INTEGRATION OF BIM AND DSM TO IMPROVE DESIGN PROCESS IN BUILDING CONSTRUCTION PROJECTS

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ABSTRACT

Design process is complex in collaborative environments having large team size and many disciplines. Building design also has become sophisticated and schedules have been tightened. Building Information Modelling (BIM), one of the latest tools in building design, based on parametric modelling paradigm, allow the collaborators to be in physically distant locations without face to face interaction. This amplifies complexity and need for improved design management. Design Structure Matrix (DSM) is an effective tool in managing iterative tasks such as design process. Parameter-based DSM represents design parameter relationships. This paper establishes that parameter-based DSM can be integrated with BIM, which also is parametric, for effective design management. Another obstacle in collaborative BIM is that different applications following different formats affect interoperability. Industry foundation Classes (IFC) is an open format developed as a solution to this. IFC is identified as suitable level in which the integration with DSM can be done.

Keywords: Building Information Modelling (BIM), Industry Foundation Classes (IFC), parameter-based Design Structure Matrix (DSM)

1 INTRODUCTION

Five main categories of problems affecting design management has been identified by Austin (1996) as fast tracking pressure, complexity in client's organization, increased building complexity, difficulty in planning the design phase and difficulty in information management. The first three categories are not easy to control and the studies concentrate on planning the design phase and information management.

Building design is information intensive and complex. Collaborative effort of disciplines like architecture; structural engineering and Mechanical, Electrical, and Plumbing (MEP), generates information both intra-disciplinary and inter-disciplinary.

Complexity is mainly due to accelerated project schedules which cause concurrency. More sophisticated designs that are possible by recent software tools increases complexity. Using BIM software, working on big projects, having different disciplines, huge team size and different locations of teams is challenging to the design management. This can be viewed from two perspectives. First is that a central BIM model is created reducing the redundancy, increasing the visualization, reducing conflicts and so on. Second is the complexity in management because of increased early-communication between disciplines and changed communication pattern.

The developments in Information and Communication Technologies (ICT) open a lot of possibilities in design. As parametric BIM models replaces the traditional CAD based drawings, the new design process models also need corresponding modifications. The disadvantage of this new method is the voluminous data which can be handled only by powerful computing facility and limits manual intervention. The BIM data are generated in various geographic locations and it is dynamic because of frequent changes of parameters or its values. Also, to handle heterogeneous software for BIM, Industry Foundation Classes (IFC), the open BIM data model has become a standard for interoperability.

Even though, BIM, a powerful modelling tool in Architecture Engineering and Construction (AEC) industry and parameter-based Design Structure Matrix (DSM), an effective product modelling tool, are parametric in nature, only limited studies had been done to integrate them for better design management. The only publication in this area is by (Pektas, 2010). This effort for integration showed that Parameter based DSM along with high level IFC model gives more detailed and accurate representation of processes. It also highlighted that IFC, which primarily support product modelling and information exchange, can also be used for process modelling.

Objectives of this study are to explore the information flow of collaborative BIM in current building design projects and propose a framework to integrate BIM and DSM to improve design process.

The paper is organized in five sections. The following section explores collaborative working using BIM software. The third section discusses on the level at which information to be captured for DSM formation. Fourth section discusses relevant standards in the product development and particularly in AEC industry. Last section suggests a framework for the integration of BIM and DSM.

2 COLLABORATIVE WORKING USING BIM SOFTWARE

"BIM can be described as the process containing activities of generating, storing, managing, exchanging, and sharing of building information in an interoperable and reusable way throughout the lifecycle of a building" (Vanlande, 2008). BIM improves inter-disciplinary collaboration across geographically distributed teams having intelligent documentation and information retrieval, greater consistency in building data, better conflict detection and enhanced facilities management (London, 2008).

BIM can allocate parts of the project divided into discrete shared units across the project team. These units can be worked concurrently by collaborators. The team members may be from different disciplines and working in geographically distant locations. The concept remains same in different BIM implementations even though the approach varies. For instance, there are two approaches of collaboration in Autodesk Revit 2011 namely linking and work sharing. The combination of these two also is possible (Autodesk, 2011).

