Industry Foundation Classes-Based Approach for Managing and Using the Design Model and Planning Information in the Architectural Design

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Abstract
Architectural design work depends on information created from the initial phase and this information has great influence on various parts of the design process. Despite this, the poor management and use of initial information still is one of the major problems in design. Design tools with planning information created in the initial phase do not address the need for data interoperability. This study aims to develop the Industry Foundation Classes (IFC) extension model for the management and use of planning information through integration of design models and planning information in design work. This paper introduces the scope, rationale, method, implementation, and verification of study. The validity of the proposed method is also demonstrated.

Keywords: design model; planning information; Industry Foundation Classes (IFC); property set; Pm-DPIMS; ISO 10303 part 34

1. Introduction
Architectural design modeling is dependent on information created through cooperation and adjustment from the initial phases, such as feasibility analysis, plans, and schematic design. Planning information, such as design objectives, requirements, and constraint conditions, has a considerable effect on several aspects of the design process. Planning information is evolved into a building model by way of process phases, and is used as significant information for enhancing working efficiency in the phases of construction and maintenance as well as design 1). Therefore, cooperation and adjustments among the participants from the initial phase of design are very important, and planning information created from these activities should be managed and used systematically.

The current design work in Korean design offices, however, has been managed by designers' supervision methods. Consequently, some problems have arisen from such methods of design, from that deficiency of management and from the misuse of information. The main problems are summarized as follows:
• Mistakes by team leaders in decision-making have arisen due to deficiency of communication among the participants 2);
• Deficiencies in management and use of planning information have increased problems and errors in design 3,4);
• Insufficient management of planning elements in the initial design phase makes it difficult to collect and analyze necessary information 5); and
• Work efficiency has decreased due to non-compatibility among different types of file formats and the mixed use of paper documents and electronic files 6).

To solve these problems, various channels for communication should be set up from the initial phases of the design process, with a systematic approach based on design practice, in which planning information is delivered in oral form. The planning information should also be shared and exchanged continuously based on the design model among application tools. The studies currently observed in the design area tend to focus on the systematic and standardized form instead of the design practices that are executed based on the empirical and informal methods in the work.

Related studies were performed by Hitchcock 5), Cooper 7), Boddy 8), Ozkaya 9), and Kiviniemi 10). The ones done by Hitchcock, Cooper, and Boddy focus on recording, tracing, and managing the rationale information rather than including the contents of planning information used in design work. The study by Ozkaya records and manages requirements based on user definitions. However, the study may be restricted to sharing and using information continuously, due to the lack of predefined planning elements. The development of the IFC extension model proposed by Kiviniemi allows the sharing and exchanging of information. The development, however, may cause problems, such as the contradiction and
overlap in meaning with IFC details, the difficulty in incorporating various planning elements in different building types, the large increase in size of the IFC instance file due to extension development based on classes, and the difficulty in quality assurance of IFC-based BIM tools by additional extension development.

Application tools, such as EcoProP™, Design Intent Tool™, Facility Composer™ and Trellegence Affinity™, have also been developed and used to manage planning information. In particular, the Affinity™ tool related to this study provides the specific formats and functions through add-on in BIM tools, such as Revit™ and ArchiCAD™. The tool also provides the ability to record, accumulate, and manage the planning information using BIM tools. In terms of managing information, however, it is supported by each format to design model and planning information, not by a unified format; the Affinity add-on used in BIM tools supports the file format of each vendor in the case of modifying the design model and the affinity file format in the case of the planning information. This means that two types of format should exist to use the design model and the planning information. This approach is restrictive during the process of design and construction, and makes it difficult to share and exchange information among BIM tools.

Reviewing previous studies and application tools reveals that they have the restrictive problem in sharing and exchanging information continuously for the management and use of the design model and planning information. In this context, the Industry Foundation Classes (IFC)™ developed by International Alliance for Interoperability (IAI)™ has been recognized as a solution for sharing, exchanging, and managing information among application tools used in the construction industry. The IFC enables the establishment of an integrated process, the consistent streaming and accumulation of information, and the approach of a project-based method. An integrated information form of IFC here is effective in terms of managing and using information. As the current IFC includes only the limited requirement entities and properties in terms of management of the planning information, however, an IFC extension model needs to be developed.

