Automated Master Project Schedule for Construction Incorporating Building Information Model and IFC

David Cheng[1], Ernest Abbott[2], David Chua[3], and Ahmad Tashrif[4]

Abstract

At the end of a predesign phase of a building design, it is essential for the consulting firm to be able to generate from the BIM design, take-off quantities and construction activities durations efficiently at a short timeframe to derive the cost budget estimates and schedule for project tendering purpose. However, these efforts require prior construction site experience and knowledge together with their association to the BIM and IFC construction component data to automate a Master Project Schedule. The research and development of the automated master project schedule is the focus of the project which will read IFC data from a BIM application and display the model while the data are distributed to a database repository. The automated project schedule can then be generated with the activities and timeline of each building component presented by floor levels and component types. Finally, the challenges in changes in the construction methods such as precast and/or cast in-situ, and the additional building component information from BIM to IFC that provide a set of data to derive a practical project schedule are discussed while these data can also be used to estimate the bill of materials of building components. The aim of this research project is thus to enable planners to use a platform that holds and manages construction knowledge and applying BIM and IFC standards to generate a master project schedule automatically.

Keywords: automated project schedule, building design, construction activities, short timeframe, BIM, IFC data

Introduction

The Architecture, Engineering and Construction (AEC) industry today is faced with many software tools that offer to provide an integration platform to manage various aspects of planning, design and construction activities. In today’s state of such an integration, it is still evolving in the industry under the direction of BIM (Building Information Model) and IFC (Industry Foundation Classes) (buildingSMART 2014) initiatives.

Many of the BIM software are developed based on their former 3D CAD environment and there are others on new programming methodology. IFC data as a text-based neutral format for interchangeability between BIM and IFC compliant systems is the current international standard in the industry for its intended purpose. There are already a number of public software developed by research institutions as IFC data checkers, readers and viewers; these are used mainly to check if the IFC data generated by different BIM systems if the format is compliant to the format specified in the standard’s specification and version.

[1] Research Associate, National University of Singapore, Email: ceectld@nus.edu.sg
[2] Research Engineer, National University of Singapore, Email: ceeaels@nus.edu.sg
[3] Associate Professor, National University of Singapore, Email: ceedavid@nus.edu.sg
[4] Research Engineer, National University of Singapore, Email: ceeats@nus.edu.sg

BIM software also needs to keep up-to-date progressively with the higher version of the IFC data specification. These are challenges that the BIM software have to accommodate especially when IFC data interchangeability is concerned.

The IFC data are used for re-construction of the BIM model in another platform, for example, an Architectural design, Structural components' model and others in the AEC discipline where besides geometrical information there are information such as sizes, area, material descriptions, height as found in the IFC data standard specification that one can derive many other information needed for engineering and quantitative calculations.

These objectives of this paper are (1) to demonstrate that the use of IFC data in a BIM software can be applied to perform a project schedule construction knowledge computation with the use of a database system and (2) to generate a master project schedule from the IFC data / database. As the BIM software used in the prototype is a development platform, many programming algorithms can also be applied to achieve its purpose such as intelligent design analysis to check for compliance to building codes and public authorities' requirements such as boundary's setback and as fire escape route.

The focus here is on the planning stage of a building development project where a master project schedule derivation using IFC data, project management time duration precedence and database system can support the building developer and its consultant with a cost budgeting estimates' expectation and over an estimated duration to complete a proposed building project. As the prototype is at its current stage to prove this approach, the coverage is thus limited to structural building components.

The logistics in assembling the BIM model in this paper are EyeShot (EyeShot 2014) software (a development software and modeler that is coded in C# object programming to manage BIM classes and entities), IFC data convertor to EyeShot (http://www.devdept.com/ where an IFC convertor had been developed to accept specific IFC data object type and property information), MySQL (a database system to store and manage IFC data and construction knowledge), C# programming within MS Visual Studio 2012 (to provide algorithms for computing that re-organize the database) and extracted data to generate the project schedule using a developed software MyPlanDo (David Chua 2013) and .NET framework 4.5.

Industry Review

A number of literature reviews had shown that most BIM software had their own IFC importer. The IFC data after importing are usually reference models that one has to select and incorporate into the BIM 3D model environment before more work can be carried out such as modeling the model from the IFC data.