In linking approach, the project can consist of many linked models to create an aggregate model so that each model can be of manageable size. This method is appropriate for separate buildings in a site, different parts of the building designed by different teams or for coordination among different disciplines. For instance a site can be created in one file which acts as main file; the buildings in the site can be created in separate files; and these separate files can be linked in the main file in appropriate positions. It is also possible to nest linking.

Work sharing approach allows simultaneous access by team members to a shared model called central file. Copy of the central file called local file is used by team members to work with. Discrete functional areas, known as work sets, will be owned by the team members which can be borrowed by other members for modification. The concept is shown in Figure 1.

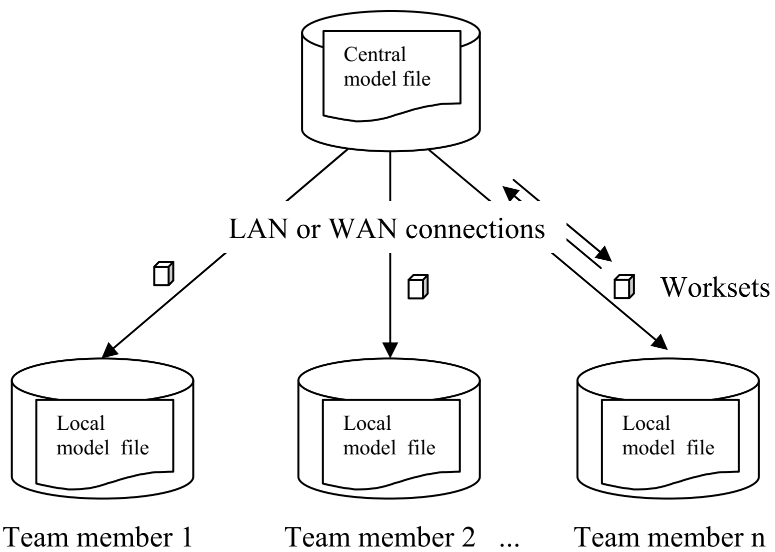

Figure 1. Collaborative working using BIM software

In case of distant locations of collaborators, a central server stores the central model and communicate with a local server through WAN. Also both linking and work sharing approaches can be used in the same project forming a mixed strategy.

By proper coordination across disciplines and teams expensive errors and reworks can avoided. There are tools for coordinating design and managing change. Options for monitoring an element cause to get alerts on any change on it; coordination review lists the changes on request; and interface checking can show the invalid intersections between host project and a linked models (Autodesk, 2006).

3 PARAMETER-BASED DSM

DSM as a management tool was introduced by Don Steward in 1981. Now it is so accepted that a community is formed around it. It provides a project representation that allows feedback and cyclic task dependencies and is less space consuming compared to other tools like networks. This is extremely important since most engineering applications display such a cyclic property.

DSM can be formulated to capture dependencies at various design levels such as component, team, activity, parameter, etc. (Browning, 2001). The classification is detailed in Table 1.

Table 1. Types of DSM (Browning, 2001)

DSM data types	Representation	Applications
Component-based (Product)	Component relationships	System architecting, engineering and design
People-based (Organization)	Organizational unit relationships	Organizational design, interface management, team integration
Activity-based (Process)	Activity input/output relationships	Process improvement, project scheduling, iteration management, information flow management
Parameter-based (low-level Process)	Design parameter relationships	Low level activity sequencing and process construction, sequencing design decisions

In practice it was difficult to arrive at a suitable level of abstraction to formulate the Activity DSM. Based on evaluation of DSM on a live project (Senthilkumar and Varghese, 2009) proposed *drawing* as the suitable level of information control and developed a Drawing DSM approach.

Currently, BIM has substantially changed design and documentation approaches. So, it has become necessary to identify new levels suitable for representing information for DSM.

As shown in Table 1, parameter-based DSM analyses design process at the level of design parameter relationships. Its applications include low level activity sequencing and process construction, and sequencing design decisions. In this paper, Authors propose parameter as the suitable level for representing information from the fact that BIM is parametric. The resulting complexity caused by the large volume of data can be managed using automated DSM based approach.

