BUILDING ON IFC: E-INTERACTION WITH/WITHIN STRUCTURAL DESIGN DOMAIN

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ABSTRACT

Current conventional interaction with/within structural design domain of construction project ends up with cost ineffectiveness and low-level quality product. However, lack of interoperability among interaction parties is the main reason for such drawbacks. In this research work authors did build their methodology on Industry Foundation Classes (IFC) which has been developed by the International Alliance for Interoperability (IAI). Authors did submit their interoperability proposal for IAI International Technical Management (ITM) and it has been accepted as formal project, namely ST-7. Hence, IAI mission has been extended to structural design stage of construction project. In other words, interoperability has been enabled among structural analysis software packages. This, in turn, replaces the conventional interaction by an electronic one (E-Interaction) throughout importing/exporting standard format files. In this research paper, current conventional interaction drawbacks have been clarified. In addition, the new interaction methodology has been addressed as remedy to empower and promote construction industry. Proposed interoperability has been tested in an integrated earthquake simulation as a numerical experiment.

KEY WORDS

interoperability, industry foundation classes, construction industry, structural design domain, conventional interaction, e-interaction

INTRODUCTION

Construction industry is a complex industry that does obligate different parties from different disciplines to interact with each other to produce the final product. At any stage of construction project life cycle if any interaction drawback happened, it would affect drastically all subsequent stages. Moreover, cost ineffectiveness and time consuming increase by being late in catching such drawbacks throughout project life cycle. The International Alliance for Interoperability (IAI 2003) has started a mission, since 1995, to use Information Technology (IT), Object-Oriented Technology, to secure the aforementioned interaction. IAI is developing ISO standard data model for each discipline based on the required information

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to be exchanged. The container for data model of the aforementioned disciplines is called Industry Foundation Classes (IFC). IFC is technology transfer model for interaction with/within discipline to achieve interoperability. Interoperability is defined by IAI as: "*It is the open sharing of information without regard to the hardware or software applications in use. It places emphasize on the value of information and how it is used rather than on the systems which use it. So, it empowers the owner and user of information*".

This research represents the technology transfer model at Structural Design stage of construction project. At this stage, the problem becomes more serious and more complicated in case of huge international construction project. In this case X designers will interact with Y revisers and Z of other structural domain parties (ex., steel fabricator, concrete fabricator, construction manager, etc). Moreover, designers, revisers, and other parties can be from different countries. Hereafter, current conventional interaction drawbacks have been clarified; moreover, new interaction methodology has been addressed as remedy to empower and promote construction industry. Implementation steps and benefits have been introduced.

PROBLEM STATEMENT

The current conventional way of interaction with/within Structural Design domain of construction project has the following drawbacks, Figure 1:

1. Hard-copy interaction between structural domain parties.
2. Manual checking, i.e. tedious work.
3. Individual interpretation for design codes,i.e. inconsistency.
4. Heterogeneity, ease cheating of structural design.
5. Multiple sources of information.

Lack of interoperability among structural analysis software packages is the main reason for abovementioned drawbacks. This research aims to enable such interoperability based on IT as part of IAI mission. It is fact that Interoperability is a secured interaction.

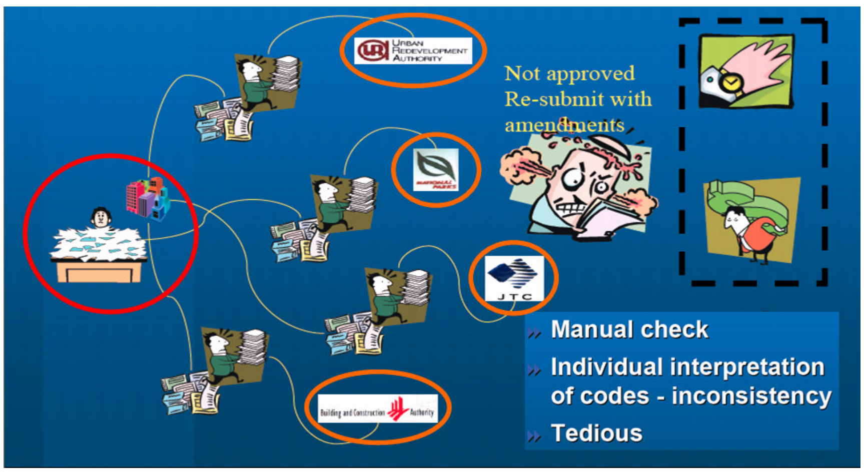


Figure 1: Conventional Interaction with/within Structural Design of Construction Project