There are many IFC Viewers and Readers which are published in the public domain to support users to verify if the IFC data file is compliant to specific versions. Some are black-boxes and there is no further work can be done on them by adopters. Some provide IFC libraries for adoption by programmers to develop an IFC importer but specific programming language has to be used in order to make the IFC libraries work properly in the development environment. Unfortunately the original developer response to any queries is usually slow.

It would be good for companies in the BIM and IFC industry to develop IFC libraries and other IFC Viewers and Readers and share them in a common repository so that the AEC industry can move quicker into BIM with interchangeability between BIM software.

The Approach

The prototype is developed using industry standards' tools and data format that are acceptable by the AEC industry. In this respect, BIM concept and IFC data specifications were studied and applied through the adoption of a BIM development platform (EyeShot) by the university and importing IFC data and re-organizing the data to database, in this case, MySQL is adopted. The theory behind the approach is no stranger to many as in project management there is a need to understand precedence network and the calculation of the dates of activity sequences and time duration.

The approach is modeled in the diagram as shown in

Figure 9 which is self-explanatory. The IFC import routine was developed in EyeShot and it is configured to read and filter out non-essential information. The IFC data files were generated by other BIM software such as Revit. This is intentional as it was from here that the appropriate IFC data format version IFC2X3 was based on for importing to EyeShot and according to the widely used industry BIM tool Revit. After several tests to convert IFC data to BIM software, the IFC importer developed under EyeShot was observed to work as intended after minor enhancements to it when better understanding of the way the properties are organized.

<u>The IFC Data Importer</u>

The IFC Data Importer, at the current moment, reads in the following main building component types and their properties are briefly described below:

a) Component Type : Beam, BeamStandardCase, Column, ColumnStandardCase - Name - Description - IsDefinedBy o IfcRelDefinesByProperties • RelatingPropertyDefinition • Name o BASEQUANTITIES ▪ NOMINALLENGTH ▪ LENGTH ▪ CROSSSECTIONAREA ▪ OUTERSURFACEAREA ▪ TOTALSURFACEAREA ▪ GROSSVOLUME ▪ NETVOLUME ▪ GROSSWEIGHT ▪ NETWEIGHT o PSET_REVIT_DIMENSIONS o DIMENSIONS ▪ L ▪ B ▪ H ▪ V ▪ LENGTH ▪ BREADTH ▪ HEIGHT ▪ VOLUME	b) Component Type: Wall, WallStandardCase - Name - Description - IsDefinedBy o IfcRelDefinesByProperties • RelatingPropertyDefinition • Name o BASEQUANTITIES ▪ NOMINALLENGTH ▪ LENGTH ▪ NOMINALWIDTH ▪ NOMINALHEIGHT ▪ GROSSFOOTPRINTAREA ▪ CROSSSECTIONAREA ▪ NETFOOTPRINTAREA ▪ GROSSSIDEAREA ▪ NETSIDEAREA ▪ GROSSSIDEAREALEFT ▪ NETSIDEAREALEFT ▪ GROSSSIDEAREARIGHT ▪ NETSIDEAREARIGHT ▪ GROSSVOLUME ▪ NETVOLUME o PSET_REVIT_DIMENSIONS o DIMENSIONS ▪ L ▪ B ▪ H ▪ V ▪ LENGTH ▪ BREADTH ▪ HEIGHT

	▪ VOLUME

c) Component Type: Slab, SlabStandardCase - Name - Description - IsDefinedBy o IfcRelDefinesByProperties • RelatingPropertyDefinition • Name o BASEQUANTITIES ▪ NOMINALLENGTH ▪ LENGTH ▪ PERIMETER ▪ GROSSFOOTPRINTAREA ▪ NETFOOTPRINTAREA ▪ GROSSVOLUME ▪ NETVOLUME ▪ GROSSWEIGHT ▪ NETWEIGHT o PSET_REVIT_DIMENSIONS o DIMENSIONS ▪ L ▪ B ▪ H ▪ V ▪ LENGTH ▪ BREADTH ▪ HEIGHT ▪ VOLUME	d) Component Type: Stair, StairFlight - Name - Description - IsDefinedBy o IfcRelDefinesByProperties • RelatingPropertyDefinition • Name o BASEQUANTITIES ▪ NUMBEROFRISERS ▪ RISERS ▪ NUMBEROFTREADS ▪ RISERHEIGHT ▪ TREADLENGTH o PSET_REVIT_DIMENSIONS o DIMENSIONS ▪ L ▪ B ▪ H ▪ V ▪ LENGTH ▪ BREADTH ▪ HEIGHT ▪ VOLUME

Other property types in the IFC file are scanned and pre-processed at the same time while others such as component types as in ramp, curtain wall, door, roof, footing, pile, plate, railing, space, windows and others, would be used in future enhancement.