4 STANDARDS

ISO 10303, STEP and IFC are standards which varies in its scope from general to domain-specific respectively. They are very similar in structure because of having similar formats based on EXPRESS modelling language. Since this study is based on building design, IFC which is specific to AEC industry and form the interoperable standard for BIM is selected as the representation schema. The following paragraphs discuss these standards in brief (ISO 10303-11:1994).

ISO 10303 exchanges product information using neutral file approach, in which transfer between two systems is a two-stage process. In the first stage data is translated from the native data format of the originating system into the neutral ISO 10303 format. In the second stage the neutral format is translated into the native format of the receiving system. ASCII file is the exchange medium. Bindings of the format to several computer programming languages, like Java and C++, have been published.

STEP (Standard for The Exchange of Product model Data) is a set of international standards under the designation ISO 10303. Typically STEP can be used to exchange data between Computer Aided Design, Computer-Aided manufacturing, Computer-Aided engineering, Product Data Management and other CAx systems. STEP addresses product data from mechanical and electrical design, building construction, automotive, aerospace, ship, oil and gas, process plants and others. It covers life-cycle stages like design, analysis, planning and manufacturing of the product.

IFC platform specification, ISO/PAS 16739, provides data structures for the AEC industry. It is defined and maintained by buildingSMART International. It supports shared project model and enable data sharing across diverse applications by representing building products related information. The specification is modified a number of times to add and update a large number of new classes. Current version available is Release 2x4 (IFC2x4) Release Candidate 2. IFC also make use of EXPRESS modelling language to define building product models(buildingSMART, 2011b).

EXPRESS is a formal modelling language used to define product data models. It is formalized in STEP as ISO 10303-11. EXPRESS schemas can define entities to be captured and exchanged along with their relationships. Entity, as defined in ISO 10303-11, is a class of information defined by common attributes and constraints. As EXPRESS is computer-processable, entities can be verified automatically for syntax and existence of appropriate links to other schemas.

5 INTEGRATION LOGIC

The authors' proposal for application of DSM in BIM is shown in Figure 2. The class definitions based on the EXPRESS modelling language schema is used to guide the extraction of details and incorporation of modification in the original IFC model file. The DSM, fed with these objects, does the optimisation or sequence change. Changed data is incorporated back in the model. The same logic can be used partially to extract filtered information for better understanding. Four major components used here are EXPRESS modelling language, IFC specification, IFC model file and DSM.

1. EXPRESS is the formal modelling language used to define product data model. EXPRESS sets the rules and patterns to identify class definitions used in IFC model file and IFC specifications.
2. IFC specification is the information that holds the class definitions required to extract entity parameters from IFC model file. EXPRESS schemas guide the reading of IFC model file.
3. IFC model file is the file usually exported from a BIM application and contains the ASCII format information for objects used in the product model. The class definitions identified by EXPRESS from IFC specifications suits the objects in the model file.
4. DSM is generated using the object parameters generated from the model file as input. This parameter-based DSM can be used for analysis of the selected objects which are important for design decisions.

