IFC-based Information Modelling and Model Server Technologies for Product Lifecycle Information Support

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Abstract – Enabling the information interoperability among AEC product lifecycle processes is identified as an emerging demand from the AEC industry. The IFC (Industry Foundation Class) technology provides standardized definitions for the development of lifecycle information models and unified exchange mechanisms to facilitate the software interoperability and the lifecycle information support. Based on the IFC technology, this CRP has developed a design information modelling methodology, by which the IFC-compliant interoperable and extensible product information models are established for AEC product lifecycle information support in design, analysis, and change order management. These models have also been implemented in a Web-enabled IFC/XML model server software system to provide the IFC and XML information to AEC application systems in design collaboration, structural calculation, and cost optimisation.

Keywords: Industry Foundation Class (IFC), Design information modelling, Product model server, Design collaboration, Change order management

1 BACKGROUND

The IFC technology [1] establishes a standard framework to uniformly define, represent, exchange and share the product lifecycle information in AEC domain. However, in order to cater for the application-specific information needs from project to project, the standardised IFC object model has to be customised and extended as IFC-compliant information models. Although substantial efforts have been seen in the development of such models in various AEC application domains, the IFC technology has not achieved widespread adoption on a general level in the industry [2]. Especially in developing the modelling methodology and in establishing the IFC-compliant interoperable and extensible information models of industrial applications, further research is urgently needed.

To facilitate the use of the IFC-based models in the real-world AEC software applications, the IFC models have to be implemented in software systems, usually in the IFC model servers. A Web-enabled IFC model server is defined as an online digital product information system capable of storing and manipulating the IFC model data in a central repository, and providing concurrent access to the neutrally-formatted lifecycle information required by multi-disciplinary project teams across distributed and heterogeneous environment.

This CRP is intended to develop a framework for modelling the IFC-compliant interoperable and extensible information models; for designing and implementing an IFC/XML product model server with the Tamino XML server as the database support; and for exploring the methods, algorithms and software components used in design collaboration, structural analysis, and cost optimisation in change order management.

2 OBJECTIVE

This project is a collaborative R&D effort between PDD, SIMTech & School of CEE, NTU. The main objective of this CRP is to develop methodologies, techniques and software components for:

- IFC-compliant product lifecycle information modelling with concentrations on the information interoperability and extensibility;
- IFC/XML product model server development on Web servers and XML database implementation;
- IFC-based product lifecycle information support for AEC software applications of CAD design, structural analysis, and change order management.

3 METHODOLOGY

The methodologies and algorithms developed in this CRP are discussed in this section, including process modelling and IFC-compliant information modelling; product model server development; XML database design and implementation; matrix application of cost optimisation; and genetic algorithm in change order management.

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3.1 IFC-compliant information modelling

A generic method, the process-oriented information modelling methodology has been developed for information requirements analysis and IFC-based information models development by IFC dynamic extension mechanism. It aims at improving the effectiveness and efficiency of both process model and information model development by integrating the IDEF0 and enhanced IDEF1 methods, i.e. the IDEF1 information models are developed on the basis of IDEF0 process models. General rules and requirements for conversion between the two types of models are defined in this method. Detailed procedures for developing IFC extension models from process models are also specified. By applying modelling rules, procedures, and integrated approaches, this method improves the traditional development process of the IFC-compliant models by minimizing modelling concept conflicts and implementation confusions. This method has been used in developing the IFC-compliant information models with dynamic extensions for the structural analysis domain. Fig. 1 is a schematic diagram to describe the integrated process and information modelling methodology.

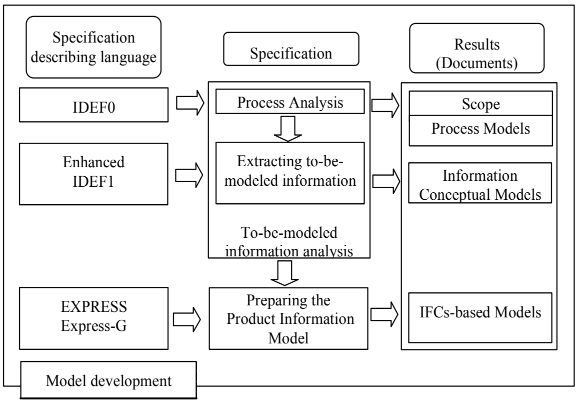

Fig. 1. Integrated process and information modelling methodology.

