

AUTOMATED DESIGN OF STRUCTURES IN BIM ENVIRONMENT

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ABSTRACT

BIM is an advanced technique based on information technology that is becoming widely adopted in the AEC industry. The construction industry has started to realize the importance of latest innovative technologies. Various project participants such as planners, designers, engineers and subcontractors are using BIM to improve their project performance. However, successful implementation of BIM is directly measured by the integration and exchange of wealth of information contained in BIM model among different parties and different stages of the project. Interoperability seems to be the major barrier in the successful implementation of BIM. The dependence of the industry on proprietary software for exchange of data constitutes the main cause of interoperability. To achieve seamless interoperability among various team members of a project, it is crucial that we make use of vendor neutral tools and software for communication among project team members. In this study open source applications have been used to extract information for generation of the structural model of a building from its architectural BIM model. An integrated workflow is implemented to describe why openBIM includes substantially more than just a standardized file-format. The principle motivation behind the work is to advance the utilization of open source technology.

Key words: BIM, IFC, ifcopenshell, interoperability, openBIM, python, structural model.

1. INTRODUCTION

In the realm of data innovation, the construction industry is likewise redesigning quickly towards computerization. Technological advances are presently changing practically all parts in the life-pattern of construction project, from plan conceptualization through development to destruction of a development project. Engineers are ceaselessly looking for better ways to deal with improve and keep the speed on the current economy, to be more useful, to work quicker and to use wise judgment in regards to the determination of the optimal construction methodologies for coming to higher than ever. In view of the unique and fragmented nature of projects, paper-based drawings and support of experts from various disciplines and furthermore ever-increasing complexity of the development projects requests for use of specialized techniques in Architecture, Engineering, and Construction (AEC) industry [1]. The center part for the effective fulfillment of a building project is legitimate participation and joint effort among the fragmented disciplines of the undertaking and to make the process more productive and subjective.

With the advances in new innovations, there has been a rising interest in the use of building information modeling (BIM). BIM is an advanced methodology in view of data innovation that is turning out to be generally taken on in the AEC business. The result of BIM process is building information model commonly known as BIM model is an integrated entity that comprises of data about entire structure from different disciplines, for example, structural data, MEP data, environmental data, construction management data etc. As indicated by the American National BIM Standard (NBIMS),

"BIM is characterized as a computerized portrayal of physical and practical qualities of an office. As such it fills in as a common data resource for information about an office outlining a trustworthy justification for decisions during its lifecycle from origin ahead" [2].

BIM implies different things to different experts. For some expert BIM is a product, to others it is an interaction for planning and recording data of structures. Some say it is a comprehensive way to deal with plan, development and support of a structure. There can be numerous abbreviations for this idea. The sole hypothesis behind it is to gather the structure foundation and development data at a typical spot, so that shared information might be used by the individuals in various phases of a project.

Today BIM is an area of most extreme interest which can give a game-changing answer for address the difficulties experienced in the AEC business. It is a recently arisen digital technology for the generation of virtual 3D model having project related information and giving experts the new experiences and instruments to all the more proficiently plan, develop and oversee structures and framework. BIM is characterized by [3] as quite possibly of the most encouraging improvement in the AEC enterprises by giving carefully built exact virtual models. Individuals working in many spots, with various devices and in various times can join their work to make a typical outcome. It also thinks about better examination of conditions through reproduction.

BIM Models are the records holding semantic data connecting with building parts which can be traded for dynamic about a development project. Exactly when used fittingly will save time, cash and simplify the development interaction. The development business has begun to see the advantages of BIM. Draftsmen, creators, project administrators, and workers for hire are utilizing BIM to work on their cycles. A few contextual investigations have demonstrated the way that BIM can diminish revise. Development costs are turning out to be more unsurprising. The progressions made in the model are consequently conveyed all through the undertaking in this manner dispensing with the coordination blunders.

