CREATING STRUCTURAL MODEL FROM IFC-BASED ARCHITECTURAL MODEL

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ABSTRACT

Building information model is an integrated entity that consists of building information from various disciplines, such as architectural, structural, electrical, HVAC, construction management, etc. Direct data sharing and exchange between the architectural and structural disciplines without using paper-drawings is highly desirable in building design and design collaboration. However, structural analysis and design is based on finite element modeling, its concept and data platform are remarkably different from those employed for constructing architectural CAD model.

In this paper, based on the Industry Foundation Classes (IFC) standard, a procedure was developed to adapt architectural information directly for construction of a structural model. To this end, a study was performed to determine the relationships and differences of data to be handled between the architectural and structural domains. A unified finite element data file was introduced to capture the data from the architectural domain necessary for the establishment of a structural model. This unified data file is logically organized with ample transparency so that it can be conveniently adopted by different structural analysis systems. The entire data analysis procedure is built around a structural-model server which is equipped with various functions, such as data selection, model editing, visualization, load analysis, data check, preliminary structural analysis, and data interface with various finite element systems. A general algorithm on structural model generation from IFC compatible architectural model was presented with an illustrative example.

KEY WORDS

Structural Model, Finite Element Model, Model Generation, Design Integration, Industry Foundation Classes (IFC).

INTRODUCTION

In view of the need for exchange of complex information in Architecture, Engineering and Construction (AEC) industry, it has become apparent that building product models, such as the General AEC Reference Model, (Gielingh 1988), the Building Systems Model (Turner 1990), the RATAS Model (Björk, 1989), and the Building Construction Core Model (Wix and Liebich 1997), were studied and proposed for information exchange, such as 3D geometries and product design of building structures since 1980s. Liebich and Wix (2002)

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gave an elaborated review on the historical development of building product models and the prevalent AEC status. After nearly ten years of development work, the Industry Foundation Classes (IFC), which was developed by the International Alliance for Interoperability (IAI), has been widely accepted as the leading standard for building product models within the AEC domain (Tarandi 2003).

Although IFC provides a standardized language for exchanging project data, the model-based approaches for data integration are only beginning to reach practical viability and many areas still require additional development before a comprehensive interoperability solution can be reached (Froese 2003). For instance, design integration between the architectural domain and structural domain still remains unresolved. This is due to the fact that the representation of IFC-based architectural model, which is essentially a physical model, is much different from that of IFC-based structural model, which is an abstract finite element model. A few researchers (Chen et al. 2005) proposed algorithms to deduce the topological relationship among different structural elements for creating a structural model from the corresponding IFC-based architectural model. However, the created structural model was limited to their in-house software for structural analysis, not suitable for any commercial packages in the open domain. The objective of this research is, however, to develop a general procedure for creating structural models for various structural analysis software packages from IFC-based architectural models.

IFC IMPLEMENTATION

The introduction of IFC has been given in a reference by (e.g., Yu et al. 1998), thus it will not be repeated herein. After the initial founding of IAI in 1995, the first generation of IFC appeared in 1997, starting with IFC version 1.0, followed by successive improvements up to the current IFC 2x Edition 2, which was released in May 2003. The IFC system is a data representation standard and file format for defining architectural and construction CAD graphical data as 3D real-world objects, primarily to enable architectural CAD users to transfer design data between different software applications. IFC model is defined using the EXPRESS language defined in ISO 10303 part 11 (1994) and the physical file of IFC model is defined using the clear text encoding of the exchange structure defined in ISO 10303 part 21 (1994).

Implementation of an IFC model consists of two parts: a) IFC file parser, and b) IFC model schema. The IFC file parser was developed to import/export the physical file of an IFC model, and then the IFC model schema was developed to generate all corresponding objects defined in the physical file of IFC model. The architecture of IFC model schema is organized in four conceptual layers: a) resource layer, b) core layer, c) interoperability layer, and d) domain layer. Within each conceptual layer, a set of model schemata are defined and illustrated in other references (e.g., Liebich et al. 2004).