3.2 IFC/XML model server development

The software development methodology of the product model server is based on the J2EE (Java 2 Platform, Enterprise Edition) standard [3], the Web and XML technologies, and the CAD geometry processing algorithms. The collaborative activities between the architects, structural engineers, and project managers have been analysed and simulated in the prototype system. Based on this analysis and understanding to the collaboration process, the software implementation is conducted to provide and share lifecycle information in IFC and XML formats among design professionals, engineers, and other project participants. The model server uses a multi-tier architecture (see Fig. 2). The MVC (model-view-control) pattern is applied to the server side software development together with the application logic development as shown in Fig. 2. The geometric mapping algorithms are developed to transform the 3D CAD information into structural model information. The client-side applications can easily use a Java3D enabled browser to view and comment the 3D structural models, to add or edit the IFC property sets (Pset) [4] in a design model, or to exchange/share IFC and XML data with others in a collaborative development effort.

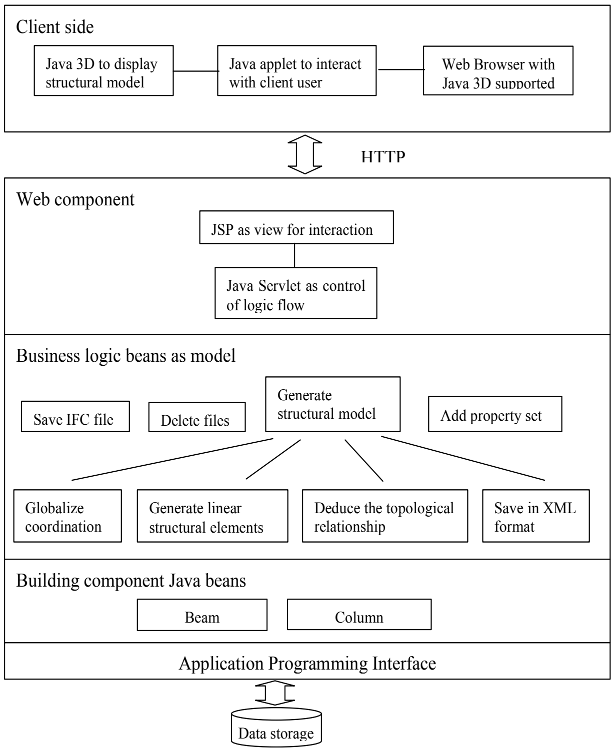

Fig. 2. Model server architecture.

3.3 XML database design

The Tamino XML database [5] is used to encode, store, transform and manage the native XML data for IFC extension definitions, for structural models, and for IFC-compliant design models, so that the hierarchical and interconnected XML objects can be effectively manipulated and maintained in this data repository. Native XML storage is the essential method to avoid performance limitations in this model server. The BLIS-XML schema for IFC is selected and modified to be the Tamino database schema. An XML transformation is conducted to convert the BLIS-XML schema in XDR (XML Data Reduce) format into the W3C approved XSD (XML Schema Definition) format for use in the Tamino database. Two XML data query methods, XPath and XQuery [6] are implemented for this IFC/XML model server. Other techniques developed include XML data indexing in Tamino, combination of batch query and single query, and XML data integrity and consistence control with Tamino. The batched Tamino XPath query shows better performance for this application.

3.4 Matrix method for cost optimisation

A matrix method, the modified matrix application, for IFC-based cost optimisation in change order management has been developed in the CRP. In this method, the integration of the IFC compliant cost and schedule information is achieved by using the four basic matrices to derive another four obtained matrices (see Table 1 for details).

Table 1. Matrix definition for cost optimisation.