1.1. Interoperability and openBIM

The embracing of BIM brings enormous benefits to the AEC industry. BIM unites the entirety of the data about each part of a structure, in one spot and makes it feasible for anybody related in the project to access that information for any purpose. Information stored in BIM can be leveraged for many new and exciting applications including the generation of structural models, quantity takeoffs, 4D scheduling, energy analysis and building simulations. However, it has been found that a number of firms that follow BIM are not reaping the full benefits because of difficulties such as the lack of communication between the various professionals in design and construction. Successful implementation of BIM is directly measured by the integration and exchange of wealth of information contained in BIM model among different parties and different stages of the project which is technically known as interoperability. Interoperability is a process of data import and export among heterogeneous software tools, in which a software tool exports its model in a standard format for sharing and exchange of data and the other one imports this model for further use [4]. For example, a structural engineer imports the architectural model for structural design and analysis and then exports an updated model to the architect for collaborative design. The idea is not new since there is always a need for communication between the people and tools working in the same field. However, in case of BIM, this concept has become main issue as integration and exchange of information is essential to the success of BIM. The main reason for the absence

of interoperability is the proprietary nature of BIM software. There are diverse software used in the construction industry which claims to support BIM but in practice, the level of information exchange is extremely poor. Most of the software programs used in development of models are usually developed to work as standalone applications and are not typically designed to share data with other programs. Proprietary software applications develop their own data exchange formats specific to their domain which restricts the user to exchange data by selecting his desired BIM software. If the user got the freedom of data exchange and sharing by successfully using a common sharing platform and effective interoperability, then it saves a lot of time and improves communication amongst various stakeholders. According to a report from NIST (National Institute of Standards and Technology) on costs of inadequate interoperability, \$15.8 billion interoperability costs were quantified for the US capital facilities industry per annum [5].

OpenBIM can be solution to these issues. OpenBIM basically implies working with BIM utilizing open standards. It is an initiative started by buildingSMART International [6] to inspire international interoperability for BIM. It is based on a method and workflow where all participants can collaborate and exchange project information with each other using non-proprietary, neutral file formats irrespective of the BIM tools and applications that they use. OpenBIM helps to avoid different interpretations and mistakes. The global aim is to work together without errors. Participants are allowed to focus more on the compatibility of workflow rather than that of data in openBIM [7]. In a closed BIM environment, communication between project members is possible only through a format compatible to that software whereas in openBIM flow, standard file formats are used for data transfer and any tool of any participant can be part of the workflow (Fig. 1) [8]. OpenBIM uses Industry Foundation Classes (IFC), an object-oriented standardized terminology and a common data model, which aims to achieve high level of interoperability to facilitate data exchanges between BIM tools in building industry. IFC is an openBIM data repository for the semantic information about building objects, including associated geometry, properties and relationships, to facilitate data sharing and exchange across IFC-compatible applications and data reuse for analysis and other downstream tasks. IFC is discussed latter in more detail in this paper.

During the past few years, many efforts have been made to develop information exchange standards to address the interoperability challenges in building projects. An IFC-based integration tool was developed by [9] to extract a PKPM structural model from an architectural model. Also, a bi-directional conversion among various structural analysis models was made possible by developing an IFC and Web-based tool [10].