BACKGROUND AND OBJECTIVE

The International Alliance for Interoperability (IAI) was founded in order to provide "*a basis for process improvement and information sharing in the construction and facilities management (AEC/FM) industries*" (IAI 2003). All effort is reflected in a multi-vendor capable standard, the Industry Foundation Classes (IFC). The goal of this product model standard is to define an integral, object-oriented and semantic model of all components, attributes, properties, and relationships of and within a "building product" and to gather information about its originating process, life cycle and disposal. To account for global relationships, in many countries so-called "chapters" have been established which work on several projects by extending the IFC object data model. The IFC product model is specified using the modeling language EXPRESS, which has been used to define STEP-based product models within ISO 10303 before. Since 2002, the current release IFC 2.x is certified as ISO/PAS 16739 standard.

Interoperability in structural design domain of construction project has been started by the work done in the ST series projects: ST-1 did emphasize on steel frame construction, ST-2 did emphasize on reinforced concrete construction, ST-3 did emphasize on precast concrete construction, ST-4 did emphasize on structure analysis, ST-5 did emphasize on structural timber construction, ST-6 did emphasize on further extension for steel construction. It is obvious that previous ST series projects had paid much attention for construction-oriented data models for structural design domain such as geometric representation for designed steel members and connections and how to exchange such representation throughout project life cycle. Analysis-oriented data models, however, have been started in ST-4 project that did define only structure mechanical model in addition to static loads. To complete structural analysis process, analysis discrete model (Finite Element Model, FEM) needs to be defined in addition to structural dynamic loads and analysis results.

The objective in this research work is to extend the work done in ST-4 project to complete structural analysis process. Hence, enable interoperability among structural analysis software packages to afford new methodology of interaction with/within structural design domain namely Electronic Interaction (E-Interaction), see Figure 2a. Figure 2b shows the proposed E-Interaction scenario snapshot between Designer and Agency. Agency means any party need to interact with Designer; it can be another Designer party. The main data to be transferred are structural analysis model (Finite Element Model, FEM), loads, and results. In this scenario, Designer plays the role of data sender while Agency plays the role of data receiver. Data Center is constructed as mediator between the two parties of interaction, i.e. Server. It receives submission from Designer and delivers it to Agency. It also receives reply from Agency and notifies Designer. Accordingly, it contains an operating system and group of messages.

Structural analysis software vendors are key factor in this research work because the abovementioned interoperability has to be enabled for software packages in hand. In other words, it has to be enabled for software packages in the market and which are used by structural engineers worldwide. Hereafter, methodology that is used to make software vendors act as partners in this research work has been clarified. In addition financial support and procedure has been mentioned.