Basic Matrices	Obtained Matrices
$Q_{w\times r}$: Activity_Resource Quantity Matrix	$Q_{r\times t}$: Resource_Time Quantity Matrix
$U_{r\times 1}$: Resource_Unit Cost Vector	$C_{a\times t}$: Account_Time Cost Matrix
$S_{w\times a}$: Activity_Account Relation Matrix	$C_{w\times a}$: Activity_Account Cost Matrix
$P_{w\times t}$: Activity_Time Progress Ratio Matrix	$C_{w\times t}$: Activity_Time Cost Matrix

The integrated cost and schedule data in the basic matrices are retrieved from the IFC information model. By matrix manipulation, parameters are generated for these derived matrices, which provide constraints to a mathematical model for cost optimisation in change order management. The three variables in the optimisation objective function are defined as changes in investment allocation, resource supply and weather influence of change orders. A cost optimisation framework is also developed for implementation of both the IFC object model and the optimisation model in a software prototype. The prototype will be built on top of the IFC model server developed in this project. With this software system, the change order information and its impact to project cost can be reliably calculated, exchanged and shared with other IFC compatible software systems for better project collaboration and quicker decision making on cost control.

3.5 Genetic algorithm for change order management

A genetic algorithm based and resource-constrained cost-time optimisation methodology is proposed for managing the change order information in IFC format to obtain an optimised solution for the project cost and duration as the result of the impact of change orders. Based on the mechanics of natural selection and genetics to search through decision space for optimal solutions, the genetic algorithms simulate the natural selection process for optimum or sub-optimal solution to a problem. The optimisation algorithm involving the genetic method can be described as follows, where P(*t*) and C(*t*) are parents and offsprings (new generations) in current time *t.*

```
Begin
    t ← 0;
    Initialise P(t);
        (Randomly generate a new population of solutions)
    Evaluate P(t);
        (Evaluate the new solutions)
    While (terminating condition not met) do {
        Recombine P(t) to yield C(t);
        (Recombine solutions using genetic operators)
        Evaluate C(t);
        Select P(t +1) from C(t);
        (Select the better solutions)
        t ← t + 1; }
End
```

The basic procedures of the genetics-based approach for the resource-constrained time-cost optimisation in change order management are shown in Fig. 3.

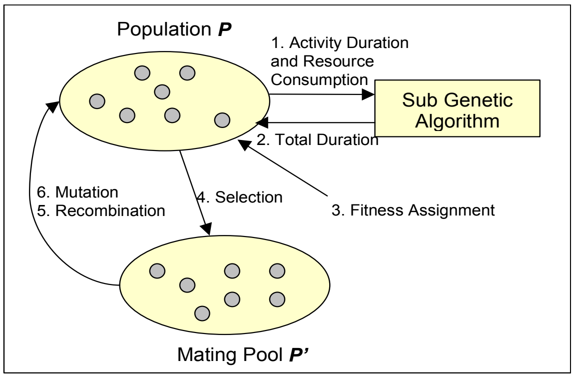

Fig. 3. Genetic approach for resource-constrained. time-cost optimisation.

4 RESULTS & DISCUSSION

4.1 IFC-compliant information models with Pset extensions

New entities and new types are defined for modelling the IFC-compliant information models in structural analysis. Fig. 4 illustrates one of them.

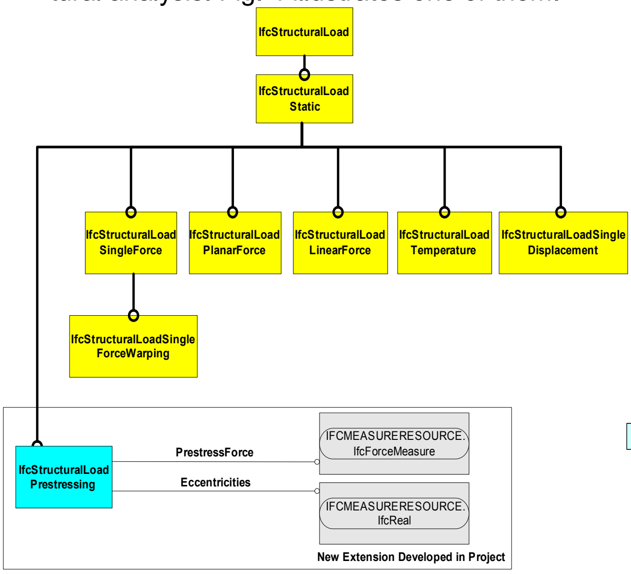

Fig. 4. New entity definition.