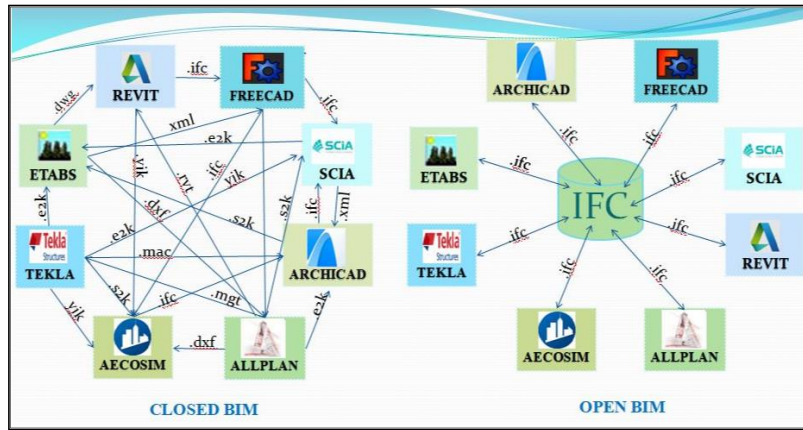


Figure 1 Closed BIM vs open BIM

1.2. BIM in Structural Engineering

Structural design/analysis is most important field for implementation of BIM. If performed manually, structural analysis and design is time consuming, tiring, and error prone work. Structural engineers can take a huge advantage of the BIM technique. A significant amount of input data can be obtained directly from BIM physical model for structural analysis purposes, saving a lot of time for creating this model from drawings, increase accuracy and support automation within a BIM-based design process [11]. So, high level of interoperability is required between BIM authoring tools and engineering design/analysis software to benefit from employing BIM for structural design purposes. Currently, BIM authoring tools cannot export structural analytical models in non-proprietary file formats. For example, Autodesk Revit is capable of exporting structural analysis models to the file format of common structural tool Robot Structural Analysis and similar connection exists between Tekla and SAP2000 and STAAD. Structural model extraction is an important preprocessing step to prepare BIM data for use in downstream applications [13]. In this study open source applications have been used to extract information for generation of the structural model of a building from its architectural BIM model. An integrated workflow is implemented to describe why openBIM includes substantially more than just a standardized file-format. For the execution of the tools, the most popular language Python and the open source library IfcOpenShell are utilized. The main purpose of the work is to promote the use of open source technology.

2. MATERIALS AND METHODS

To transfer BIM information for structural purposes while maintaining the meaning of different pieces of information in the extraction, the research methodology involves (1) preparation of the BIM model, (2) conversion of the model into IFC file format (3) identifying exchange requirements (4) development of the framework for parsing ifc file (5) execution of parsing tool.

In the first step, a BIM tool is adopted to create building model and then model is

exported as *.ifc* file. Based on the exported IFC model, for extraction of information from the architectural model, that is pertinent to the structural model, a Python code, integrated with the ifcopenshell library, was written to extract the target information that takes an IFC file as input. The reading of IFC files was accomplished by incorporating the ifcopenshell [14] into the IFC Parser program. Fig. 2 shows the workflow of indirect method for data transformation between BIM model and structural analysis model.

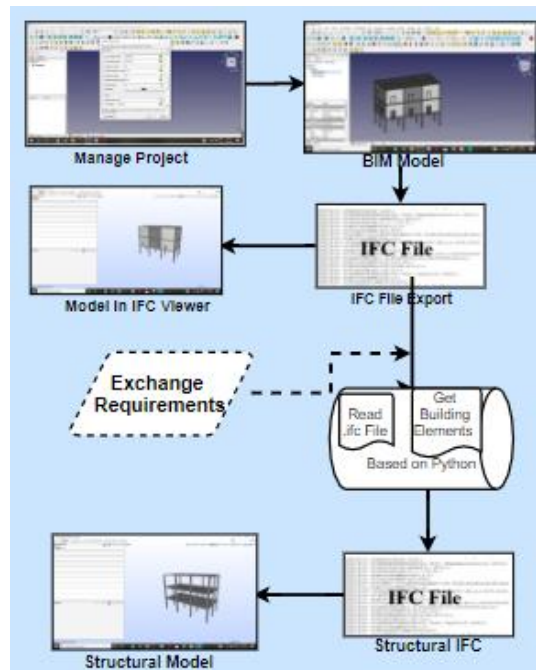


Figure 2 BIM information extraction framework

2.1. Building Model Preparation

The main requirement for the presented framework is a valid and well-formed BIM model which contains geometry and material data. The architectural model must be created to include the information necessary to the automatic achievement of the structural model. A 3D BIM-based model was prepared using FreeCAD. FreeCAD is a general-purpose parametric 3D computer-aided design (CAD) modeling tool which meets all the requirements in order to be used as an open source platform. It is extremely customizable, scriptable and extensible. New functions and open source libraries can be added without changing the main core system. It includes an inbuilt Python interpreter and thus Python code can be used in the software [15]. It can be considered to be the only open-source modeling software equivalent to the current proprietary industry tools like Revit or ArchiCAD.