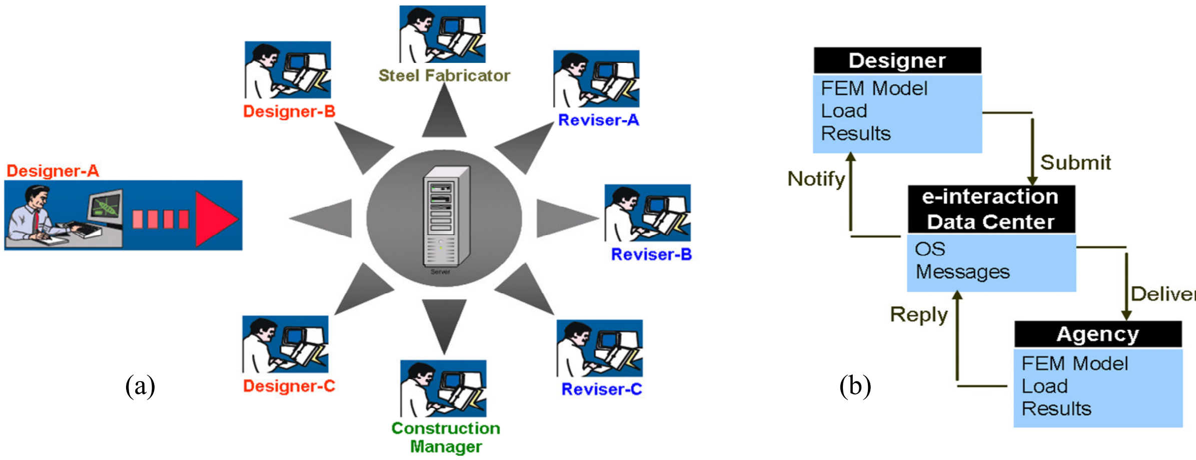


Figure 2: Electronic Interaction (E-Interaction) with/within Structural Design Domain of Construction Project: (a) Overview; (b) Scenario Snapshot

METHODOLOGY

This research is supervised by IAI as part of the collaborative development of IFC for interoperability in AEC (Architecture/Engineering/Construction) industry. Accordingly, many international software vendors are working with IAI to implement IFC ISO standard and to deliver interoperability to the real world (IAI 2004). It became high-level business for software vendors to get involved in IFC extension projects and to implement IFC standards.

Authors did submit their interoperability proposal to IAI-ITM (International Technical Management) and it has been accepted as formal IAI project on June, 2005, and assigned the coding name ST-7 (IAI 2005). Since then, task force has been assigned to ST-7 project and it has been supported by IAI-Japan chapter. Authors are leading ST-7 project in addition to fourteen members worldwide (Japan, Australia, Norway, Germany, etc) (ST-7 2005). ST-7 group members are representing different sectors: industry, software vendors, and academia.

Figure 3 shows ST-7 project development flowchart. It consists of nine steps: preparing project proposal, submission of proposal to ITM, definition of information requirement, preparation of process model and information requirement, review process model and information requirement, preparation of extension model document, submission of extension model to MSG (Modeling Support Group), integrate extension model to IFC, and finally release of extension model as ISO standard based on ISO STEP format.

The current status of ST-7 project is at step five: “Review process model, information requirement and draft extension model”. It is worthy to note that two workshops have been conducted in order to review process model, information requirements, and draft extension model. The first workshop has been held on November, 2005, among industry people and software vendors at IAI-Japan chapter, Japan. However, the second workshop has been held on December, 2005, among academic people at The University of Tokyo, Civil Engineering Department. Moreover, the second version of ST-7 data model has been released for project group members on, January, 2006. According to ST-7 project schedule plan, the model will be integrated into IFC, step eight, by the end of 2006. On the other hand, it will be integrated into ISO standard, step nine, by the end of 2007.