After importing the IFC data into EyeShot, the 3D BIM model can be viewed, inspected and accepted for writing to the database tables named under each of the component types including their GUIDs, elevations, levels, component types and physical detailed properties. So basically the IFC model is now stored in the database. The database is further described in the next section “Database Preparation”.

Another module of the prototype is the Construction Knowledge (CK) application which is developed to assign construction methods to the building component types such as Prefab or/and Cast In-situ methods and these are maintainable through a Maintenance module.

When the CK module is launched, EyeShot is also launched to provide the 3D BIM model view on selection of a project model of interest to the user. The project model is then retrieved via the database and its 3D graphics are then re-constructed in its 3D viewport. At the same time, a tree-view window presented on the side of the interface maps the graphic 3D entities in a hierarchical graph form where one can traverse to identify the component and its location in the 3D viewport and vice versa for more object details.

Database Preparation

Preparation of the database was required so that the imported IFC data can be distributed to the respective database tables in MySQL.

A database “IFCBUILDINGDATA” was created with 14 tables and 1 view to store and re-organize the IFC dataset.

A database “CONSTRUCTIONKNOWLEDGE” was created with 10 tables as activities template for which on acceptance of the set of activities they are written onto one of the columns in table “ifcconstructionknowledge” located in the database “IFCBUILDINGDATA” such as <A, Activity <n>, Duration;> format. The construction method that goes by the notation in-situ <building component-type> or prefab <building component-type> can be re-sequenced as required. <Building component-type> is either beam or slab or column or wall or stair.

A database “SCHEDULEDB” was also created with 3 main tables for formatting the IFC and construction knowledge data that are consolidated to one of its tables to enable a project schedule application to retrieve, manage and plot the project schedule (Gantt chart). This will be described in another section “The Project Schedule Generated Automatically”.