It has much better support of IFC and IFC files are treated as first-class citizens in FreeCAD. [18] used FreeCAD to demonstrate how semantically driven high-level spatial constraints can directly influence precise parametric models involving a combination of topological, visibility and movement constraints. [12] used FreeCAD to illustrate the use of open source Computer-aided design (CAD) environment in order to develop BIM plug-ins to be able to import and edit digital representations of cultural heritage models derived by

photogrammetric methods.

The process of modeling as outlined in Figure 3. BIM workbench of FreeCAD was used for modeling the prototype for this study. This is external workbench which can be added through add-on manager in FreeCAD. The first step of modeling process was to define the initial settings such as grid spacing, setting the working plane and manage structural levels. Been established the bases of modeling, it is then possible to proceed to the creation of the BIM architectural model. This is initiated by the insertion of columns and the arrangement of beams on the adopted grids. The sequence of the modelling made was, first manage project, grid dimensions and structural levels then create columns, beams, walls, doors, windows and slabs. To use the architectural model as a reference model for creating BIM structural model each structural element should be modeled individually and structural behavior of elements is incorporated. All the building elements were modeled as objects and then assigned an IFC type to each of these objects based on the categories and subcategories appropriate to the elements. For example beam is assigned a type as *ifcbeam*.

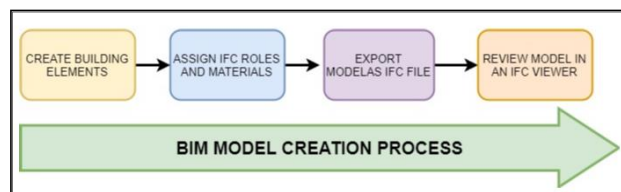


Figure 3. BIM model preparation

If beam is not assigned to the entity *Ifcbeam*, it is not allocated all the attributes that it requires to be described clearly. This means that it will not be interpreted correctly by other coordinating programs in turn. Then materials were assigned to these elements. For instance beams, columns and slabs were assigned to concrete and doors and windows to wooden materials. Architectural model was enriched with data necessary to automate the transformation procedure and to ensure that remodeling is not required when analyzing the structural behavior in structural analysis software applications. Figure 4 represents the BIM model created.

2.2. Conversion of BIM Model into IFC File Format

The architectural model is exported to IFC file format using 'Export' function of FreeCAD, which changes the model information into a general language which is understood by the structural software applications it is send to. To ensure that all information is available in the exported IFC model, the model could be reviewed in an IFC model viewer. Solibri Model viewer (SMV), open source software designed for use in BIM projects, was used to review the IFC model. This software enables to open and visualizes standard IFC file. Fig. 5 shows the exported model in this viewer. This IFC file will be used as the source of data. The IFC model provides an object-oriented and semantic data for storing and exchanging building information. IFC files depend on a schema that characterizes the things that may be present inside an IFC file and how they are related to one another. IFC is the ISO standard

arrangement for storing BIM model information. Maintained and developed by buildingSMART, IFC is an open, vendor-neutral BIM platform for the semantic information of building objects, including geometry, associated properties, and relationships mainly to focus on ease of interoperability between software platforms. IFC is described in EXPRESS language, a model description language of the ISO 10303-11.