IFC property sets are defined for the dynamic extension of the IFC-compliant models, such as the following one in Fig. 5.

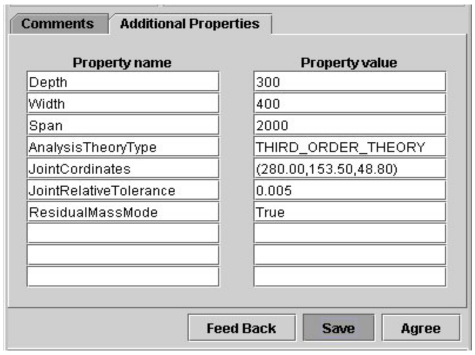

Fig. 5. Pset definition of structural analysis.

4.2 Model server prototype

The IFC/XML model server software design, including the system functional specifications, the OO design and analysis, the XML schema for IFC implementation on Tamino, and the XML database design are documented and delivered. Fig. 6 shows the basic functionality of the IFC and XML model server. The basic services of the model server include:

- Defining object extensions from the standard IFC object model;
- Interpreting and storing the CAD design data based on this extended object model;
- Extracting 3D geometric data, process/cost data from the object model and transforming them into structural analysis models, scheduling/cost models, or other lifecycle application models;
- Viewing IFC design models and XML structural models; and
- Supporting the data communication based on this extended object model in IFC and XML formats.

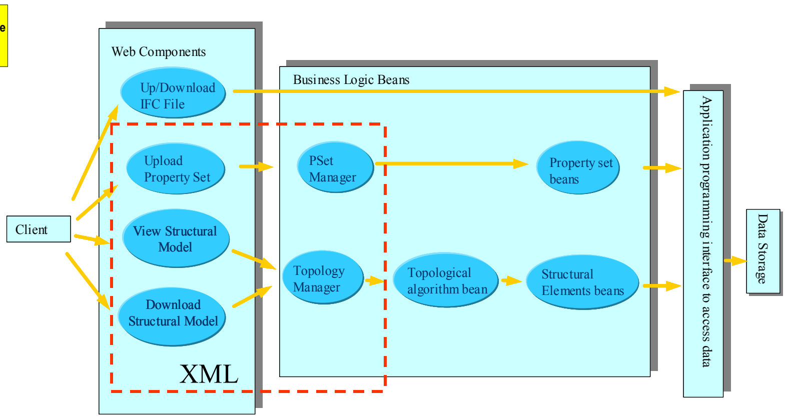

Fig. 6. Functionality of the IFC/XML model server.

From Fig. 6, it is known that the IFC property set definitions, the structural models, and the design models can be imported-to or exported-from the model server in XML. Fig. 7 lists the XML Schema definition of the structural analysis model used in the IFC/XML model server to generate and transform structural model data in XML from 3D design model data in IFC.

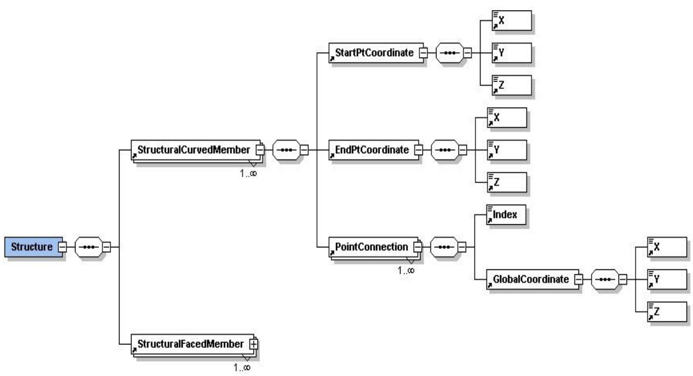

Fig. 7. XML schema for structural analysis model.