INFORMATION EXTRACTED FROM THE ARCHITECTURAL MODEL

The issue of information sharing and exchange to be addressed herein is to establish direct data communications for a building design between the architects and structural engineers without necessarily relying on paper-form drawings. The end products of the data format are, of course, the architectural and structural design models, respectively. The relationship of information between the architectural and structural models is shown in Fig. 1. On one hand, the architectural model consists of structural member information and non-structural member information, such as geometric locations, member section profiles, and material data. On the other hand, the structural model is normally a finite element model that consists of the original structural members that are provided by the architects as a vertical and lateral load transferring system. It also contains new structural members that are defined or amended by structural engineers, different load cases and their combinations during the building life cycle, geometric boundary conditions, etc.

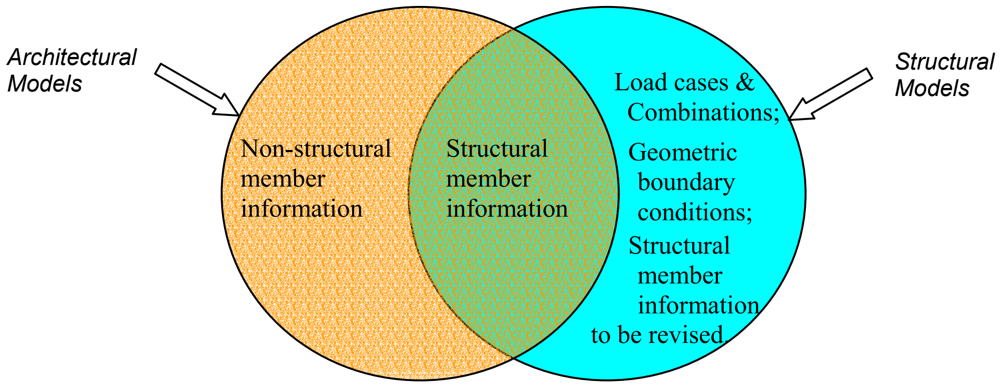


Fig. 1 Relationship of Information between Architectural and Structural Models

BUILDING ELEMENTS TO BE EXTRACTED FROM THE ARCHITECTURAL MODEL

From Fig.1, obviously a significant amount of information for creating a structural model must come from the architectural model. Fig. 2 shows a collection of all types of building elements defined in the interoperability layer of IFC schema, which are used to represent both the structural and non-structural information of the architectural model. The structural information is normally represented in terms of specified building elements, such as IfcBeam, IfcColumn, IfcWall/IfcWallStandardCase, and IfcSlab. Therefore in the proposed research, these specified building elements are extracted from the architectural model as the preliminary structural members in the structural model; other building elements are filtered, but not extracted. Another type of special element, IfcOpeningElement, that is normally employed to represent the opening at the location of a door or window on a wall element, shall be extracted from the architectural model also.

INFORMATION TO BE EXTRACTED FROM THE BUILDING ELEMENTS

For all of the above building elements to be extracted, their geometric information including the locations and cross section profiles of structural members, and material information related to the elements can be extracted by analyzing the physical file for the representation of building elements. For instance, Fig. 3 shows the representation of a building element, e.g., IfcBeam. The geometric location of the building element is represented with its attribute object, IfcLocalPlacement. The geometric representation of a building element is designated by an associated attribute object, e.g., IfcProductDefinitionShape, IfcShapeRepresentation, etc. On the other hand, material information of a building element, e.g. IfcBeam, is linked to the related material object, IfcMaterial, affiliated with a relationship object, IfcRelAssociatesMaterial.