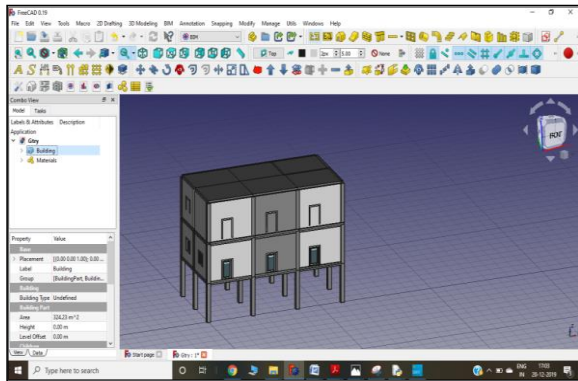


Fig. 4 BIM Model in FreeCAD

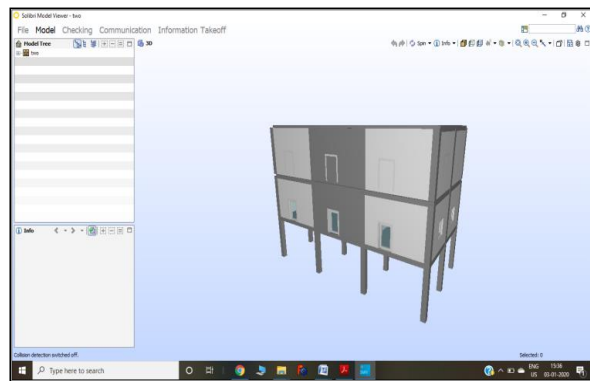


Fig. 5 Model review in Solibri model viewer

Therefore, it inherits the object-oriented programming concept of EXPRESS [17]. Moreover, the IFC data schema provides a basic modular structure to the information model and a framework for the sharing of information between various areas of the construction industry. It defines an abstract data schema and an exchange file format for BIM model information.

2.3. Exchange Requirements for Structural Model

Architecture model can store detailed information about various disciplines, however only part of information which is created by architects, is of interest to structural engineers. The structural model only requires information pertaining to structural analysis, including the global location and geometric representation, building elements' structural function, the types of materials and their properties. Information from the architectural model that is related to the structural model is detected, classified, processed and transformed to the structural model during the process of conversion between these two types of models.

In order to ensure accuracy of data exchange for structural purposes in collaborative design, the exchange requirements (ER) were identified to improve the reliability of structural design information. This step identifies the ERs for structural model. An ER is a set of information that needs to be exchanged to support domain specific requirements for a particular phase of a project. For a successful conversion, it is necessary that ERs incorporates the semantically required information for each object in that exchange. This subset of constituent IFC entities required for any given exchange and their needed definitions must be explicitly defined. Therefore, in an IFC-based BIM model, to create structural model, the target information is the global identifier, number of the IfcObject instances and the attributes associated with IfcObject instances. This work has identified objects directly relevant for

structural model generation such as ifcbeam, ifccolumn etc. Sub-elements which are necessary for establishing the relationships between elements and systems that define the object completely for example *IfcProject*, IfcRoot and IfcElement etc. were also defined. The target information was stored in an information dictionary, which is a self-defined data structure.

2.4. Framework for Parsing IFC File

The exported IFC model has been defined in EXPRESS language which is not a programming language rather it is a modeling language. Therefore, information in IFC model about buildingobjects and their attributes needs to be mapped to a programming language to support the generation of structural model. Python language is employed in this study for this purpose. For extraction of information from the architectural model, that is relevant to the structural model, an IFC Parser tool has been developed that extracts BIM objects directly from an exported IFC model primarily written in Python. IFC files are not readable by Python. The reading of IFC files was accomplished by incorporating the Ifcopenshell into the IFC Parser program [14]. Technically visualization of model could be achieved by opening the FreeCAD model using IfcOpenshell in the program.