In this context, this study aims at developing the IFC extension model for managing and using the planning information with a design model. Fig.1. shows the application of the IFC with development of an extension model in this study. The Product model-based Design and Planning Information Management System (Pm-DPIMS), which is a prototype system of this study, undertakes the input, management, and use of the planning information, which will be recorded through investigation and analysis of documents collected among the participants. The Pm-DPIMS and its Revit add-on support the method of managing information in design work, following separative management between the design model and the planning information. They also support an integrated management of the planning information with a design model, following the application of the IFC as a method for solving practical problems, as mentioned above. The planning information existing within the IFC design model can be used as intention and rationale for creating the design model in the design process, and the IFC makes it possible to share and exchange this information continuously.

2. Establishment of Planning Elements

Internationally, there exist diverse classification systems of check lists and requirements related to design planning elements. They include performance, function, service, environment, and cost. Fig.1. Application of IFC in this Study
In this study, a classification system is required for the systematic management of planning information in the architectural design area. From a practical point of view, the classification system should include the detailed classification items and properties required in design work. In this context, a VTT Prop classification system (16) developed by the VTT Institute in Finland is applied in this study. The type of building focuses on apartment house to which the prototyped form of planning elements is applicable. After the interview with the practitioners of design offices during the collection process, the planning elements are analyzed and classified.

Fig. 2 shows the relationship of the practical guideline elements and the VTT Prop classification system used to define the planning elements. The planning elements are additionally defined using the VTT Prop classification system for items not defined in the practical guideline elements. The planning elements, however, need to be defined in a more accessible form. They have been reviewed by the practitioners in charge from the five design offices in terms of their practical use, which has then been defined in a commonly applicable form (17).

3. Development of IFC Extension Model
3.1 Representation structure of IFC

In the IFC model, the representation structure related to planning elements is defined by the property sets, the entity IfcConstraint, the entity IfcControl, spatial structure elements (IfcSite, IfcBuilding, IfcBuildingStorey, and IfcSpace), and building object (IfcBuildingElement). After analyzing the IFC representation structure, however, the problems found in terms of design work are summarized as follows:
- The design model (spatial structure element) and the planning elements (objectives, requirements, and constraint conditions) are difficult to manage separately. In the IFC model, the entities related to requirements and constraint conditions are connected after the completion of design objects;
- The IFC model defines the property sets connected to spatial structure elements and building elements. However, the property sets related to planning elements are insufficient, and exist separately in each object;
- The entities related to constraint conditions are used restrictively in the IFC model. The entity IfcControl and IfcConstraint are connected to spatial structure elements and building elements. However, they include only partly the quantitative and qualitative information applicable to design evaluation, not in terms of managing a variety of planning information used in design work; and
- The IFC model is difficult to develop on a class basis to include the planning elements. Users share and exchange a variety of information, not included in the IFC. Class-based IFC extension with detailed elements makes the implementation of application tools difficult, by complicating the data structure of IFC. In other words, there is the possibility that significant confusion and overlap will arise among the existing planning elements in IFC, and the class-based IFC extension makes both the quality assurance of IFC-based application tools and the flexibility of additional extension development more difficult.

The development principle of IFC is to establish the commonly applicable standard based on the separative discernment and integrative analysis between the concepts of the extension model and the existing IFC model. The IFC does not include all the information corresponding to the construction environment of each country. However, the IFC does provide the theory and method that can be externally developed through agreements by developers among communities requiring the exchange and sharing of information. The IFC property set (18) offers a theory and method that are externally definable, which makes it possible to develop an extension of the IFC. The management and use of planning information, therefore, can be achieved by using the applicable entities and property sets in the IFC and by defining the additional property sets.

3.2 Extension method by property set mechanism

Property set means a set of properties, and is used to define the detailed properties of IFC objects. The property set is defined as an EXPRESS data definition language and as meta-data defined in outside of IFC objects. The property exists as a standard type within the property set.

Rules defined to develop the property sets and the properties are as follows:
- Reuse of the predefined property sets: If reusable property sets exist, they should be used;
- Level definition of the property set specification: The property sets should be connected to the IFC...
classes or the type objects; and

- Definition of name and data type of the property sets and the properties: The property sets and the properties should be defined as name and data type, and their names should be defined in a discernible form.

Types of property are composed of single value, enumeration value, bound value, list value, object reference, and complex property. This study applies the single value (IfcPropertySingleValue) and the list value (IfcPropertyListValue), considering the method of imputing information of users.

3.3 Application concept of IFC extension model

In this study, the development of the IFC extension model is to distinguish and use the existing property sets and properties of IFC related to planning elements, and to define additionally the property sets and properties in terms of the IFC extension development. Planning elements and their characteristics explained in the previous section are defined by new property sets and properties with the existing IFC objects and property sets.