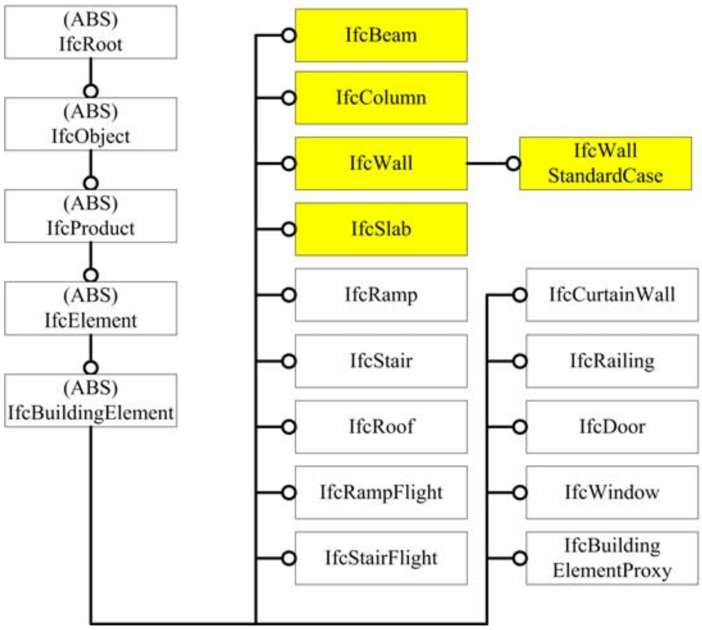
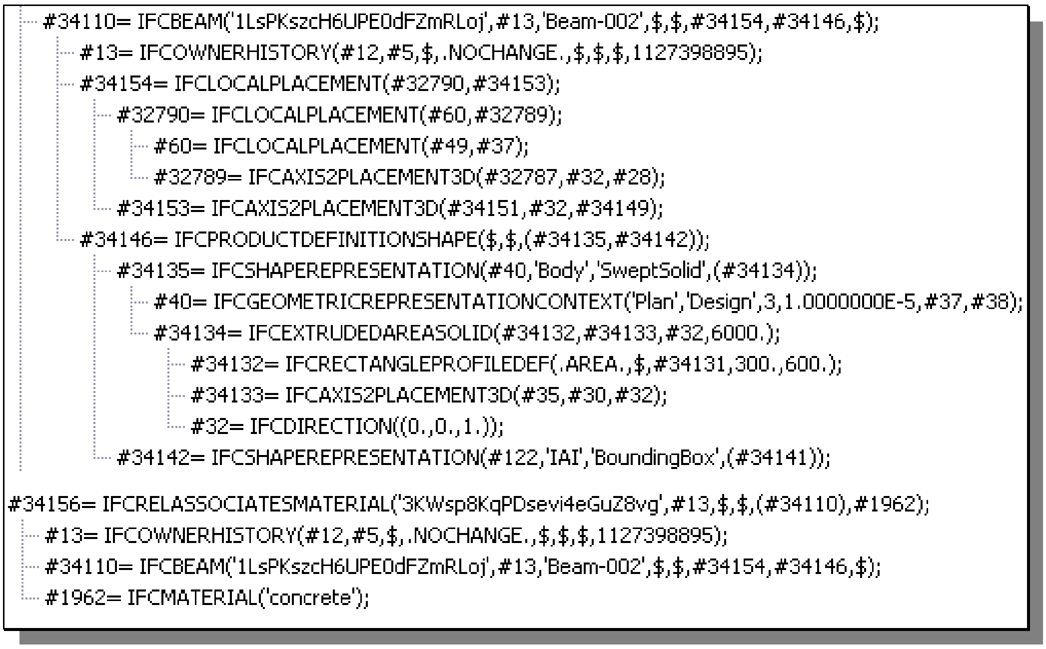


Fig. 2 Collection of Building Elements Defined in IFC Schema



```
#34110= IFCBEAM('1LsPKszcH6UPE0dFZmRLoj',#13,'Beam-002',$,$,#34154,#34146,$);
    #13= IFCOWNERHISTORY(#12,#5,$,.NOCHANGE.,$,$,$,1127398895);
    #34154= IFCLOCALPLACEMENT(#32790,#34153);
        #32790= IFCLOCALPLACEMENT(#60,#32789);
            #60= IFCLOCALPLACEMENT(#49,#37);
            #32789= IFCAXIS2PLACEMENT3D(#32787,#32,#28);
        #34153= IFCAXIS2PLACEMENT3D(#34151,#32,#34149);
    #34146= IFCPRODUCTDEFINITIONSHAPE($,$,(#34135,#34142));
        #34135= IFCSHAPEREPRESENTATION(#40,'Body','SweptSolid',(#34134));
            #40= IFCGEOMETRICREPRESENTATIONCONTEXT('Plan','Design',3,1.0000000E-5,#37,#38);
            #34134= IFCEXTRUDEDAREASOLID(#34132,#34133,#32,6000.);
                #34132= IFCRECTANGLEPROFILEDEF(.AREA.,$,#34131,300.,600.);
                #34133= IFCAXIS2PLACEMENT3D(#35,#30,#32);
                #32= IFCDIRECTION((0.,0.,1.));
        #34142= IFCSHAPEREPRESENTATION(#122,'IAI','BoundingBox',(#34141));

#34156= IFCRELASSOCIATESMATERIAL('3KWsp8KqPDsevi4eGuZ8vg',#13,$,$,(#34110),#1962);
    #13= IFCOWNERHISTORY(#12,#5,$,.NOCHANGE.,$,$,$,1127398895);
    #34110= IFCBEAM('1LsPKszcH6UPE0dFZmRLoj',#13,'Beam-002',$,$,#34154,#34146,$);
    #1962= IFCMATERIAL('concrete');
```

