construction project, and facilitate the development of the application software to meet requirements of the construction project.

Keywords: construction schedule management, collaborative construction, BIM, IFC standard, information model

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1. Introduction

As an important management target, the schedule management has been a research hotspot in the AEC (Architecture, Engineering and Construction) industry in the past 50 years (Lorterapong & Ussavadilokrit, 2012). The implementation of the schedule management not only improves the effective use of various resources in the construction project, but also achieves an optimization through coordinating the cost management, the quality management, the risk management and so on. With the more complexity, huger of construction projects, the schedule management target often is out of control (He, Luo & Ren, 2012). On the other hand, the information processing and coordination among information systems and stakeholders are difficult in complex construction projects.

The construction is a process of the collaborative construction (Nikas, Poulymenakou & Kriaris, 2007; Soibelman, Sacks, Akinc, Dikmen, Birgonul & Eybpoosh, 2010), which needs the multi-disciplines' cooperation, and more attentions have been attracted by the collaborative construction, for example, the collaboration knowledge management (Dave & Koskela, 2009; El-Diraby, Lima & Feis, 2005), the collaborative working supported by IT (Hammad, Wang & Mudur, 2009; Isikdag & Underwood, 2010) and so on. With the development and application of IT in the AEC industry, it provides a collaborative environment (Erdogan, Anumba, Bouchlaghem & Nielsen, 2008). Especially Building Information Modeling (BIM), it provides the platform for the collaboration among the multi-disciplines and multi-stakeholders through exchanging and sharing the data (Singh, Gu & Wang, 2011).

As the sharing platform, BIM has been used in the construction schedule management to track the construction information, to avoid the schedule delays caused by component conflict, and to management the schedule information, so BIM provides an innovative way for the information management in the construction project. In order to increasing the adoption of BIM, the Industry Foundation Classes (IFC), the one of major enablers is a research hotspot in the AEC industry (Tse, Wong & Wong, 2005).

This paper studies the description and extension of the IFC standard in the construction schedule. Based on the theory of the construction project management, the information flow model is established to describe the each stage of construction schedule, and the IFC entities including the existing and extended are established relationships to describe the process in different stages. Through establishing the IFC standard of construction schedule, the dynamic and complex process of the construction schedule can be analyzed collaboratively, and BIM-based application software can be developed.

2. Literature Review

The IFC standard is developed by buildingSMART, which is an international organization for openBIM, and their mission is "to enable interoperability among industry processes of all different professional domains in civil engineering projects by allowing the computer applications used by all project participants to share and exchange project information". The first vision of the IFC standard was released in 1997, and the new vision is the IFC4 released in March, 2013. In the IFC standard, there are 4 layers (Resource layer, Core layer, Interoperability layer and Domain layer), and lots of types, entities, rules and functions are defined in EXPRESS data specification language to describe the actors, process, control, resource, product and so on (BuildingSMART, 2014).

As the standard of BIM, lots of researchers paid attention to the IFC standard. Fu, Aouad, Lee, Mashall-Ponting and Wu (2006) developed an IFC viewer, which was defined as the holistic interface of the nD modelling tool to integrate the decision-making information. Based on BIM, Vanlande, Nicolle and Cruz (2008) researched the information management in the full lifecycle of the AEC industry, and used IFC files to facilitate the sharing process. Based on the IFC standard, Nepal, Zhang, Webster, Staub-French, Pottinger and Lawrence (2009) researched the expression of the geometry and topology of the components in BIM. Man and Sun researched the structure and expression of the construction information based on the IFC standard (Man & Sun, 2011). Taking the cost estimation for tendering of building projects as the example, Ma, Wei and Zhang (2013) discussed the key issues for semi-automatic and specification-compliant cost estimation based on the IFC standard. Göekce, Göekce and Katranuschkov (2013) presented a new product catalog structure based on the IFC standard, which could achieve the integration of the product and cost information.

As one of the most important targets for a construction project, the schedule management was studied based on the IFC standard. Froese and Yu developed the models which were the project-management-related portions (including the estimates and schedule) of IFC, and the various modelling issues were discussed, for example, costs, construction processes, resources, products, and project documents for work plans and cost estimates (Froese & Yu, 1999). Faraj, Alshawi, Aouad, Child and Underwood (2000) developed the WISPER (Web-based

IFC Shared Project EnviRonment), which provided a collaborative working environment for construction. Based on IFC and the web, the main project database was developed, which could be used by the construction applications, such as the design, visualization, estimating, planning, specifications and so on. Tanyer and Aouad developed a web-based 4D planning tool, which was a part of an IFC-based single project database (Tanyer & Aouad, 2005). When completing the graphical user interface (GUI) of building elements, the users could create the construction planning, and building elements could link with the time information to see the 4D simulation. Based on IFC, Ma, Wei, Song and Lou (2011) established the information model for construction cost estimating for tendering in China. There were seven parts included in the information requirement model, and each part was established the IFC-based information model. In the schedule information model, the objects, the relationships, and the attributes of the IFC 2×3 final were used to describe the project schedule. Zhang, Yu, Li and Hu (2014) presented the IFC-GIM for Virtual Construction (VC). Based on the model, a 4D construction analysis and management system was developed, and descriptions and relationships of the quantity, the schedule, the resource consumption, and the cost based IFC were studied to achieve the data exchange in the system.

In these cases, the data based on IFC were exchanged and shared commendably, which promoted the applications for the various construction management systems. However, the IFC entities are not sufficient to support the use cases, and the further development is required for the more use cases in the AEC/FM industry (Weise, Liebich & Wix, 2009). Such as the schedule management, the information model was based on the existing objects, relationships, and attributes of the IFC standard. But the schedule is a dynamic and complex process, which requires the more detailed information model.