The IFC Importer and Modeler

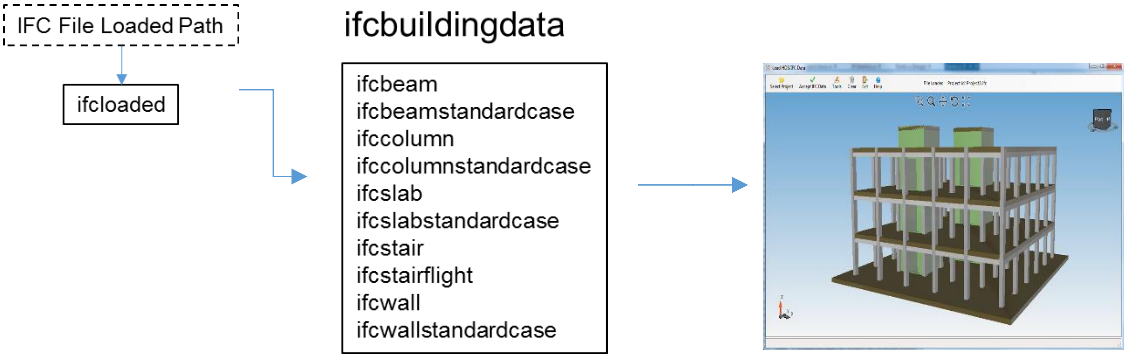


Figure 1. IFC data file loaded and viewed

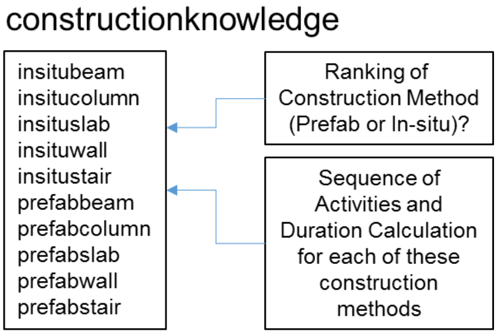
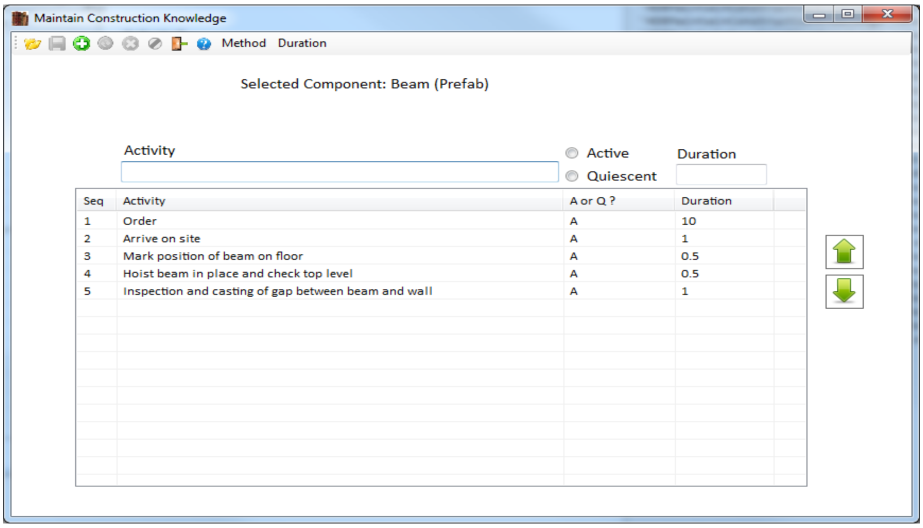

constructionknowledge
insitubeam
insitucolumn
insituslab
insituwall
insitustair
prefabbeam
prefabcolumn
prefabslab
prefabwall
prefabstair
Ranking of Construction Method (Prefab or In-situ)?
Sequence of Activities and Duration Calculation for each of these construction methods

Figure 2. Construction Knowledge table

In the viewport as shown in Figure 2, each building component type can be assigned different construction methods such as prefab or cast in-situ as a group for walls, slabs, columns, beams and stairs. Even the individual component such as “Concrete-Rectangular-Column: 300 x 450mm:300 x 450mm:147467” can also be assigned specific construction method (Figure 3). As for this prototype example, the building component types are grouped as prefab “Column” (shown in one color type) within a specific floor level. However if some columns within this floor are required to have a different construction method such as in-situ, one can select the component and change the columns from prefab to in-situ. Because of the construction methods ranking setup, the project schedule will place the construction sequence according to the ranking rule.

Maintenance of the Activity Sequence



Selected Component: Beam (Prefab)

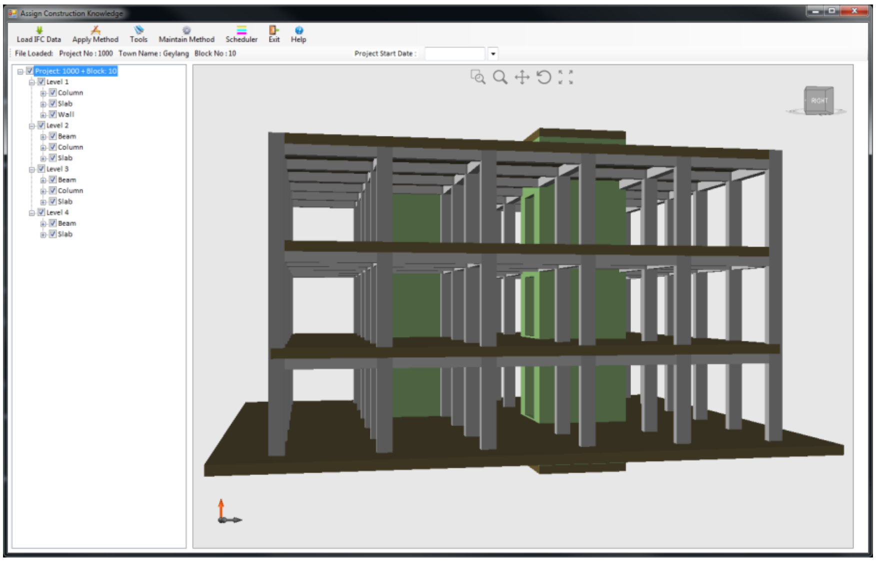
Seq	Activity	A or Q ?	Duration
1	Order	A	10
2	Arrive on site	A	1
3	Mark position of beam on floor	A	0.5
4	Hoist beam in place and check top level	A	0.5
5	Inspection and casting of gap between beam and wall	A	1