4.3 Application scenarios

4.3.1 Design collaboration

A building design effort involves multiple participants of architects, structural engineers, M&E (mechanical and electrical) professionals. They need to share design information in a neutral format across different application software systems. The IFC/XML model server provides capabilities to realise such design collaboration. In a typical design case, an architect logs in the Web site of the model server. The server assigns certain roles to the architect, which allows him to upload IFC files. Once receiving an IFC file submission, the server translates the IFC into XML and stores the XML data in the Tamino database. It also conducts the IFC geometry manipulation to extract the structural data and generates a 3D structural model in XML. A structural engineer logs in now. He may add some additional Psets to the structural model to elaborate the material requirements in structural analysis. He may also add or delete the joints of the structural elements. After finishing the model modification, the engineer sends the feedback to the architect through the server's notification function. If the architect agrees on his modifications, the server will incorporate the Pset into the design model and regenerate a structure model with the new added/modified information in IFC or XML.

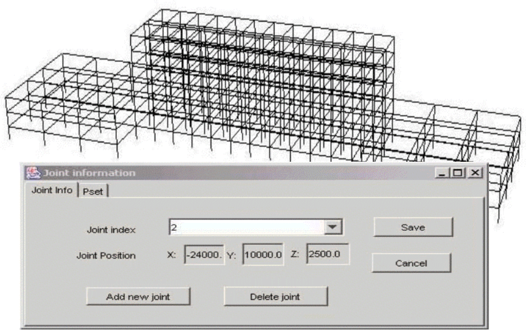

Fig. 8. Structural model with additional joint data.

Fig. 8 is a 3D wireframe model for structural engineering in this use scenario. Similarly the M&E engineers can also exchange, update, and share the IFC/XML data with other professionals in the design collaboration.

4.3.2 Structural analysis

The structural models, such as that one in Fig. 8, generated from the model server can be employed directly in structural analysis. To do so, an adaptor which maps the structural models in XML to the input format of the SAP2000 analysis package is developed and incorporated in the model server prototype. Structural analytical case studies are conducted to demonstrate the interactions between the model server and the SAP2000 software. The system framework used for these case studies are shown in Fig. 9.

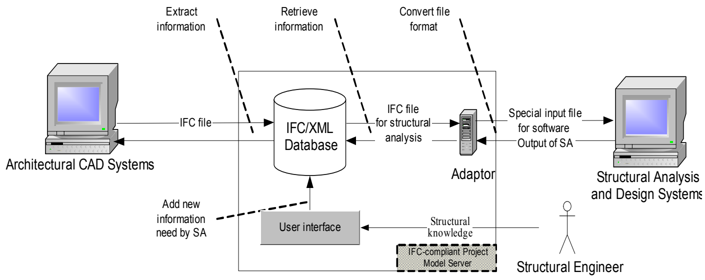

Fig. 9. Structural analysis framework.

Table 2 lists a part of the results from the case studies for information gap analysis. It also shows the Pset extensions proposed for structural engineering.

4.3.3 Cost optimisation

Test cases are conducted to verify the genetic algorithm for the resource-constrained cost-time optimisation problems by using the IFC-complaint information model and the IFC/XML model server as the data model and data repository. Fig. 10 gives an example - the network representation of a 12-activity project to illustrate the IFC-data-based genetic optimisation methodology. Table 3 shows the associated time, cost and resource consumption rate for the options of activities in Fig. 10.

The final generation of the test problem with resource constraints is plotted in Fig. 11. It can be seen that the project duration is postponed due to the limitation of the resource availability.

5 CONCLUSION

Methodologies, models, algorithms and software components have been developed in this CRP for enabling the information interoperability and IFC/XML data sharing across AEC product lifecycle processes. The process-oriented information modelling method integrates the process and information models for effective representation of IFC-compliant product models, which are with the interoperable and extensible Psets to cater for the information needs from CAD design, structural analysis, and cost optimisation applications. To process the model data, algorithms are developed, such as IFC geometry reasoning, cost optimisation matrices, and genetic approach for cost-time optimisation. These information models, extensions and algorithms have been implemented in the IFC/XML model server. The application scenarios show the functionality of the model server for product lifecycle information support. The Web-based IFC and XML model server has been deployed at our project collaborators' site for the future's IFC/XML research projects of graduate students.

Table 2. Information gaps analysis.