Fig. 3 A Sample for Information Representaiton of a Buillding Element: IfcBeam

GENERAL FORMAT OF UNIFIED FINITE ELEMENT MODEL

There are numerous commercial software packages that can be used for structural analysis and design. For example, the popular packages in China market are PKPM series, ETABS, SAP2000, etc. Although all the software systems are based on the same numerical technique, their input data formats are different from each other. In other words, a finite element model created for one software system may not be useful for the other. Since the proposed development is intended for finite element applications of different systems, a unified finite element model, consisting of nine data blocks in XML-based file format, is specially defined for building structures as shown in Fig. 4.


```xml
<?xml version="1.0" encoding="GB2312"?>
<DATA>
<TABLE Name="System">
  <Control ID="AppInfo" Name="IFC2SGF" Version="1.00"  Producer="SJTU-DXY"/>
  <Control ID="FileInfo" Title="DefaultSGF" Author="DXY" Organization="SJTU"
          TimeStamp="11/28/2005 21:47:59" Description=""/>
  <Control ID="Units" LengthUnit="MM" ForceUnit="KN"/>
</TABLE>
<TABLE Name="Storey">
  <Storey ID="Story2" Elevation="3000"/>
  <Storey ID="Story1" Elevation="0"/>
</TABLE>
<TABLE Name="Material">
  <Material ID="CONC" Mass="2.40277E-012" Weight="2.35631E-008" Type="Isotropic"
          E="24.8211" U="0.2" A="9.9E-006"/>
  <Material ID="STEEL" Mass="7.827E-009" Weight="7.682E-005" Type="Isotropic"
          E="199948" U="0.3" A="1.17E-005"/>
</TABLE>
<TABLE Name="Joint">
  <Joint ID="1" X="-4000" Y="10000" Z="0"/>
</TABLE>
<TABLE Name="FrameSection">
  <FrameSection ID="FSEC1" Material="CONC" Shape="Rectangle" XDim="600" YDim="600"/>
</TABLE>
<TABLE Name="Frame">
  <Frame ID="FRAME1" JointI="21" JointJ="22" Type="Column" Section="FSEC1"
          Angle="0" Jointo="21" Storey="Story1"/>
</TABLE>
<TABLE Name="AreaSection">
  <AreaSection ID="Wall1" Material="CONC" MatAngle="0" AreaType="Shell"
          Type="Shell-Thin" Thickness="380" BendThick="380"/>
</TABLE>
<TABLE Name="Area">
  <Area ID="1" Joint1="1" Joint2="2" Joint3="3" Joint4="4" Type="Wall"
          Section="Wall1" Angle="90" Storey="Story1"/>
</TABLE>
<TABLE Name="Opening">
  <Opening ID="1" Joint1="59" Joint2="60" Joint3="61" Joint4="62" AreaID="4"
          Storey="Story1"/>
</TABLE>
</DATA>
```


Fig. 4: XML-based General Format of Unified Finite Element Model

The data structure and its general format of the unified finite element model are similar to that of a typical structural analysis software package. An XML-based data structure was chosen for the convenience of importing/exporting data by various structural analysis software packages. There is no direct data exchange between the IFC-based architectural model and various structural analysis software packages. The extracted structural model from the IFC-based architectural model is converted to the general format of a unified finite element model first, then its format is further transformed to a corresponding structural model, which can be imported by various analysis software packages. By so doing, it is more convenient for future maintenance and upgrading of the proposed system.