Figure 3. Activity Sequence Setup

The Activities for each building component types can be modified and set up according to the project planner's experience on construction site. The activity sequence that describes them using the <A, Activity <n>, Duration;> format can be easily maintained and even change to practical activity descriptions which are currently used in a typical construction project. The term A or Q was reserved for future purpose although it may change. 'A' is active that denotes active activity in the process.

Assignment of Construction Methods

Before assignment of construction methods to each of the building component types, the pre-defined construction methods in the preceding section on Maintenance are set up according to prefab or in-situ, and their activity sequence planned for.



File Loaded: Project No : 1000 Town Name : Geylang Block No : 10

Figure 4. Before assignment of construction methods to the building component types

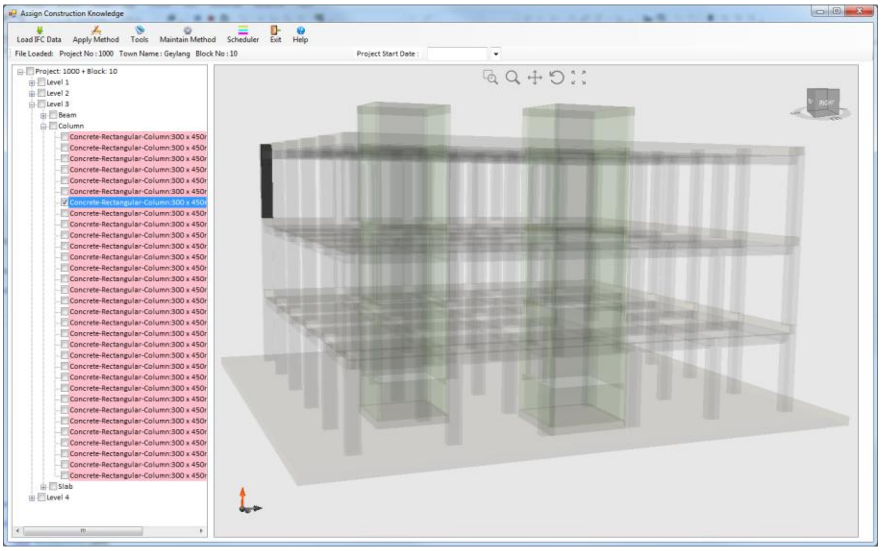
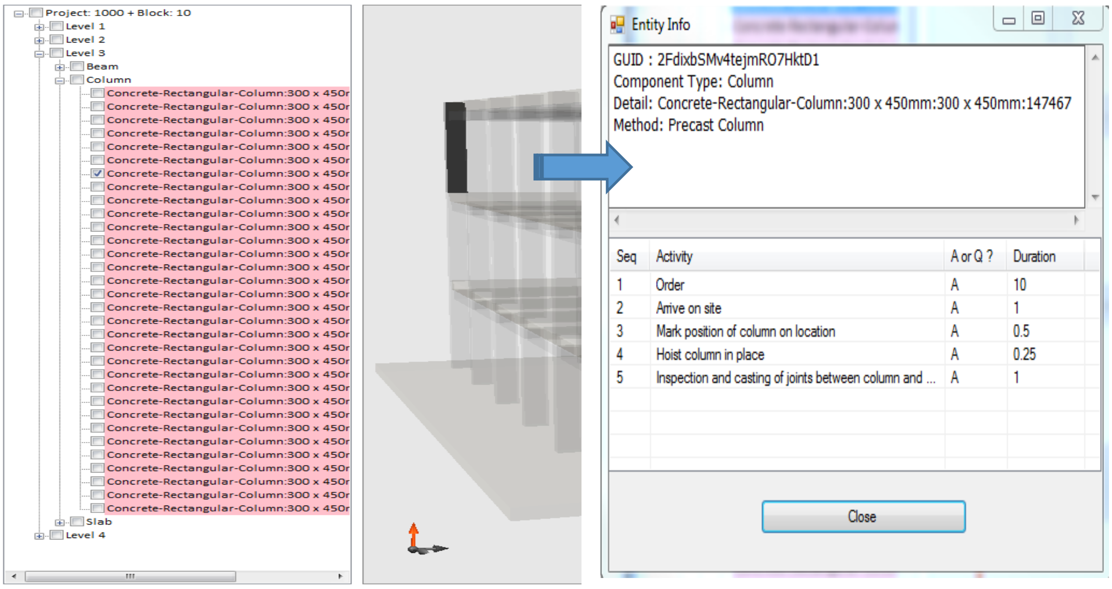