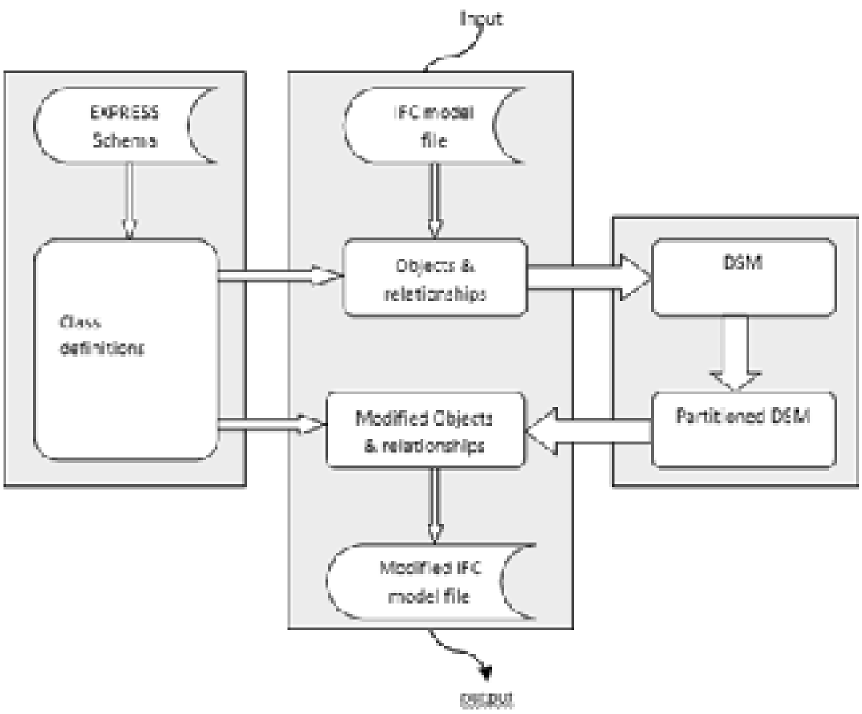

Figure 2. Logic of integration of IFC and DSM

Figure 2 shows the logical sequence of incorporating the above four components. IFC specifications, containing class definitions are processed using EXPRESS schema to get a library of all possible classes in the AEC industry. This can be early binding, in which the classes of a particular IFC version are pre-processed to make available at any time, or late binding, in which the class identification is done at the time of requirement only. The input to the system is IFC model file which is already generated by exporting a BIM file from an application using a built-in logic or using an external utility. The library of class definitions are utilised to extract the filtered information from model file, outputting parameters of required objects and relationships. This is the input for generating DSM. The DSM here is parameter-based, because, it is having selected parameters from the model file. This DSM can be partitioned or used for description of relationships between objects. Application program can modify the objects or sequence and incorporate back in the IFC model file using the same extraction logic in the opposite order. The modified IFC file can be used by any BIM application by importing using a built-in logic or using an external utility.

There are several tools and solutions for supporting implementation of IFC-related software which are categorised as follows.

1. IFC-Toolboxes: these are APIs for interfaces in applications.
2. IFC Model Servers: these are Databases for sharing IFC files.
3. IFC-Viewers: used for viewing the graphical presentation of IFC models.
4. IFC File-Browsers: used for viewing hierarchies of the data structure of IFC models.
5. IFC File-Validators: used for testing the semantics in IFC models.

The commercial IFC-based developing systems like libraries provided by 'Eurostep', ActiveX components like 'IFC Active ToolboX' and Express Data Manager (EDM) databases of IFC models developed by EPM Technology are also available. But many of the commercial software applications are both costly and need updating or recompiling for future versions of IFC specifications. (buildingSMART, 2011a) Custom tools can be developed in Java or Dot NET platforms.

For DSM solutions a number of tools are available as shareware or commercial. The main commercial tools are ADePT Design software suite, Lattix, Loomeo, PlanWeaver, ProjectDSM, Structure 101, SonarJ, Plexus, IntelliJ IDEA, Complex Problem Solver and ACCLARO DFSS (DSMweb, 2011). Fast and effective algorithms like genetic algorithm are also developed for DSM solutions (Yu, 2003).

6 CONCLUSION

BIM made very sophisticated designs possible and at the same time the complexity and need for improved design management increased. This paper explores the information flow in collaborative working of BIM and integrates DSM, the management tool that allows feedback and cyclic task dependencies, for improvement of design process. Parameters are identified as the level in which the information to be captured as input to DSM, from the fact that BIM is parametric and the parameter-based DSM is suitable for it. A suitable standard is required to represent BIM in order to interact with DSM. IFC is identified as the appropriate standard because it is an interoperable open format developed particularly for AEC industry. A framework to integrate DSM and BIM in IFC format is proposed to improve design process.

Future research on this chain will be the extensions in IFC for representation of DSM and implementation of the framework to verify its applicability.

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- Standards
- Integration Logic
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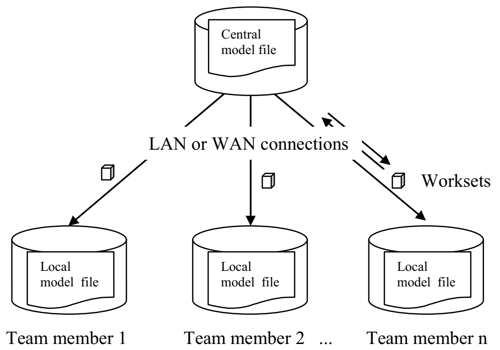
Introduction

- Objectives
  - Explore the information flow of collaborative BIM in current building design projects.
  - Develop a framework to integrate BIM and DSM to improve design process.