3. Methodology

The new version of the IFC standard is the IFC4. Comparing the IFC2×3 final version, the IFC4 covers eight domains: building controls, plumbing fire protection, structural elements, structure analysis, HVAC, electrical, architecture and construction management. In the construction management, the major improvements of the IFC4 include rework of the scheduling definitions, adding calendar support, simplification of task relations, rework for cost items and construction resources which linked to the schedule and BIM. In this paper, the study of the IFC entities for the construction schedule will base on the IFC4.

In the IFC4, there are 1609 entities which include objects, attributes and relationships, and relationship entities are 48, and property sets are 408. Through the relationship entity, the object entity can associate with another object(s) or attribute(s). As researched in other papers, the EXPRESS-G is used to express information models. On the other hand, the IFC

standard is not sufficient for the schedule management, so it is necessary to extend the IFC standard to meet the requirement for the paper.

It is three mechanisms that are used to extend the IFC standard, *IfcProxy*, extending new entities and property sets (or types) (Weise et al., 2009). About the *IfcProxy*, the undefined entity can be expressed by the *IfcProxy*. The entity *IfcProxy* can be expressed by using an instance, and the defined entity can be described by using the ProxyType and the Tag attribute. About extending new entities, it is the feasible way to upgrade the version of the IFC standard from the IFC1 to IFC4. The new entities which be extended should be contact with existing entities, for example, the derivative relationship, the associated relationship. About extending the property sets or types, new attributes can be extended to describe the information. Extending new entities and property sets (or types) are appropriate mechanisms to improve the IFC standard, so they will be used in this paper.

4. Information Requirements of the Schedule Management

The schedule management is one of the "three most important goals" for the construction project management. It presents construction activities of the construction site in the space-time. The quality of the construction schedule is directly related to the benefit of construction enterprises, the duration, the cost and the quality of the project, and the expected benefits, costs, plans can be reflected through the construction schedule.

The construction duration is the object of the schedule management. In the schedule management, the following works can be involved: (1) according to the target duration, different plans are made; (2) implementing plans, and monitoring the actual schedule in the construction process continuously; (3) analyzing reasons of the schedule variance; (4) controlling the construction process through making the appropriate adjustments and modifications. Through controlling the factors, coordinating the relationships, and implementing a variety of possible ways, the actual duration can be followed with plans. On the other hand, shortening the construction duration which is associated with the cost management, the quality management, and the risk management is the other goal for the schedule management.

4.1. Making the Schedule Plan

Under the total duration and construction conditions, the reasonable construction durations of different stages and construction procedures should be determined to coordinate all construction aspects in space-time. The schedule management includes different plans, for

instance, the general plan, the unit project plan and so on. In the plans, maximizing the rational use of funds, labors, equipment and supplies should be considered.

4.2. Implementing the Schedule Plan

According to the plan, the appropriate construction technologies are chose. The flow construction is the sound technology, and the construction process is divided into different construction sections and construction layers to connect the different construction procedures, which reduces the obstructions in the construction process, and improves the productivity. At the same time, the actual influences of the cost management, the quality management, the risk management are considered.

4.3. Examining the Schedule Plan

In the examining stage, the following works have to be done: (1) collecting the data of the construction process; (2) analyzing the deviation (comparing the actual schedule to the schedule plan); (3) analyzing the trend of the construction schedule and forecasting the subsequent construction schedule. Examining the schedule plan and forecasting the schedule provide the reliable basis for the subsequent schedule adjustment, and improve the sensitivity and accuracy of the schedule control.

4.4. Controlling the Construction Schedule

Because of the influencing factors in the construction schedule, the deviation is reasonable, and the control is more important. In the control stage, the following works have to be done: (1) analyzing the reasons of the deviation; (2) adjusting the schedule dynamically; (3) optimizing the adjustment. Deviation analysis, dynamic adjustment and optimization are the most difficult and the most critical parts in the schedule management.

In order to reveal the relationships between making the schedule plan, implementing the schedule plan, examining the schedule plan and controlling the construction schedule from the system perspective, the IDEF0 is used to describe the relationship of the input and output information among the modules, and realize the information requirements between the modules, as showed in the Figure 1.
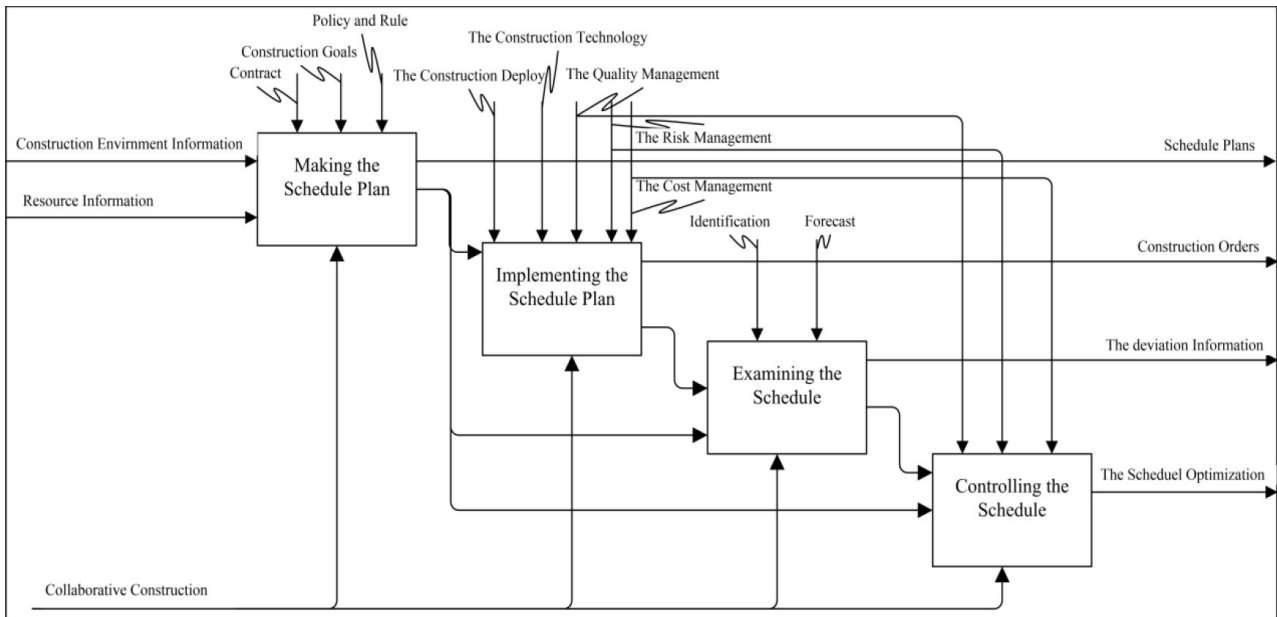
Figure 1. The information flow of the schedule management by IDEF0