	Gaps	Scenarios for IFC Development	Possible Development in Different Ways	
			Method	Extensions
Geometry	Location of Elements	Concepts exist in the IFC Model	Additional property sets	Derived the absolute displacements from relative displacements
	Restraints / Releases	Concepts exist in the IFC Model	Additional property sets	Derived from IfcBoundaryCondition Pset_StructuralConnectionCommon Pset_StructuralMemberCommon
	Length	Concepts exist in the IFC Model	Additional property sets	*Pset_ColumnCommon_Height* *Pset_BeamCommon_Span (already included in Edition 2)*
	Restraints of Joint	Concepts exist in the IFC Model	1. add derived attributes 2. Additional property sets	Pset_StructuralConnectionCommon_Restraints
	Releases of Frame Element	Concepts exist in the IFC Model	1. add derived attributes 2. Additional property sets	(notice the conditions- release combinations which are not permitted)
	Joint Pattern	New Concepts	1. New classes 2. Additional property sets	IfcPattern IfcRelConnectsJointPattern
Load	Distance	Concepts exist in the IFC Model	Additional property sets	Derived the direct displacements from relative displacements
	Load Direction	Concepts exist in the IFC Model	Additional property sets	1. not necessary; 2. Pset_ StructuralActivity
	Prestress Load	Concepts exist in the IFC Model	New class	New class for prestressing cable: IfcPrestressingCablePattern
	Type	Concepts exist in the IFC Model		No need to modify the IFC Model, just process and decompose the load data to two parts: force and moment when programming
	Temperature Load	Concepts exist in the IFC Model		No need
	Combo type	Concepts extend the IFC Model	1. Add new attributes 2. Additional property sets	1. new attribute to IfcStructuralLoadGroup; 2. Pset_LoadCombination

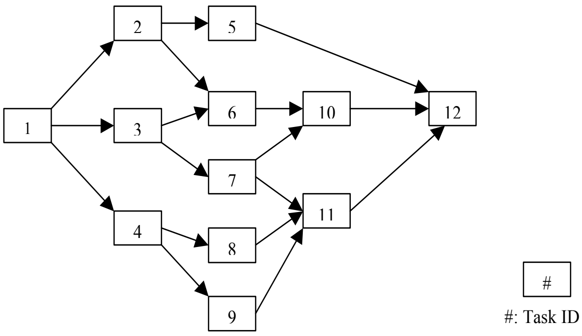

Fig. 10. Network representation of a project.

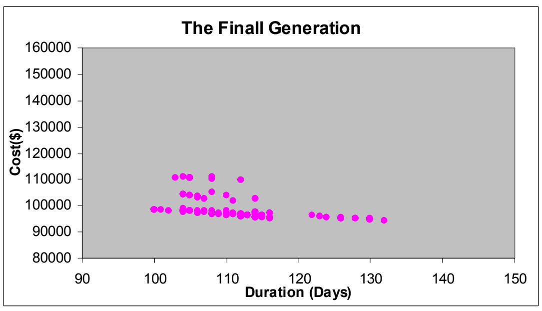

Fig. 11. Final generation of test problem.

Table 3. Options of test problem.

Activity (ID)	Duration (Day)	Cost	Resource Consumption (unit)	Parent Activities
1	14	$2,400	10	
1	24	$1,200	5	
2	15	$3,000	7	1
2	23	$1,500	4	1
3	15	$4,500	6	1
3	33	$3,200	2	1
4	12	$45,000	16	1
4	20	$30,000	10	1
5	22	$22,000	18	2
5	30	$10,000	12	2
6	14	$40,000	20	2,3
6	24	$18,000	8	2,3
7	9	$30,000	17	3
7	15	$24,000	14	3
8	14	$220	4	4
8	21	$208	1	4
9	15	$300	4	4
9	20	$180	2	4
10	22	$2,000	10	6,7
10	30	$1,000	3	6,7
11	9	$3,000	8	7,8,9
11	18	$2,200	4	7,8,9
12	20	$3,000	12	5,10,11
12	24	$1,750	8	5,10,11

6 INDUSTRIAL SIGNIFICANCE

The IFC and XML technologies developed in this CRP can be applied to the local AEC industry for representing, processing, managing and sharing the AEC product information among lifecycle processes. By doing so, it will leverage the competitive edge of the AEC industry and support some national IT programs in AEC. The technical achievement and the manpower trained through this CRP will contribute to the further development and implementation of the IFC and XML technologies in the local AEC industry.

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