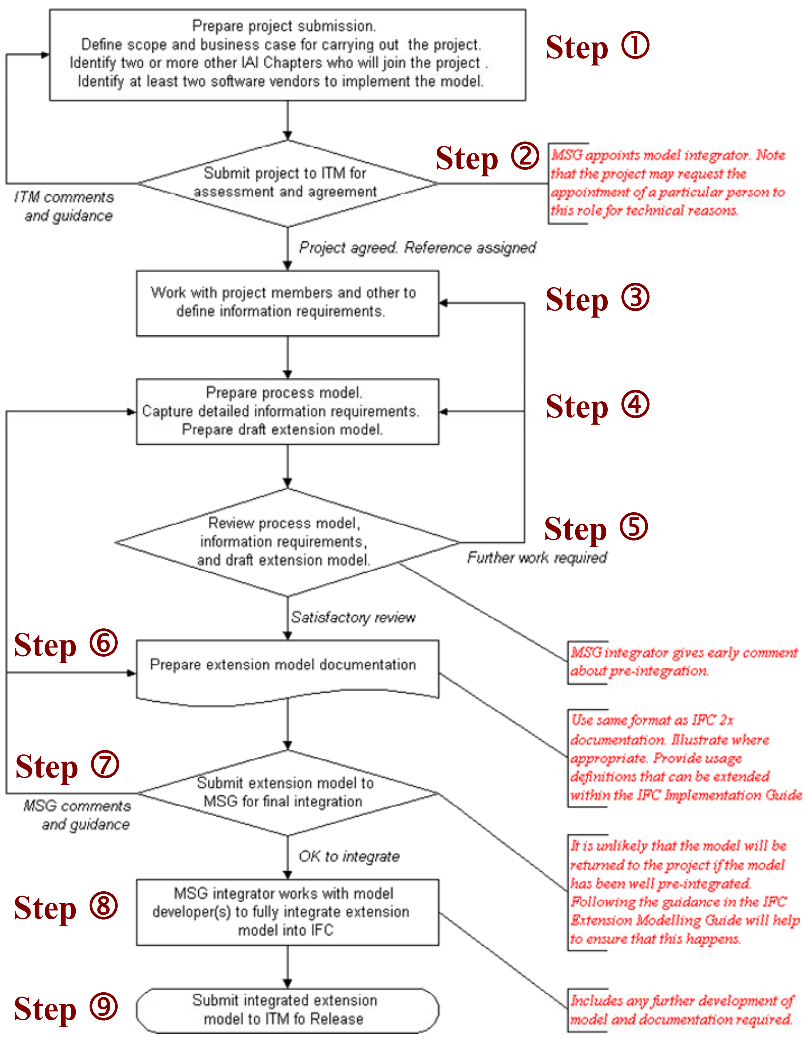


Figure 3: ST-7 Project Development Flowchart, IAI

In ST-7 project, data model for Finite Element Model (FEM) has been defined in addition to structural loading and analysis result. Figure 4 shows two types of FEM that have been considered. First type is called Mechanical FEM which consists of two separate stages: *Idealization* that idealizes architecture model to mechanical model and *Discretization* that discretizes mechanical model to finite element model. The second type is called Physical FEM which relates the architecture (physical) model to finite element model directly. In other words *idealization* and *discretization* stages are done in one process. Data entities have been derived in a manner that ensures integrity between architecture, mechanical, and finite element models. This in turn overcomes any discrepancy between analysis model and physical model.