5. Expression of the Schedule Management Information by Using the IFC Standard

5.1. The Schedule Plan

A construction project can be expressed by the entity *IfcProject* (an abstract entity). In the plan stage, the entity *IfcProject* includes different kinds of plans which can be described by the entity *IfcWorkPlan*, and the entity *IfcRelDeclares* can be used to describe the relationship between the construction project and the schedule plan. The relationship *IfcRelDeclares* is used to handle the declaration of the objects or properties to a project in the IFC4. The new entity *IfcConstructionGeneralSchedule- Plan* is the subtype of *IfcWorkPlan*, which expresses the general plan of the construction project. The general plan can be decomposed to many unit project plans, which are described by the new entity *IfcUnitProjectSchedulePlan*. In the unit project, there are many construction sections, which are constructed in sequence, and the construction project can be finished step by step. The new entity *IfcConstructionSection* is used to describe the construction section, and it can establish relationship with the entity *IfcUnitProjectSchedulePlan* by the entity *IfcRelNests*. On the other hand, some entities also can expresse the decomposition applied to the non-physical object. In the IFC standard, the entity *IfcTask* expresses an identifiable unit of work to be carried out in a construction project. In this paper, the entity *IfcTask* expresses the explicit work in the plan(s). The entity *IfcRelSequence* describes the sequence of these tasks, for example start to start, start to finish, finish to finish or finish to start. The entity *IfcWorkSchedule* expresses the control of these tasks, which establishes the relationship with *IfcTask* by the entity *IfcRelAssignsToControl*. Figure 2 shows the schedule plan information model.
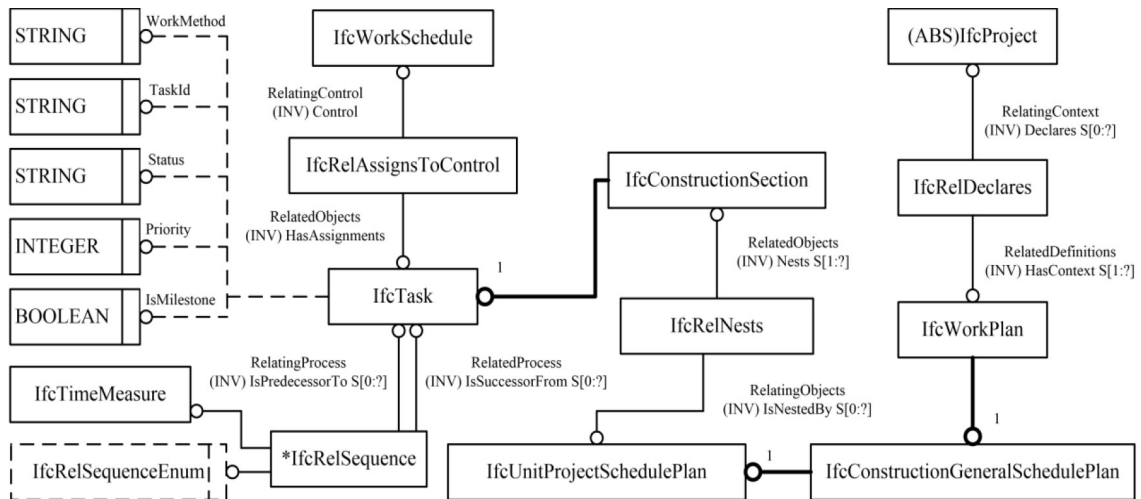
Figure 2. The schedule plan information model

5.2. The Schedule Implementing

The abstract entity *IfcProcess* expresses the construction process. In the process, the schedule is affected by the cost, the quality, the resource, the product, the risk and so on. The new entity *IfcConstruction* is used to describe the implementing of the construction schedule plan, the entity *IfcCostItem* is used to describe the cost which happened in the construction process. The new abstract entity *IfcQualityManagement* describes the quality management in the construction process, the new abstract entity *IfcRiskManagement* describes the risk management in the construction process, and the entity *IfcResource* is used to describe the resource which used in the construction process. The entity *IfcProduct* is used to describe the in-put products and the out-put products in the construction process.