Python is a great object-oriented, open source, flexible and easy to learn a programming language. Python is a progressively composed language, so the variables are characterized automatically. The simple syntax rules of the programming language further make it easier to keep the code base readable and application maintainable. Likewise, Python can be effortlessly coordinated with other programming languages. Its enormous and strong standard library makes Python score over other programming languages. The standard library allows you to choose from a wide range of modules according to your needs. The data visualization libraries and APIs provided by language help to visualize and present data in a more appealing and effective way. FreeCAD's use of Python as its scripting language makes it extremely flexible for modeling parts. A user without any programming background can also effectively start developing programs in Python. A code written in a language like Python provides means to extract entities from IFC instance models using the entity and attribute relations defined in the IFC schema, making it an effective tool to extract target information [18].

IfcOpenShell is an open source software library that helps users and software developers to work with the IFC file format. The format is frequently utilized for Building Information Modeling. It is a project that has a Python library that allows parsing IFC files. IfcOpenShell uses Python library to query and parse ifc files to get placement exactly as expressed in Ifc Schema. IfcOpenShell supports all IFC2x3 and IFC4 entities. It is installed in Python's library in Site packages and imported in Python interpreter by using "Import Ifcopenshell" command. It has large number of libraries and modules in it and importing all these may lead to slow

working. So, to overcome this issue, command “*Import Ifcopenshell*” is used, which will allow using libraries related to IFC only so leading to less usage of memory. IFC files are not readable by Python. These are opened in Python using *ifcopenshell*. IFC file of architectural model can be imported in two ways as

- Import File = *ifcopenshell.open(r”path\of\file”)*
- Import File = *ifc.open (r”path\of\file”)*

The tool developed for this work relies on the IFC schema and the internal data structure of the IFC-based BIM model to recursively extract IFC data instances based on its internal relations with other instances. So, the thorough knowledge of the structure of IFC schema is required. An IFC model is composed of IFC objects arranged in a tree structure. Each object in IFC schema known as IFC entity belongs to a hierarchy that helps to organize the objects in the building model. At a very simple level the schema is made up of three main items namely entities, attributes and properties. An IFC entity is a uniquely defined object in the IFC data model capable of an independent existence. Entity is similar to the term “class” in common computer languages. These entities cover information on every aspect of a building’s life-cycle. Examples of the entities include building elements such as *IfcBeam*, geometry such as *IfcDepth* and basic constructs such as *IfcDirection*. The attribute is a very important concept in IFC schema. Basically, it refers to the properties that are attached to the entity which can be either required or optional as specified by the IFC Model [19]. Fig. 6 shows a number of attributes that are attached to the entity *IfcBeam*. In this study, it is necessary to get basic understanding of those attributes. All entities which are basically object-oriented components in IFC schema are associated with properties such as name, materials, geometry, size, relationships and so on. For example, *IfcBeam* has an attribute “Object Placement” that defines the location of beam in the model.

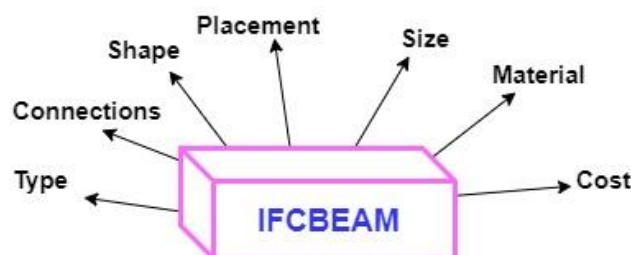


Fig. 6 Definition of attributes of a Beam

An entity has both direct and indirect attributes. An indirect attribute of an entity is inherited from the super type of the entity. For example, *IfcBeam* has an indirect attribute “Name” that is inherited from its super type *IfcRoot* [8]. In the IFC exchange file, these attributes provide the basis of defining the geometric description of a building component entity. The root of this tree is the Project entity. This means “*IfcProject*” is the topmost repository for all information in an IFC exchange file [20]. The “*IfcProject*” is not a visible

element in the schema, but it does have attributes associated with it such as *GlobalID*, *OwnerHistory*, *Name* and *Description*. In the tree structure of a building only one *IfcProject* is possible. Project may contain zero or more sites. Each site further can contain one or more buildings and each building contains one or more building stories. The underlying concept of entities and attributes in IFC is illustrated in Fig. 7. The most abstract entity in the IFC model is *IfcRoot*, which is super type of all entities. Abstract entities are the entities that cannot exist in themselves but only as one of their subtypes. The main abstract entities in this figure are represented in green.