Assign Construction Knowledge
Load IFC Data
Apply Method
Tools
Maintain Method
Scheduler
Exit
Help
File Loaded: Project No : 1000 Town Name : Geylang Block No : 10
Project Start Date :
Project: 1000 + Block: 10
Level 1
Level 2
Level 3
Beam
Column
Concrete-Rectangular-Column:300 x 450r
Slab
Level 4

Figure 5. After assignment of construction methods to the building component types

For example, a building component on the 3D view as an object can be selected and in the tree-view its component description is thus highlighted on the left window revealing at which level it belongs to while also showing the activities sequences and object description.

The activity sequence for a typical building component type on selection is highlighted or checked with a pop-up window for its brief information, as shown below:


Project: 1000 + Block: 10
Level 1
Level 2
Level 3
Beam
Column
Concrete-Rectangular-Column:300 x 450r
Slab
Level 4
Entity Info
Close

GUID : 2FdixbSMv4tejmRO7HktD1
Component Type: Column
Detail: Concrete-Rectangular-Column:300 x 450mm:300 x 450mm:147467
Method: Precast Column

Seq	Activity	A or Q ?	Duration
1	Order	A	10
2	Arrive on site	A	1
3	Mark position of column on location	A	0.5
4	Hoist column in place	A	0.25
5	Inspection and casting of joints between column and ...	A	1

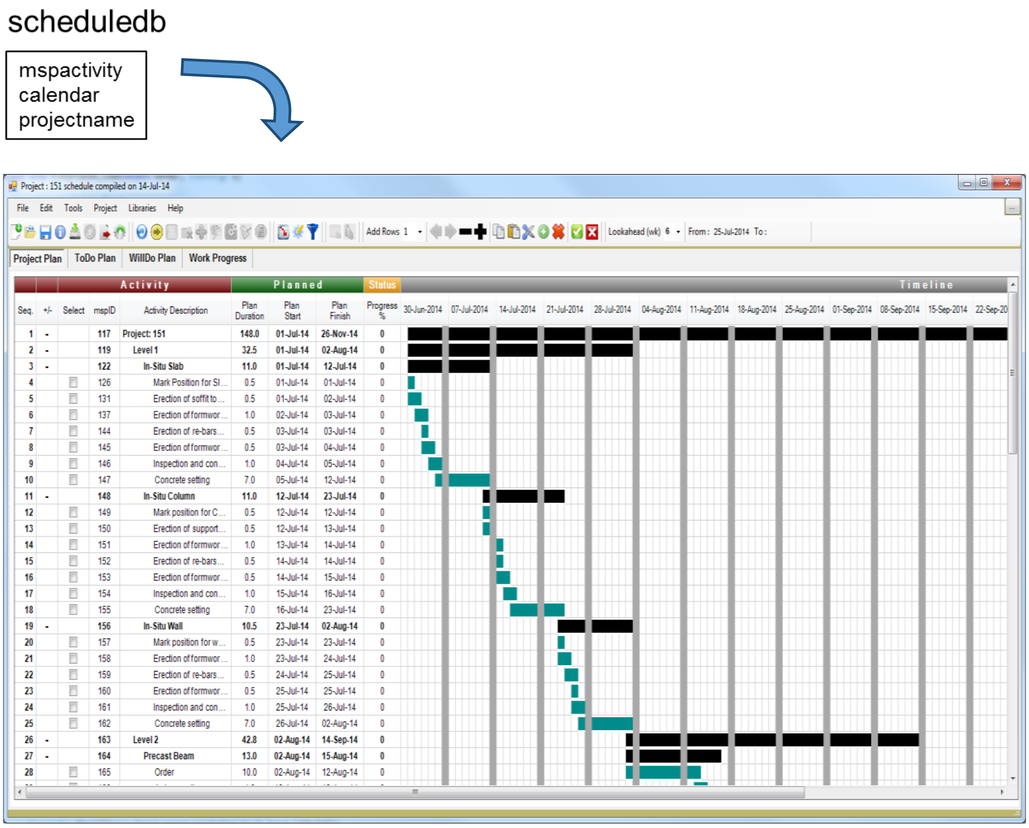
Figure 6. Highlighted Building component and its information on pop-up window