The entities of *IfcConstruction*, *IfcCostItem*, *IfcQualityManagement*, *IfcRiskManagement* and *IfcResource* can be established the relationship with *IfcProcess* by the relationship entity *IfcRelAssignsToProcess*. The in-put products can be contacted with *IfcProcess* by the entity *IfcRelAssignsToProcess*, and the out-put products can be contacted with *IfcProcess* by the entity *IfcRelAssignsToProduct*. Figure 3 shows the schedule implementing information model.
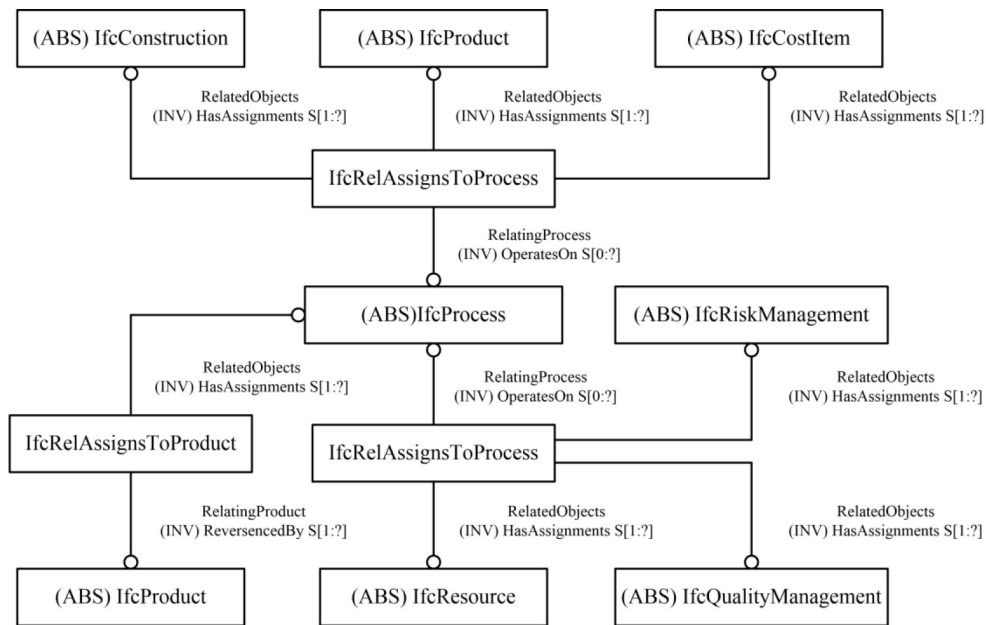
Figure 3. The schedule implementing information model

5.2.1. Expression of the Implementing of the Construction Information

There are three construction organization forms in the construction process: the sequential construction, the flow construction, and the parallel construction. Because of the advantages of the flow construction, it will be researched in this paper. The new entities *IfcSequentialConstruction*, *IfcFlowConstruction* and *IfcParalellConstruction* are the subtypes of the *IfcConstruction*, which showed in the Figure 4.

Given the different organization forms, the flow construction includes the rhythmed and specialized flow production, and non-rhythmed and specialized flow production. *IfcRhythmedAndSpecializedFlowProduction* is used to describe the construction which has the equal rhythm in the construction section, and it is the ideal way to construct. The new entity *IfcNonRhythmedAndSpecializedFlowProduction* describes the construction which has the unequal rhythm in the construction section, and it is the common way in the construction process. In the transverse section, the flow construction can be decomposed to many construction sections, and the flow construction can be decomposed to many layers in the vertical section, which is described by the new entity *IfcConstructionLayer*. In order to establish the relationship between the *IfcFlowConstruction IfcConstructionSection*, and *IfcConstructionLayer*, the relationship entity *IfcRelAssignstoFlowConstruction* is used in the flow construction information model, which describes assignment of the objects to a flow construction. Different construction sections and layers have the different construction teams, and the new entity *IfcConstructionTeam* is used to describe the professional team in the flow construction, and it can establish the relationship with *IfcFlowConstruction* by the entity

IfcAssignsToActor. The construction section can be decomposed to different construction types which are described by the new entity *IfcConstructiontype*.
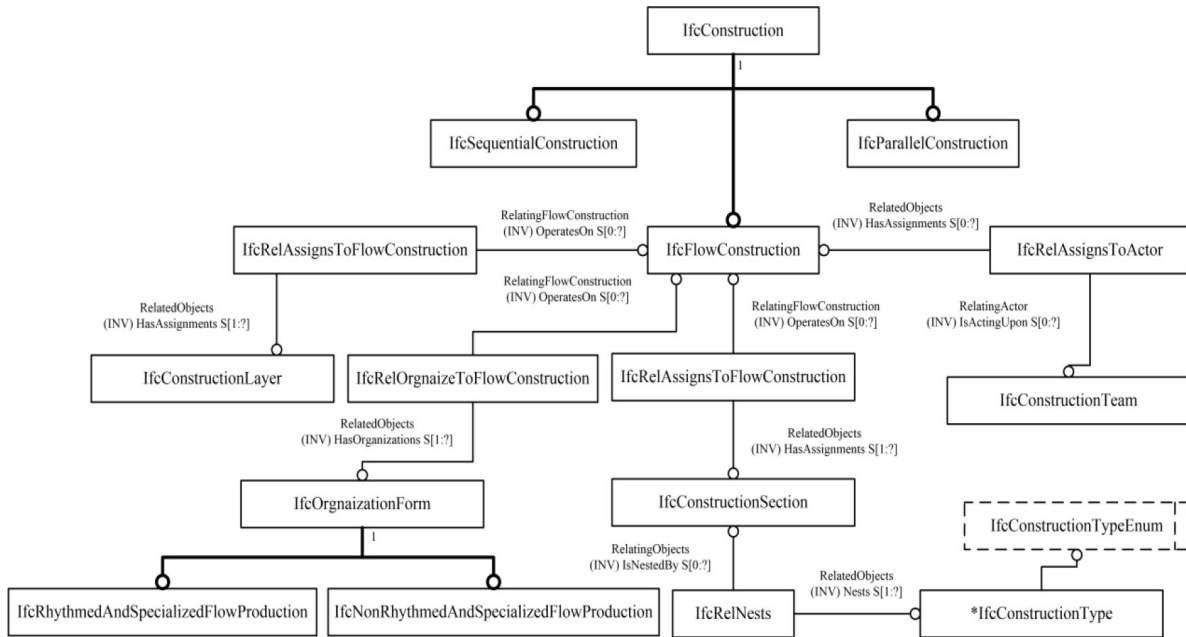
Figure 4. The implementing of the construction information model