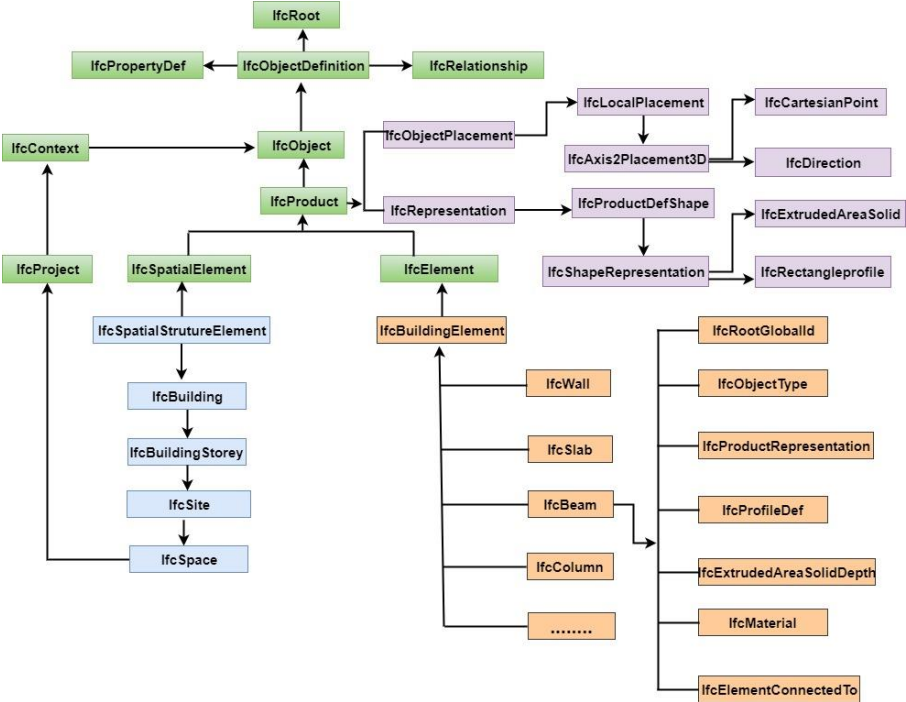


Fig. 7 Project hierarchy in IFC Schema

IfcRoot is the parent for three subtypes, *IfcPropertyDef*, *IfcObjectDef*, and *IfcRelationship*. These are the most important concepts in IFC Model. *IfcPropertyDef* describes all characteristics that may be attached to entities, *IfcObjectDef* is the generalization of all physical objects or processes and *IfcRelationship* explains all relationships among various objects. The *IfcProduct* derived from *IfcObjectDef*, defines the common type information among all building products. *IfcRepresentation* and *IfcObjectPlacement* derived from *IfcProduct*, usually hold geometric representation and placement of a building component in space. It is determined by the various subtypes of *IfcObjectPlacement*, such as *IfcAxis2Placement2D*, *IfcAxis2Placement3D* and *IfcLocalPlacement*. These entities and their subclasses are shown purple in Fig. 7. The actual position of the any *IfcProduct* instance can be located by *IfcLocalPlacement* entity. In the IFC instance model, *IfcSpatialElement* and *IfcElement* belong to *IfcProduct*. Therefore, the product information should be obtained before getting the elements' information. As a subtype of *IfcElement*, *IfcBuildingElement* has same attribute as *IfcElement*. That means all the attributes are inherited from the entities of supertypes. Entity