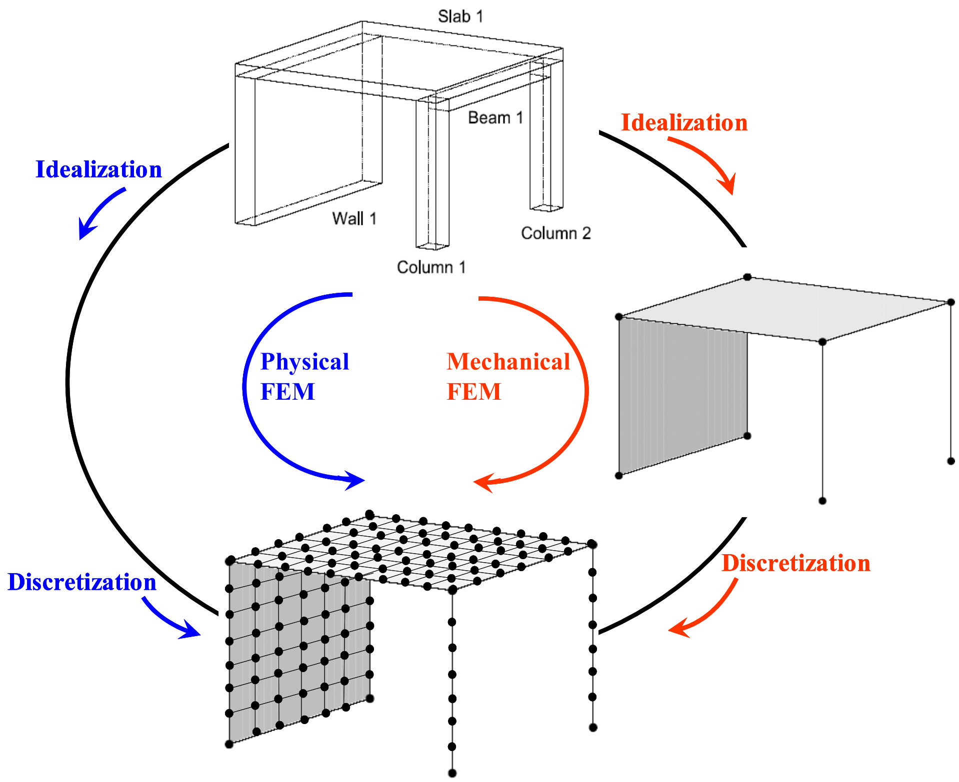


Figure 4: An Overview for ST-7 Extension Project Objective

On the other hand, Figure 5 illustrates, in EXPRESS-G, entities defined for FEM model (Zienkiewicz, O. C. and Taylor, R. L. 2000). Hatched entity is a new one defined in ST-7 project; otherwise it is defined in ST-4 project. Figure 5a shows abstract entity for all FEM items: FEM node, FEM element, FEM integration point. Figure 5b shows abstract entity for all FEM element types: curve, surface, volume, and special elements. It is worthy to note that attributes which are shared among all elements are assigned to their abstract entity such as *ElementMaterial*, *Connectivity*, *DegreesOfFreedom*, etc attributes.

Figure 6 illustrates, in EXPRESS-G, the reference mechanism between FEM model entity and FEM element entities. In addition, it gives brief explanation for how FEM model is further assigned to mechanical or architectural model. *IfcRelAssignsToFiniteElementModel* entity is used for such assignment. This assignment ensures integrity between FEM, mechanical, and architectural models which in turn secures any discrepancy between these models.

Figure 7 illustrates, in EXPRESS-G, entities defined for structural load and analysis result. Dynamic action, Figure 7a, has been defined in three categories: equivalent static action, response spectrum action, and time history action. In addition, structural result, Figure 7b, has been defined including straining and straining action results. Dynamic action else than earthquake is beyond scope of ST-7; however, ST-7 did provide abstract entity from which further future extensions can be extended. Structural load and analysis result entities in turn are referenced by FEM entities to describe FEM load and analysis result.