5.2.2. Expression of the Resource Information

According to the IFC4, the entity *IfcResource* is used to describe the resource which be used in the project. *IfcConstructionResource* is used to describe the resources used in the construction process. The entities *IfcConstructionEquipmentResource*, *IfcConstructionMaterialResource*, *IfcConstructionProductResource*, *IfcLaborResource*, *IfcSubContractEquipmentResource* and *IfcCrewResource* describe different resources used in the construction process. Figure 5 shows the resource information model.
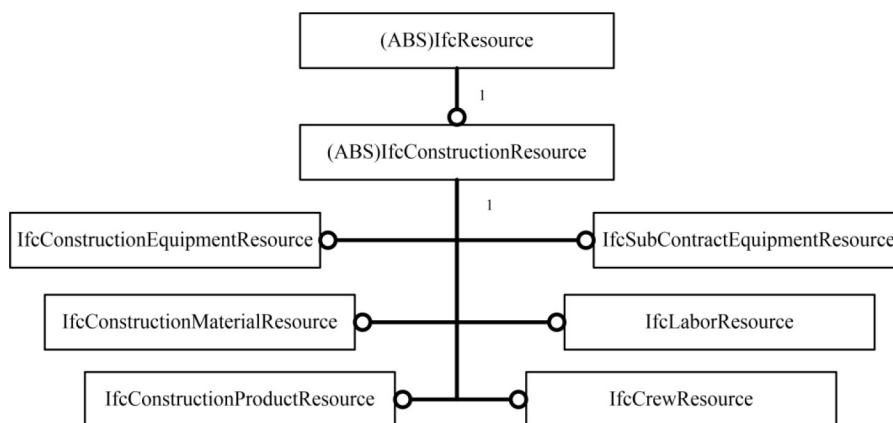
Figure 5. The resource information model

5.2.3. Expression of the Cost Information

The abstract entity *IfcCostItem* describes the cost happened in the construction process, which include two subtypes, *IfcRealCost* and *IfcCostPlan*. The new entity *IfcRealCost* describes the real cost happened in the construction process, and the new entity *IfcCostPlan* is used to describe a cost plan which can be made before the construction. The entity *IfcCostSchedule* is used to describe the cost schedule in the construction process, and it can be established the relationship with *IfcCostItem* by *IfcRelAssignsToControl*. As showed in the Figure 6.

Figure 6. The cost information model

5.2.4. Expression of the Risk Management Information

The abstract entity *IfcRiskManagement* describes the risk management in the construction process. The new entity *IfcRiskIdentification* is used to describe the identification of the risk in the construction process. The new entity *IfcRiskControl* is used to describe the risk control in the construction. *IfcRiskIdentification* and *IfcRiskControl* can establish the relationship by the entity *IfcRelAssignsToControl*. Figure 7 shows the risk management information model.
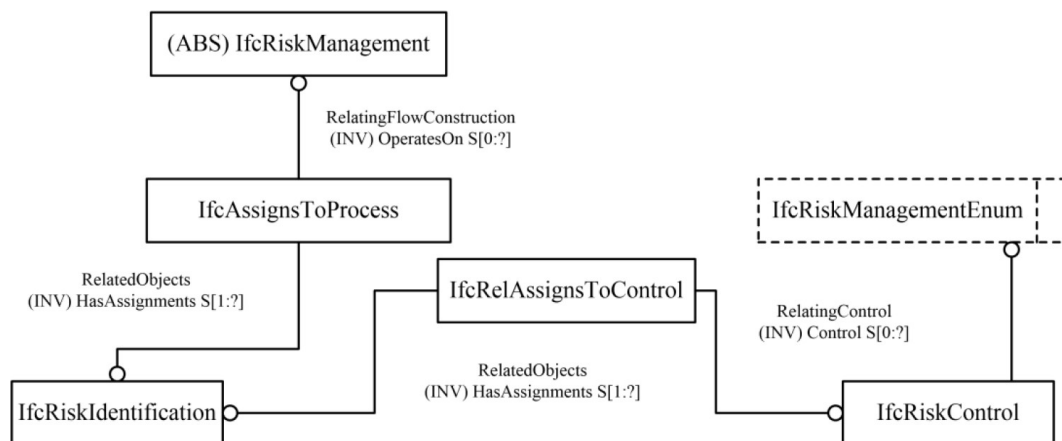
Figure 7. The risk management information model