STRUCTURAL MODEL CONSTRUCTION FROM IFC-BASED ARCHITECTURAL MODEL

FLOW CHART

Fig. 5 shows the general procedure of structural model creation from an IFC-based architectural model. On one hand, the IFC-based architectural model is imported into the proposed IFC structural model server in conjunction with the implemented IFC schema. Next, the structural building elements and their corresponding information are extracted with the module of structural building elements extraction & aggregation, and then they are transformed into XML-based general format to form a unified finite element model. Finally, the unified finite element model is further linked with targeted structural models through the data interfaces between the unified finite element model and various structural analysis software applications. On the other hand, after the completion of structural analysis and model revision, the structural model can be transformed back to the unified finite element model, and then converted into IFC-based structural model, which can be imported and integrated in the original architectural model.

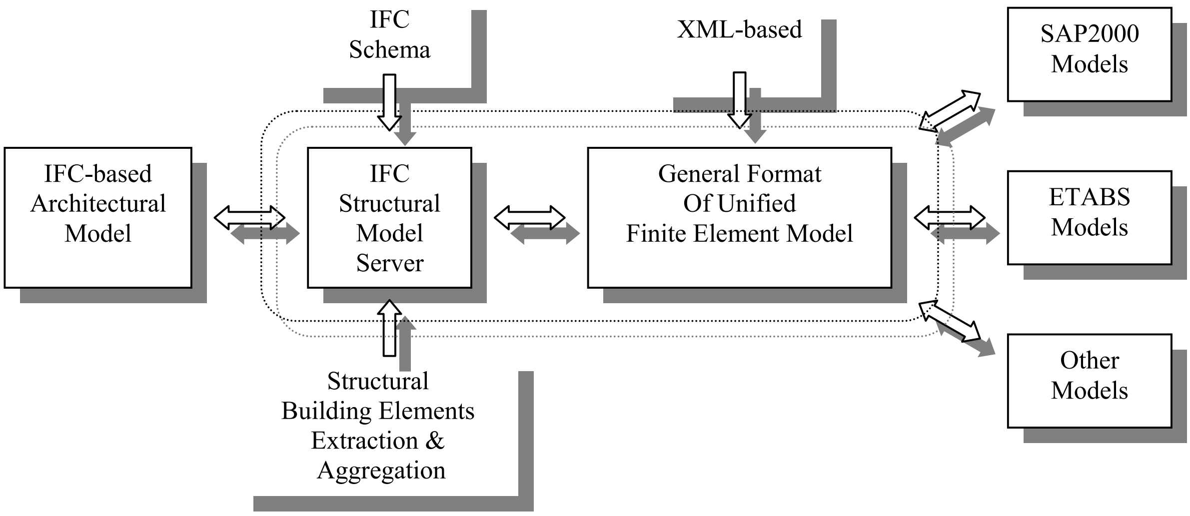


Fig. 5: General Procedure of Structural Model Construction from IFC-based Architectural Model

EXAMPLE AND DISCUSSION

Fig. 6 shows an architectural model of 12-storey twin buildings that was developed with Autodesk's ADT platform. The IFC-based architectural model (*.ifc) was exported with IFC-Utility 2x which is provided by Inopso GmbH. Through the developed IFC structural model server in this research, the IFC-based architectural model was imported, the structural building elements and their corresponding geometric information, section profiles, material information were extracted.