IfcBuildingElement is the major functional part of a building defined to model physical information in the IFC standard. The building elements included are beam, wall, column, slab, door, window, roof, etc. This entity and its subclasses are depicted in orange in Fig. 7. The IFC spatial structure is provided by *IfcSpatialStructureElement* entity. *IfcSpatialStructureElement* is the super type to four entities as *IfcBuilding*, *IfcBuildingStory*, *IfcSpace* and *IfcSite* (shown as blue in Fig. 7) which are crucial for organizing building elements inside the IFC Model. The *IfcProject*, *IfcBuilding* and *IfcBuildingStorey* are mandatory levels for the exchange of project data; however the *IfcSite* and *IfcSpace* represent optional levels to transfer (which may be extracted, if they have required data) [6]. Authors would like to mention that the Fig. 7 represents only an abstraction of IFC schema defining inheritance of some important entities and some of their attributes. The purpose of the diagram is to make understanding of complex IFC schema as simple as possible.

2.5. Execution of Parsing Tool

The process of extraction starts with querying the *IfcProject* instance in the input IFC file and finding, respectively, *IfcSite*, *IfcBuilding*, *IfcBuildingStorey* and *IfcBeam* entities contained in the building stories and so on. Figure 8 shows how the parser tool identifies the top level *IfcProject* entity and then moves down through the tree extracting the *IfcSite*, *IfcBuilding*, *IfcBuildingStorey*, *IfcSpace* entities and so on. In this work, the extracted structural building elements consist of reinforced concrete columns, beams and slabs as well as nonphysical IFC entities associated with the selected building elements.

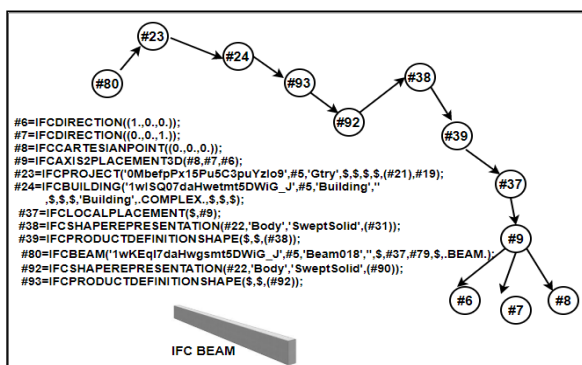


Figure 7 Entity relationships for IFCBEAM

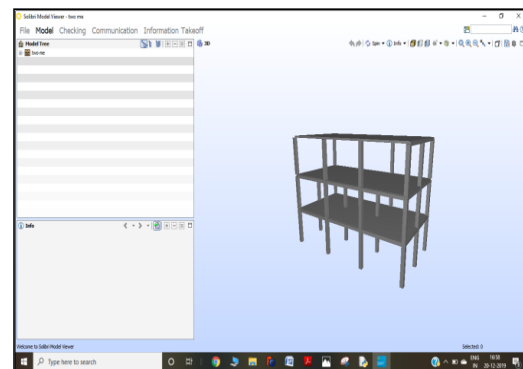


Figure 8 Extracted Structural Model

The execution of IFC Parser tool generates an .ifc file to make the output file usable by a wide range of BIM software. After the generation of IFC file the structural model was imported from IFC file in Solibri model viewer. This structural model is shown in Fig. 8. This will provide the structural engineers with an information model required for structural analysis and design purposes.

3. CONCLUSION

There is no doubt that BIM is a revolutionary concept. However, to achieve the full potential of BIM and to keep pace with the growing technology, BIM interoperability and data

exchange is still a research challenge. As most of building models come only in proprietary formats, so they can only be used in the BIM authoring tool for which they have been created. To address this issue, the study presented a framework for generating the structural model of a building from its architectural building information model based on the use of free open source applications. For the implementation of the tools, the Python language and the open source library IfcOpenShell were used to develop an IFC parser tool. In the proposed approach, the geometry and material information needed to build structural model was automatically parsed from an IFC based model. This paper describes the essential elements of this integrated workflow and also explains why openBIM comprises much more than just a standardized file-format. This research is expected to impact the overall interoperability of applications in the building information modeling field.

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