5.2.5. Expression of the Quality Management Information

The abstract entity *IfcQualityManagement* is used to describe the quality management in the construction process. The new entity *IfcQualityPrecontrol* is used to describe the quality control before the construction, for example, the pre-control for the labors, equipment, materials, the choice for the control points and so on. The new entity *IfcProcedureQuality* describes the control for the quality of operating procedures. The new entity *IfcQualityInspection* describes the quality test for the unit project, and lots of methods are used to test the product quality. Through setting the properties, the attributes are extended to describe the quality management information. *IfcQualityPrecontrol*, *IfcProcedureQuality* and *IfcQualityInspection* can be established relationship with *IfcQualityManagement* by *IfcAssignsToControl*. Figure 8 shows the quality management information model.
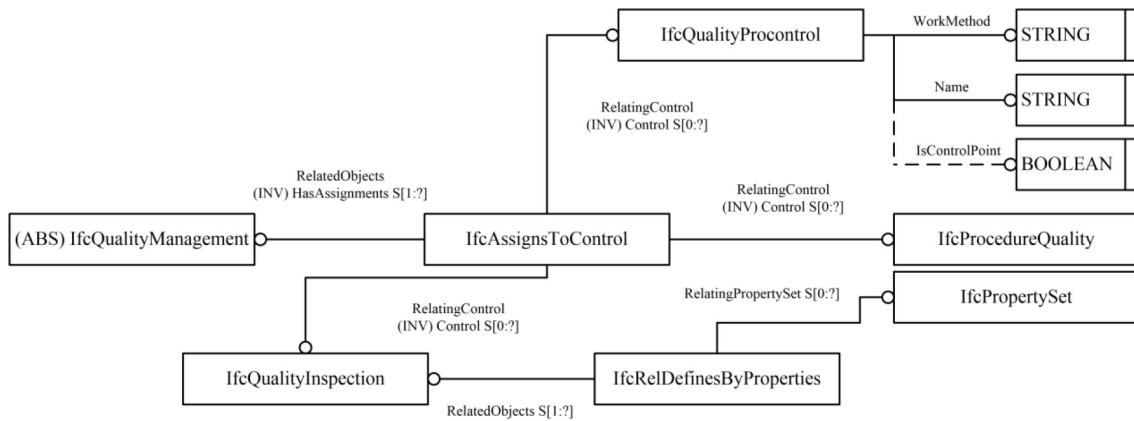
Figure 8. The quality management information model

5.3. The Schedule Examination and Control

The new entity *IfcScheduelReport* is used to describe the actual schedule of the construction process. In the *IfcScheduelReport*, the actual conditions of the cost, the resource, the quality management and the risk management are included in the schedule report. The new entity *IfcScheduelDeviation* describes the analysis for the schedule deviation, which compares the schedule plan to the actual schedule and provides the basis for the schedule control. The new entity *IfcRelAssignsToProject* is used to handle the assignment of objects (subtypes of *IfcObject*) of a project. The entity *IfcWorkPlan* and the entity *IfcScheduelDeviation* can establish the relationship by the entity *IfcRelAssignsToProject*, and the entity *IfcScheduelReport* can establish relationship with *IfcScheduelDeviation* by the entity *IfcRelAssignsToProcess*. Figure 9 shows the examination and control information model.
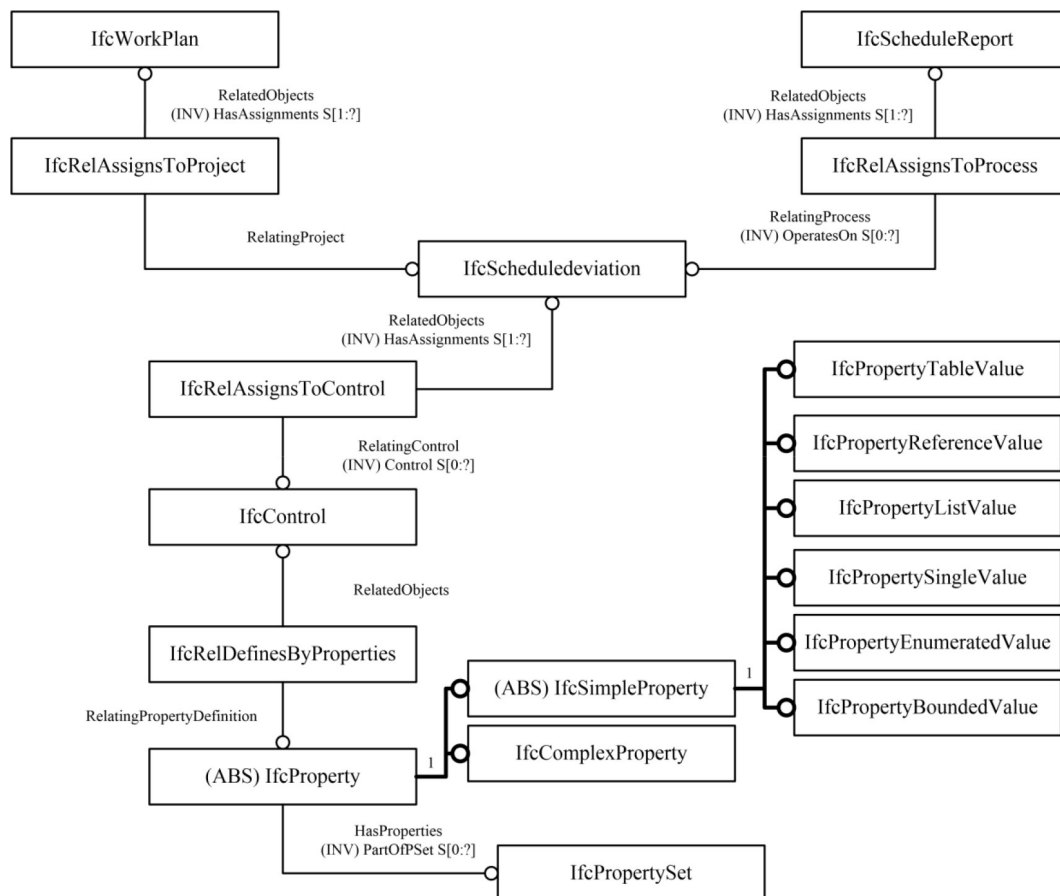

Figure 9. The examination and control information model

On the other hand, the abstract entity *IfcControl* is used to describe the control of the construction schedule. Because of complex features of the control, *IfcProperty* is used to describe the properties for the control. *IfcPropertySet* describes the dynamical extensible properties which can be used in the construction. Based on the requirements of the

information model, 25 property sets are established in the paper, as showed in the Appendix A. *IfcComplexProperty* is used to define complex properties in the construction process, which can be reused in different property set.