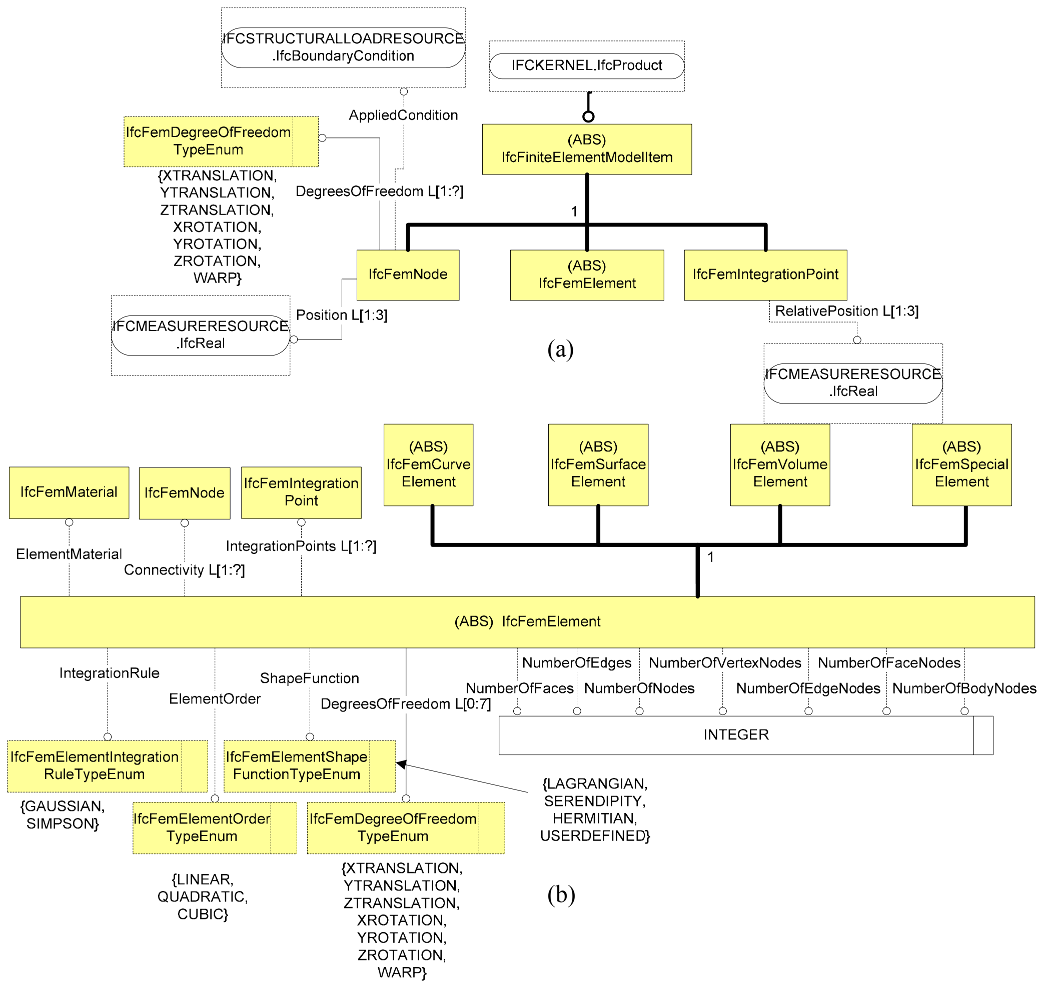


Figure 5: Entities EXPRESS-G Snapshot for: (a) FEM Items; (b)FEM Element

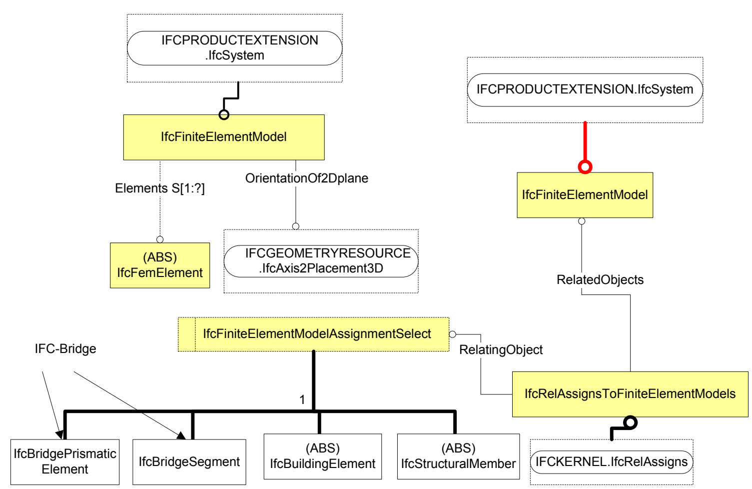


Figure 6: Entities EXPRESS-G Snapshot for FEM Model and its Assignment Relationships