Fig. 3. shows the concept of applying the IFC extension model. The entity IfcRelDefinesByProperties defines the relationship between the design model and planning elements. This representation structure supports the method of managing information of design work, following the separative management between the design model and the planning information. In other words, the IFC instance file of planning information can be generated independently through the connection of property sets and properties by the entity IfcRelDefinesByProperties in the project (IfcProject) and the spatial structure elements (IfcSite, IfcBuilding, IfcBuildingStorey, and IfcSpace). The representation structure of IFC also supports an integrated management of the design model with planning information. In other words, the planning information existing within the IFC design model can be used as the intention and rationale for creating the design model in several aspects of the design process, and this approach can be a benefit in terms of sharing and exchanging the planning information among application tools.

3.4 Details of IFC extension model

Planning elements connected to project and spatial structure elements are explained in the window on the left side of the Pm-DPIMS, as shown in Fig.4. These elements are mapped into the existing entities, property sets, and properties and extension model of IFC. For example, the Graphic User Interface (GUI) of project tree includes tabs, such as overview, conformity, cost, energy, and requirements. These tabs are defined as property sets of IFC, and characteristics existing within tabs are defined as properties of IFC. Characteristics, such as project name and code name (IfcProject), contract and delivery date (IfcScheduleTimeControl), approval date and state (IfcApproval), and client and design office information (IfcPersonAndOrganization and IfcAddress), existing within tab of general, use the definition of existing IFC schema. In another example, The GUI of building tree includes tabs, such as outline, service, safety, external view and finishing, and requirements. Characteristics existing within building information of overview tab are mapped into the properties of the IFC extension model. Pset_BuildingCommon is connected to the entity IfcBuilding, and properties defined within the property set are composed of HandicapCirculationAccess, BuildingUseChange, MultiPlanPossibility, and SpaceExtensionPossibility. The properties here are defined as the data type of IfcText in the property type of IfcPropertyListValue. In these contexts, all planning elements with the examples are mapped in an adequate form to the representation structure of the IFC schema with the extension model [17].

4. Implementation and Verification

4.1 Implementation of Pm-DPIMS

The management and use of design model and planning information are operated in the IFC standard environment, which supports the sharing and exchange of information. Product model-based Design and Planning Information Management System (Pm-DPIMS), which is a prototype of this study, is composed of the input module of planning information, the link module between design model and planning information, and the IFC conversion module, as shown in Fig.5. The input module provides the template mdb to planning elements, and the elements are items for recording the planning information. The link module
provides the functions for connecting and adding the planning information within the design model. The IFC conversion module provides the functions for creating the IFC instance file of the design model with the planning information, and makes it possible to create the planning information in the Korean language. Besides, the Revit add-on module of the Pm-DPIMS provides the functions for tracing the planning information existing within the IFC instance file of design model.

The IFC conversion module in the Pm-DPIMS is developed using the standard modules of input and output provided in the EDM™ tool of EPM Technology. This tool supports the input and output libraries of IFC schema. Implementation of the module to each function is based on the Visual Basic™ language of Microsoft. The Revit add-on module of Pm-DPIMS is developed by referring the Revit 2008 Software Developer Kit (SDK), and is based on Visual Basic.Net™.

### 4.2 Verification of IFC extension model

#### 4.2.1 Collection of verification samples

The verification of the IFC extension model is performed by participants in charge of apartment design projects performed by two design offices. To enhance the reliability of verification, the samples of design models focus on the unit and the apartment model created by the Revit tool in existing design projects performed in two design offices, and the planning information for the samples is created through the use of the Pm-DPIMS by designers in charge in their respective design office. The verification in this process is performed after collecting the planning information (mdb file) and the design model (rvt file) in each design office. This study here is introduced and discussed focusing on apartment model to perform the verification test.

![Fig.4. Extended IFC Model Mapped to Proposed Planning Elements](image)

![Fig.5. Architecture of Pm-DPIMS](image)
4.2.2 Application of international standard for verification

In general, the verification of the data model is based on the visual judgment of instance file created from application tool, which implements the data model. The implementation of application tool is based on the standard libraries of data modeling tools, such as EDM™, ST-Developer™ and so on, certified in the ISO and the IAI. The use of the libraries makes it possible to implement the application tool with developed data model, and provides the conformance of verification. In other words, standard libraries do not support the creation of instance files when the application tool is not implemented in an adequate form of the representation structure of developed data model. In this context, the verification of the IFC extension model can be performed by the Pm-DPIMS, which is implemented in an adequate form to the representation structure of IFC. However, it is difficult to verify whether the method is adequate without loss of data in terms of scope and meaning between original data and converted data. To enhance the reliability of verification, therefore, the conformance test method defined in an ISO 10303 (STandard for the Exchange of Product model data, STEP) 19) is applied in this study. The method is defined in the Part 34 20) of the ISO 10303, and the verification is performed through test methods such as pre-processing and post-processing to Pm-DPIMS.