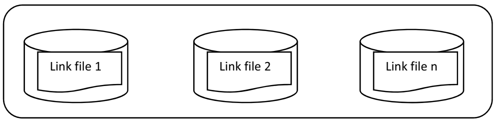
Collaborative Working Using BIM Software



1. Work sharing
   - Central model file is shared
   - Local copies called local model file are used to update central file.
   - Discrete worksets are owned by team members and borrowed by others to update

Collaborative Working Using BIM Software (contd.)

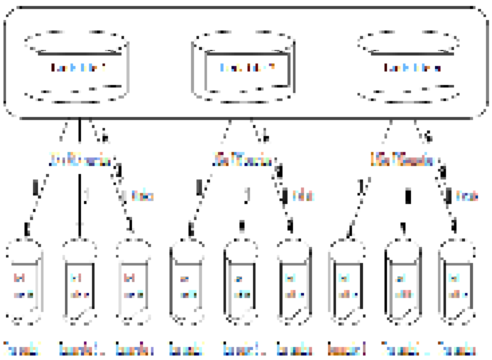
2. Linking



- Different model files works separately
- They are linked each other and so can view other models.

Collaborative Working Using BIM Software (contd.)

3. Mixed strategy



- Linked files use worksharing
- Example: Different disciplines in a project use linking to connect each other. Each discipline having a number of team members use worksharing.

Suitable Level of Abstraction for DSM

Conventionally DSMs are typed into four as shown in the table

DSM type (Browning, 2001)	Representation
Component-based (Product)	Component relationships
People-based (Organization)	Organizational unit relationships
Activity-based (Process)	Activity input/output relationships
Parameter-based (low-level Process)	Design parameter relationships

In practice it is difficult to arrive at a suitable level of abstraction to formulate the Activity DSM using the conventional levels.

Suitable Level of Abstraction for DSM (contd.)

- Based on evaluation of DSM on a live project (Senthilkumar and Varghese, 2009) proposed *drawing* as the suitable level of information control and developed a Drawing DSM approach.
- BIM has substantially changed design and documentation approaches, hence need a new level of abstraction.
- parameter is a suitable level for BIM because BIM is parametric.
- The resulting complexity caused by the large volume of data can be managed using a software-assisted DSM based approach.

Abstraction level	
Drawing DSM (Senthilkumar and Varghese, 2009)	Release of drawings
BIM model Updating	Updating of parameter attributes and parameter relationships

Standards

- ISO
  - ISO 10303- STEP
    - ISO 10303-11-**EXPRESS**
  - ISO/PAS 16739 - **IFC**

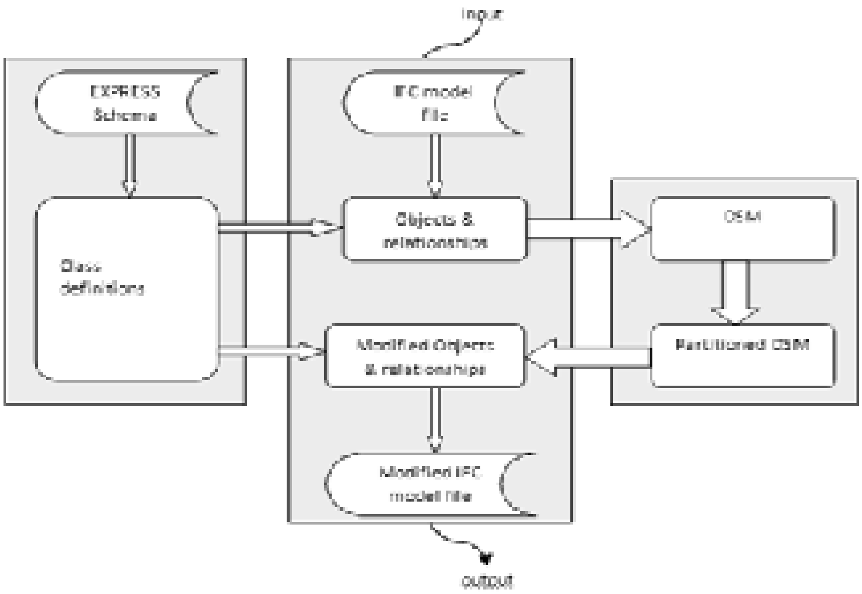
- STEP – Standard for The Exchange of Product model Data
- EXPRESS – a product modelling language
- PAS – Publicly Accessible Specification