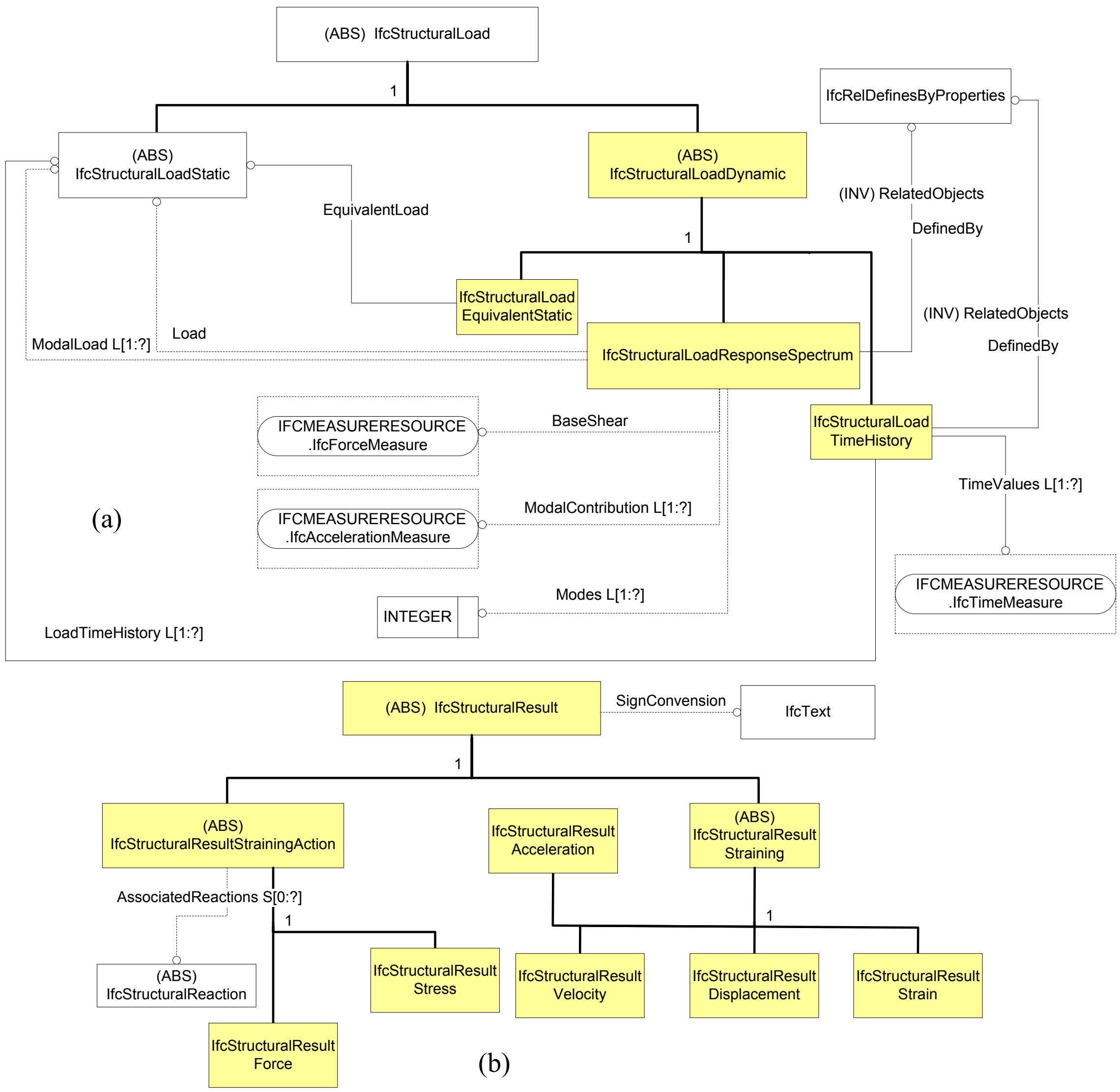
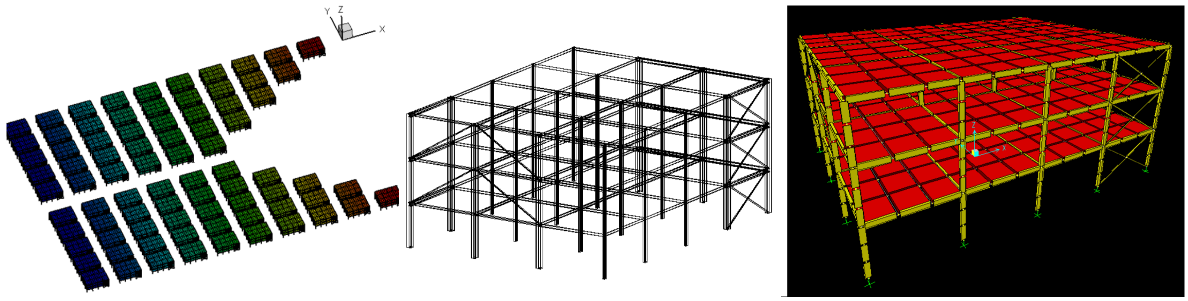


Figure 7: Entities EXPRESS-G Snapshot for: (a) Structural Load; (b) Structural Result

NUMERICAL EXPERIMENT

Authors have developed an Application Programming Interface (API), namely *STRCOMplus*, for structural domain view of IFC including proposed extension in ST-7 project. *STRCOMplus* has been tested in an Integrated Earthquake Simulation (IES) that has been developed by the authors to perform dynamic analysis for a large-scale domain, complete city (Hassanien, et al. 2005). A virtual domain consisting of eighty buildings has been constructed, Figure 8a. Three-storey building, Figure 8b and 8c, has been used as typical building in the virtual domain. Mechanical model of the building, Figure 8b, has been extracted from its IFC representation in ISO (part-21) format. Hence, Sap2000 (Computers & Structures 2003) has been used as meshing tool to generate FEM model, Figure 8c.