After assignment of construction methods and activity sequences, the 3D BIM model and its construction methods can then be written to the “SCHEDULEDB” tables with project schedule data format in mind such as MS Project. The computation consideration before writing to the database tables is to consolidate the total number of activities to construct each building component and which construction methods to start first that is ranked accordingly in the database table.

The database “CONSTRUCTIONKNOWLEDGE” together with the programming of Winforms in C# allows users to re-organize the construction activities sequence to reflect the practical experience in construction. The application (MyPlanDo) which is a project resulted from another university researcher’s work reads directly from the scheduledb table “MSPACTIVITY” which had already stored the project schedule activities data and retrieve and plot as a project Gantt chart. The MyPlanDo works with MS Project or any other project software that generates the mpp file format. What happens here is that the mpp data are actually been distributed to the scheduled table “MSPACTIVITY” after it is loaded into MyPlanDo.

The Project Schedule Generated Automatically

What the project prototype has done is incorporating IFC Importer into EyeShot for planners to assign construction methods and detail activity sequencing after which the planner can compile all these data by generating a set of data that is ready for MyPlanDo to read and construct the Project Schedule Gantt Chart layout for further planning though MyPlanDo has many other offerings such as PPC (Production Planning & Control), Constraint Management, Tracking and management of activities and others that are not covered in this paper. The prototype is also enhancing the usage of MyPlanDo as a Project Schedule generator via the BIM/IFC approach with interfacing between the BIM software EyeShot and MyPlanDo. The automated project schedule derived from the database is plotted as a Gantt Chart is shown below:



Seq.	+/-	Select	mspID	Activity Description	Plan Duration	Plan Start	Plan Finish	Progress %
1	-		117	Project: 151	148.0	01-Jul-14	26-Nov-14	0
2	-		119	Level 1	32.5	01-Jul-14	02-Aug-14	0
3	-		122	In-Situ Slab	11.0	01-Jul-14	12-Jul-14	0
4		□	126	Mark Position for Sl ...	0.5	01-Jul-14	01-Jul-14	0
5		□	131	Erection of soffit to ...	0.5	01-Jul-14	02-Jul-14	0
6		□	137	Erection of formwor ...	1.0	02-Jul-14	03-Jul-14	0
7		□	144	Erection of re-bars ...	0.5	03-Jul-14	03-Jul-14	0
8		□	145	Erection of formwor ...	0.5	03-Jul-14	04-Jul-14	0
9		□	146	Inspection and con ...	1.0	04-Jul-14	05-Jul-14	0
10		□	147	Concrete setting	7.0	05-Jul-14	12-Jul-14	0
11	-		148	In-Situ Column	11.0	12-Jul-14	23-Jul-14	0
12		□	149	Mark position for C ...	0.5	12-Jul-14	12-Jul-14	0
13		□	150	Erection of support ...	0.5	12-Jul-14	13-Jul-14	0
14		□	151	Erection of formwor ...	1.0	13-Jul-14	14-Jul-14	0
15		□	152	Erection of re-bars ...	0.5	14-Jul-14	14-Jul-14	0
16		□	153	Erection of formwor ...	0.5	14-Jul-14	15-Jul-14	0
17		□	154	Inspection and con ...	1.0	15-Jul-14	16-Jul-14	0
18		□	155	Concrete setting	7.0	16-Jul-14	23-Jul-14	0
19	-		156	In-Situ Wall	10.5	23-Jul-14	02-Aug-14	0
20		□	157	Mark position for w ...	0.5	23-Jul-14	23-Jul-14	0
21		□	158	Erection of formwor ...	1.0	23-Jul-14	24-Jul-14	0
22		□	159	Erection of re-bars ...	0.5	24-Jul-14	25-Jul-14	0
23		□	160	Erection of formwor ...	0.5	25-Jul-14	25-Jul-14	0
24		□	161	Inspection and con ...	1.0	25-Jul-14	26-Jul-14	0
25		□	162	Concrete setting	7.0	26-Jul-14	02-Aug-14	0
26	-		163	Level 2	42.8	02-Aug-14	14-Sep-14	0
27	-		164	Precast Beam	13.0	02-Aug-14	15-Aug-14	0
28		□	165	Order	10.0	02-Aug-14	12-Aug-14	0