Logic of Integration of IFC and DSM

Components used in the logic

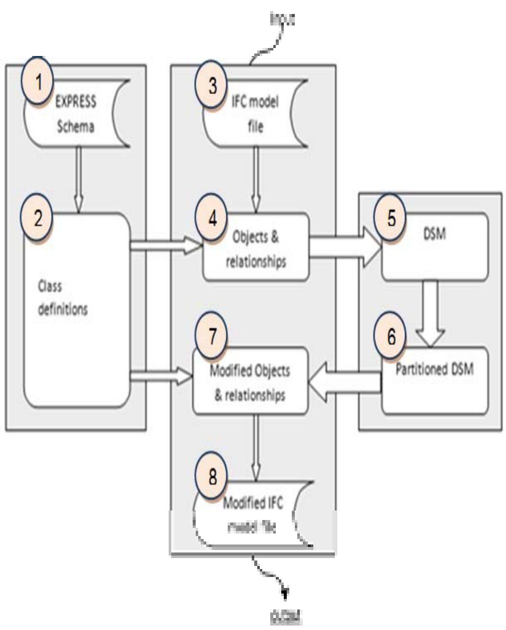
- **EXPRESS**
  - modelling language: define product data model.
  - sets the rules and patterns to identify class definitions used in IFC.
- **IFC specification**
  - class definitions to extract entity parameters from IFC model file.
- **IFC model file**
  - usually exported from a BIM application
  - ASCII format information for objects used in the product model.
  - class definitions from IFC specifications suits these objects.
- **DSM**
  - generated using the object parameters generated from the model file.
  - this is a parameter-based DSM.
  - analysis of the selected objects for design decisions.

Logic of Integration of IFC and DSM (contd.)



INVEST ON VISUALIZATION

Logic of Integration of IFC and DSM (contd.)



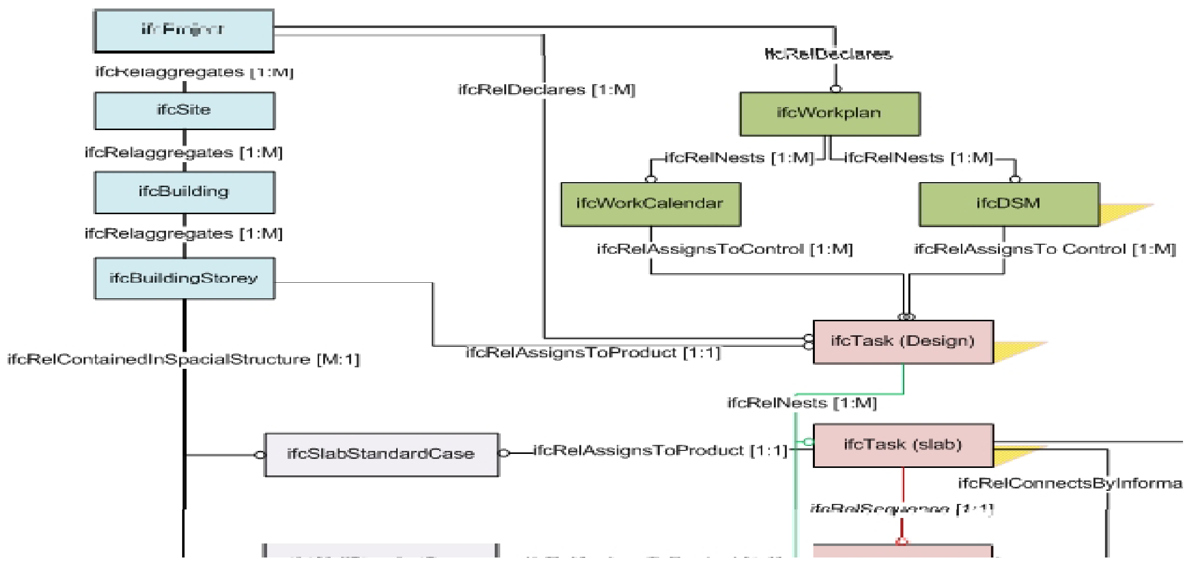
1. EXPRESS sets the rules and patterns.
2. IFC specification holds the class definitions.
3. IFC model file exported from a BIM application.
4. Objects and relationships of model are extracted using IFC specifications
5. DSM is generated using the object parameters
6. DSM partitioning/operations.
7. Modification of the model based on partitioned DSM.
8. Modified IFC is imported by the BIM application.