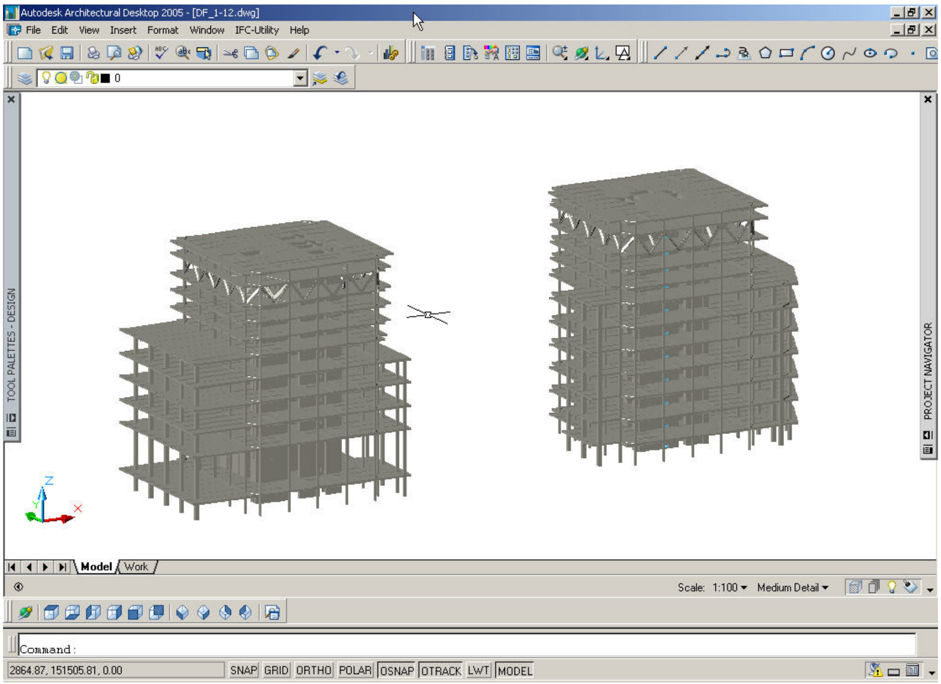


Fig. 6: The Architectural Model of a 12-Storey Twin Buildings developed in ADT

In this example, the extracted structural building elements consist of reinforced concrete columns, beams, walls, slabs, steel columns and steel beams. These extracted structural elements were converted into XML-based general format of the unified finite element model, and then converted into specific structural models for ETABS and SAP2000 software systems, as shown in Fig. 7a and 7b. The connection of structural members was implemented by introducing the identical nodal points of frame elements or area elements.

With the developed IFC model server, the time for creating the specified ETABS and SAP2000 structural models from the IFC-based architectural model is around ten minutes for this example. Structural engineers import the created structural model, carry out model checking, define and assign corresponding load cases, and input the geometric boundary conditions for the model, finally run the model for structural analysis and design with appropriate model revision.

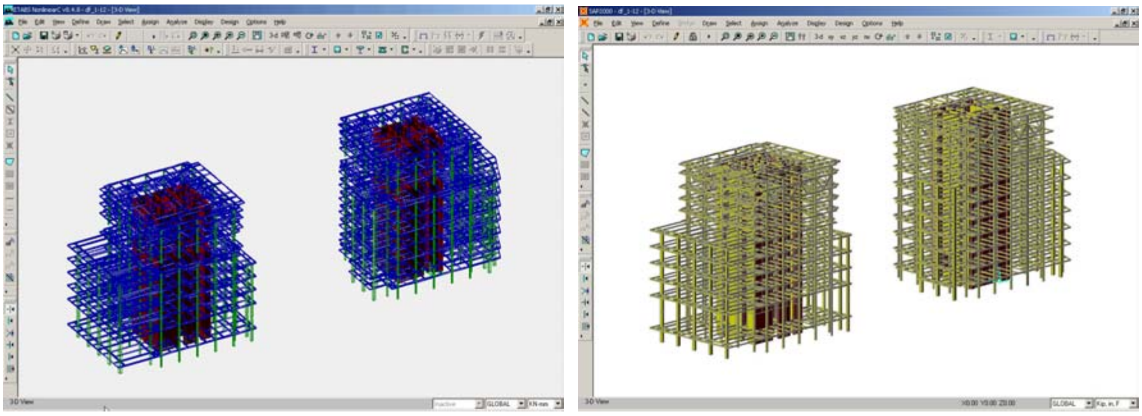


Fig. 7a: The Constructed Structural Model Shown in ETABS; Fig. 7b: The Constructed Structural Model Shown in SAP2000

CONCLUSIONS

The finite element model for structural analysis and design is still not yet supported by the latest release of IFC 2x2. Some difficulties in implementing the data between the architectural and structural domains have been realized by many researchers. In this research, a general procedure for constructing structural models from IFC-based architectural models was developed and tested with a practical project of 12-storey twin-buildings.

With the IFC structural model server developed in this research, the structural building elements of the original architectural model that are defined in IFC 2x2, such as IfcBeam, IfcColumn, IfcWall/IfcWallStandardCase, and IfcSlab can be extracted and aggregated to form a unified finite element model. The XML-based general format of the unified finite element model bridges the IFC-based architectural model and structural models for various structural applications.

The mapping between the XML-based general format of the unified finite element model proposed in this research and the IFC-based finite element model being developed by IAI Japan chapter shall be a further research topic in the area of design integration between the architectural and structural domains.

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