IfcSimpleProperty is used to describe a single property object, and the subtypes of *IfcSimpleProperty* (*IfcPropertyBoundedValue*, *IfcPropertyEnumeratedValue*, *IfcPropertyList-Value*, *IfcPropertyReferenceValue*, *IfcPropertySingleValue*, *IfcPropertyTableValue*) can be set the property value.

5.4. The Integrated Schedule Management Information Model

As showed in the Figure 10, the integrated schedule management information model is established.

In the model, the cost, the resource, the construction process, the quality management and the risk management have the many to one relationship with the process. Through the relationship entity *IfcRelAssignsToProcess*, the *IfcProject* and the *IfcProcess* can establish the relationship, which describes the guidance of the schedule plan to the construction process. Based on the schedule deviation, the construction schedule can be controlled in the right way, which considered the cost, the resource, the quality management and the risk management collaboratively. The *IfcProcess* and the *IfcControl* can establish the relationship by the entity *IfcAssignsToControl*. Because of the dynamic nature, the construction process can extend the properties to meet the information requirements through the *IfcDefinesByProperties*.

Based on the information model of the schedule management, the application software can be developed in the next step.
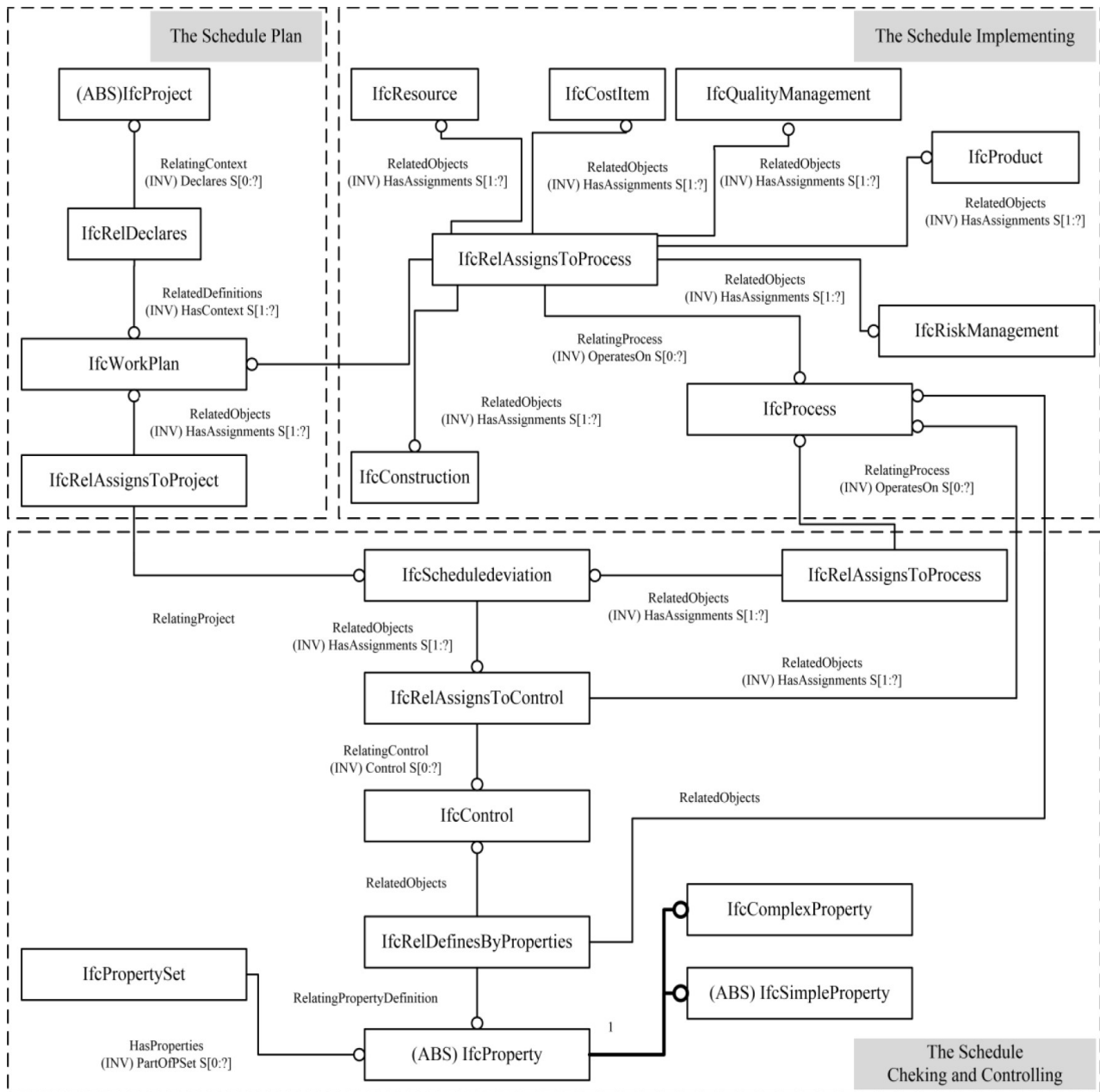
Figure 10. The integrated schedule management information model

6. Case Study

A project is a high-rise building with 103 floors and 4 floors basement. Due to the limited length of the paper, Basement A is taken as an example to be described, which provides the application case for the subsequent system development. As a construction section, there are lots of tasks should be done, for example, the support engineering, the earth excavation, the anchor cable construction and the basement construction (showed in the Table 1). The schedule is related with the cost, the resource, the quality management and the risk management in the construction process of Basement A, and the information of the cost, the

resource, the quality management and the risk management are showed in the Table 2. According to the information of Basement A and the information model described in the paper, the schedule management information model of Basement A can be established (as showed in the Figure 11). An information system can be developed based on the IFC standard to fulfill the information sharing and processing of Basement A.