Example: Representing DSM in IFC

4 walls designed in a sequence after the slab

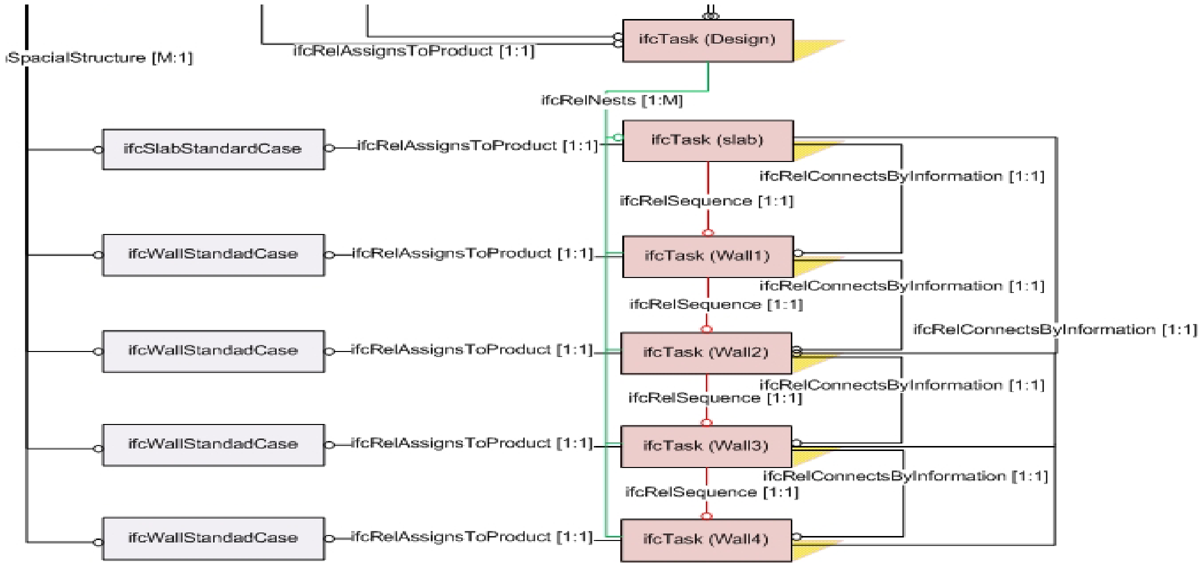
	Slab	Wall1	Wall2	Wall3	Wall4
Slab					
Wall1	x				
Wall2	x	x			
Wall3	x		x		
Wall4	x			x	

Example: Representing DSM in IFC (contd.)



Note:
The classes ifcDSM and ifcConnectsByInformation are not existing.
Extensions are to be developed for implementation of the logic

Example: Representing DSM in IFC (contd.)



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Conclusion

- BIM based collaborative design adds complexity to design management.
- BIM is parametric; Parameter-based DSM can be used to represent a building product model.
- IFC is the suitable specification for representing BIM.

- A framework for integration of BIM and DSM was developed in order to improve design process.
- Large volume of BIM data in parameter-based DSM, to be handled with software support.
- Current IFC specifications do not contain DSM classes; so, extensions to IFC are developed.

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