Fig.6. Conformance Verification Process Applying ISO 10303 Part 34
(1) Verification by pre-processing

The verification by pre-processing is performed through the certification of the testers or the development of the judgment system, to the STEP instance file created by the application tool with target schema. For creating the instance of target schema, the exchange structure defined in the Part 21 should be applied, and the verification is to review whether the instance file is created in an accurate form to the representation structure of the target schema.

In this study, the verification by pre-processing is to review whether the planning information created by practitioners of a design office is converted accurately into the instance file of IFC schema with the extension model, after using the Pm-DPIMS. As shown in Fig.6., (a) is the conversion process for supporting IFC of the design model with the planning information, and (b) shows the parts of the IFC instance file converted by the Pm-DPIMS. The verification can be judged through comparing and reviewing whether the data structure existing within the IFC instance file is created in an accurate form to the IFC representation structure with the application concept of the extension model (Fig.3).

As a result, the planning information connected to the project (IfcProject) and the spatial structure elements (IfcSite, IfcBuilding, IfcBuildingStorey, and IfcSpace) has been created in an accurate form to the IFC representation structure.

(2) Verification by post-processing

The verification by post-processing is to analyze the results of visual judgment or the response to the question by operator of the application tool for the judgment whether the STEP instance file is interpreted accurately in the application tool.

In this study, the verification by post-processing is to judge whether the created IFC instance file (b) is interpreted accurately in the Revit add-on of the Pm-DPIMS. As shown in Fig.6., (c) shows the process for interpreting the planning information in the Revit add-on module of the Pm-DPIMS after reading the IFC instance file (b) by the IFC import module of the Revit tool. In this process, the verification can be judged by analyzing whether the scope and meaning of the data are accurate without loss through the visual comparison between the original planning information stored (i.e. existing within the mdb file) in the Pm-DPIMS (a) and the IFC planning information interpreted in the Revit add-on (c).

As a result, the planning information existing within the IFC instance file of the design model has been interpreted without loss of data in terms of scope and meaning of the conversion by comparing with original planning information.

5. Conclusions and Future Work

This study was suggested in terms of application of IFC as a method for solving some practical problems arising from the deficiency of management and use of planning information in design work of Korean design offices, and this paper was introduced focusing on the developing process, implementation, and verification of the IFC extension model.

The main results of this study are discussed as follows:

(1) The sharing and exchange of information through the application of IFC

Planning information created by the existing application tools is restrictive in terms of the sharing and exchange of information among BIM tools. This study provides a method for the sharing and exchange of planning information among IFC-based BIM tools. The IFC extension model enables the assurance of quality for the existing IFC-based BIM tools. The IFC extension model does not require the modification of IFC-based BIM tools. These tools need only the implementation of the interface to trace and refer the planning information existing within the IFC instance file of the design model, with planning information. If this interface is supported in other BIM tools (other than Revit), the planning information will be shared and exchanged continuously among IFC-based BIM tools. This approach, therefore, can be a benefit in terms of the sharing and exchange of the planning information among IFC-based BIM tools.

(2) The management and use of planning information

IFC extension development makes it possible to trace the planning information connected to the project and the spatial structure elements existing within the IFC design model. Both the Pm-DPIMS and its Revit add-on support the current design work, following the separative management between the design model and planning information. They also support the integrated management of the IFC design model with planning information as a method for solving some practical problems. The planning information existing within the IFC design model can be used as the intention and rationale for creating a design model in the several aspects of the design process, and the application of IFC enables the continuous sharing and exchange of information among application tools. This approach can be used to improve the communication among participants with merits gained from BIM design methods, and to enhance the efficiency of design work.

In this study, Pm-DPIMS provides the concept and idea for developing the module to vendors of CAD systems. IFC-based BIM tools do not support the function for recording, managing, and using the planning information in design work. The Pm-DPIMS needs to be implemented as a single module, which applies the method of this study in the IFC-based BIM tools. The Application Programming Interface (API) supported in the BIM tool was restrictive in applying the method of this study. Advanced implementation, therefore, needs to be accomplished effectively with vendors of CAD systems.
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