No.	Entity	Name of the task
1	*IfcTask1*	Support Engineering
2	*IfcTask2*	Earth Excavation
3	*IfcTask3*	Anchor Cable Construction
4	*IfcTask4*	Basement Construction

Table 1. The task list of Basement A

Entity	Name
IfcLaberResource1	Reinforcing Steel Worker
IfcLaberResource2	Concreter
IfcLaberResource 3	Tower Crane Driver
IfcConstructionMaterialResource1	Reinforcing Steel I
IfcConstructionMaterialResource2	Reinforcing Steel II
IfcConstructionMaterialResource3	Reinforcing Steel III
IfcConstructionMaterialResource4	Concrete
IfcConstructionEquipmentResource1	Tower Crane
IfcConstructionEquipmentResource2	Concrete Pump
IfcConstructionEquipmentResource3	Truck
IfcConstructionEquipmentResource4	Scaffold
IfcCostItem1	Transport Charges of the Reinforcing Steel
IfcCostItem2	Transport Charges of the Concrete
IfcCostItem3	Labor costs
IfcCostItem4	Material costs
IfcCostItem5	Equipment costs
IfcQualityManagement1	The quality of the Reinforcing Steel Processing
IfcQualityManagement2	The Installation of the Reinforcing Steel
IfcQualityManagement3	Concrete Pouring
IfcRiskManagement1	Guard Rail
IfcRiskManagement2	Safety Net

Table 2. The information list of the cost, the resource, the quality management and the risk management of Basement A
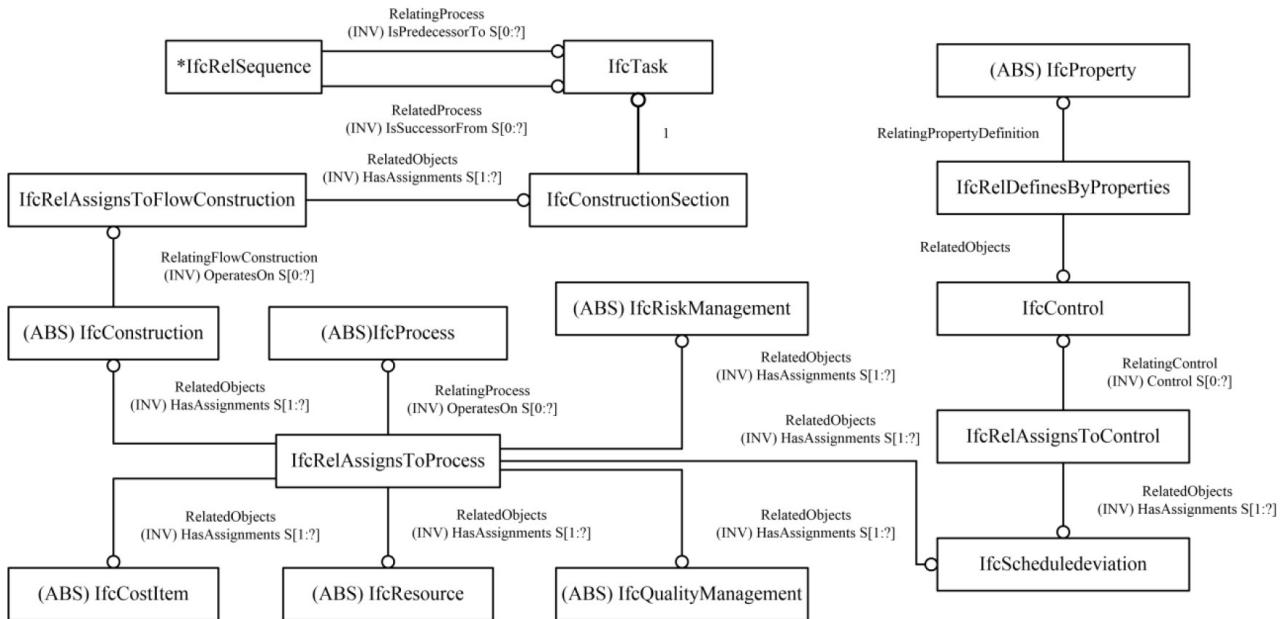
Figure 11. The schedule management information model of Basement A

7. Conclusion

The schedule management is an essential process in the construction project. Based on the construction project management theory and IDEF0, the information flow has been showed between the schedule plan, implementing, examination and control activities from the system perspective. In order to meet the information requirements for the schedule management, the new entities was extended and discussed based on the IFC4, and different information models of the schedule management are established respectively. In the integrated schedule management information model, the logical relationships among the schedule plan, implementing, examination and control are realized. Through setting the properties, the activities can be described better by the IFC standard.

The integrated schedule management information model is established, but the deeper research should be done in the future: (1) it is necessary to improve the IFC standard for the cost, the resource, the quality management and the risk management; (2) the relevancies among the cost, the resource, the quality management, the risk management and the schedule should be researched deeper to describe the dynamic and complex construction process as a whole; (3) the more detailed information model can be established; (4) based on the information models, the application software should be developed to meet the requirements of the construction project and improve the productivity.

Acknowledgement

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Appendix A

No.	Name of the Property Set
1	The construction contract
2	The construction budget
3	Engineering quantity
4	The amount of labor
5	The schedule report
6	The amount of machinery one-shift
7	Statement of the construction
8	Completion report of construction work
9	Quality objective
10	The quality check of material approach
11	The reject management
12	Precaution
13	Quality assessment of the unit project
14	Quality assessment for working procedure of the reinforcement
15	Quality assessment for working procedure of concrete pouring
16	The cost plan for the safe construction
17	Emergency preparedness and response
18	Contract management
19	Materials management
20	Mechanical cost management
21	Labor cost management
22	Other costs
23	Cost accounting
24	Records of the technological explanation
25	Risk factor

Property sets required in the examination and control information model