Dynamic analysis has been conducted for the virtual domain, using IES, to ensue adequacy of the proposed IFC extension in ST-7 project. In this experiment, converter has been provided between *STRCOMplus* and Sap2000 because Sap2000 is not IFC-compliant.



(a) (b) (c)

Figure 8: (a) Virtual Domain; (b) Mechanical Model; (c) FEM model

Figure 9 illustrates writing command inside IES simulation based on *STRCOMplus* API. It is clear that object-based data structure of ST-7 data model did enable efficient management and manipulation for simulation data. Among huge number of objects and data, small piece of information can be controlled efficiently. It gives macro as well as micro scales of data control. This is an analogy for the case of interaction with/within structural design parties where huge number of objects and data are resulted too.

```
out<<IES.get_Sites().get_mem(0)->
get_Building().get_BuildingStories().get_mem(0)->
get_GrpElements(0).get_mem(0)->
get_SlabFem().get_ShellQuadrilateralElements().get_mem(0)->
get_ConnectivityNode(0)->get_pst().get_cmp(0);
```

Figure 9: Writing Command inside IES simulation based on STRCOMplus API

CONCLUDING REMARKS

Drawbacks of current conventional interaction with/within structural design parties of construction project have been clarified. In addition, authors did propose E-Interaction to replace the conventional one. E-Interaction methodology has been clarified throughout enabling interoperability among structural analysis software packages. Authors did submit interoperability proposal to IAI-ITM and it has been accepted as formal IAI project and assigned coding name ST-7. ST-7 does extend ST-4 project vision to complete structural analysis process. It defines: structural dynamic loads from earthquake action, structural analysis results, and finite element model. Authors did develop API for structural view of IFC including ST-7 extension, namely *STRCOMplus*. Numerical experiment has been conducted to test *STRCOMplus*. Efficient management and manipulation for virtual domain simulation data give clear evidence for superiority of ST-7 data model.

Economic and social values can be summarized as follow:

1. Cost Effectiveness in construction industry. The Latham report (Latham 2004) challenges the UK construction industry to save up to 30% of the cost of building project within five years by better use of IT.
2. Automating structure design checking process.
3. Consistency in design codes interpretation.
4. Compatibility between structural and architectural design.
5. Spur construction industry toward adoption of CAD and Object-Oriented technology.
6. Transparency in structural design. Importing/exporting one data file among designers and revisers makes all data and assumptions transparent, secures design cheating.
7. Enable electronic database for project throughout its life cycle "Owner Hope". This in turn reduce cost of:
    a. Future retrofitting and changes.
    b. Facility management.
    c. Maintenance.

ACKNOWLEDGMENTS

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REFERENCES

Computers & Engineering, 2003; "Sap 2000 product version 7.4"

Hassanien, M., Inoue, J., Ichimura, T., Hori, M. (2005); "Kernel-based Message Passing Interfaced Integrated Earthquake Simulation", Topping, B.H.V., (Editor), Proceedings of tenth International Conference on Civil, Structural and Environmental Engineering Computing, Civil-Comp Press, Stirling.

IAI, International Alliance for Interoperability, Release 2x2 of IFC. (2003); Web-Page, http://cig.bre.co.uk/iai_international/Technical_Documents/documentation/

IAI, Implementation Software Packages Compliant to IFC (2004); Web-Page, http://www.bauwesen.fh-muenchen.de/iai/ImplementationOverview.htm

IAI, IFC Extension Projects (2005); Web-Page, http://ce.vtt.fi/iaiIFCprojects/ListProjects.jsp

Latham, M. (1994); "Constructing The Team", Final Report of the Government/Industry Review of Procurement and Contractual Arrangements In The UK Construction Industry HMSO, London, P.7.

ST-7 Extension Project (2005); Web-Page, http://groups.yahoo.com/group/ST-7

V. Treeck, C., Rank, E. (2004); "Analysis of Building Structure and Topology Based on Graph Theory", Proceedings of the 10th International Conference on Computing in Civil and Building Engineering (ICCCBE), Weimar, Germany.

Zienkiewicz, O. C. and Taylor, R. L. (2000); "Finite Element Method", Vol. 1