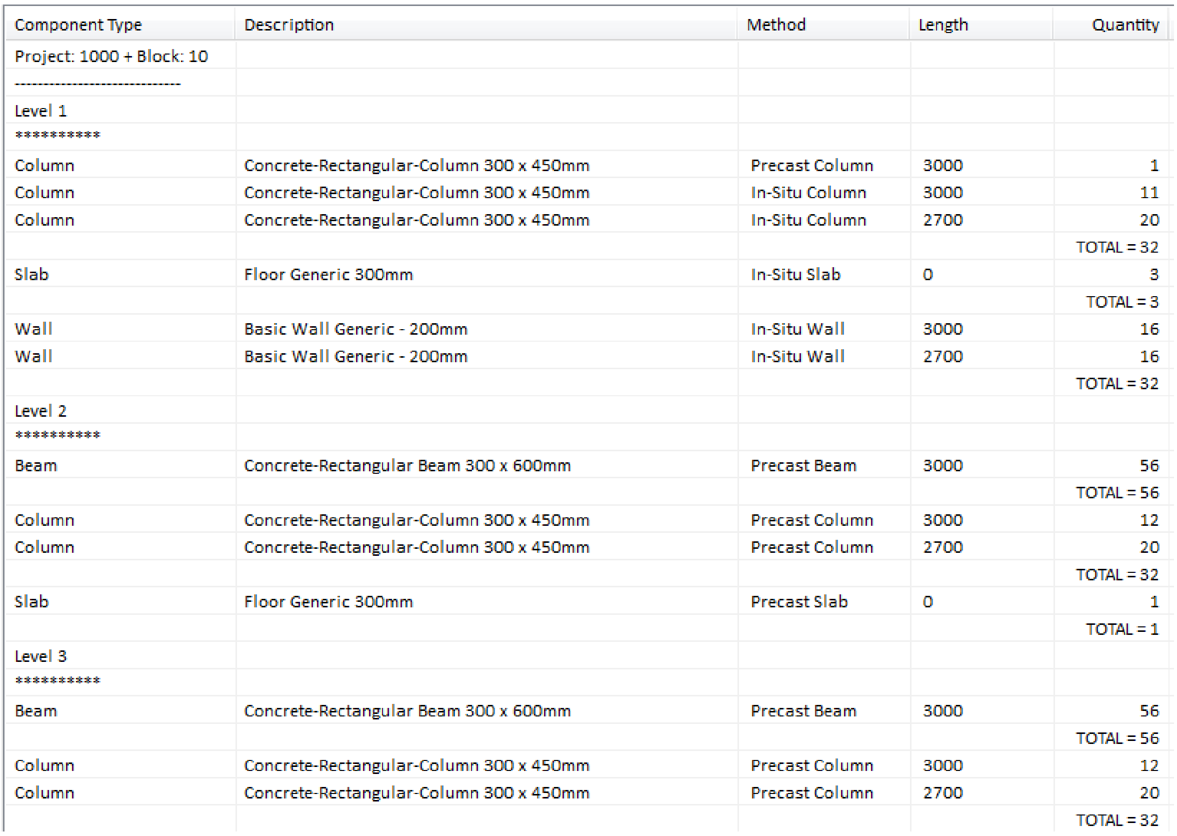
Figure 7. MyPlanDo – Project Schedule Generated

In the EyeShot platform, the Quantity take-off for the number of columns, beams, walls, stairs and slabs can be easily calculated and presented by floor levels and grouped under each building component type. From the tree-view, one can also observe the quantities involved for each of the building components.

Quantity Take-off from the Project Model

More details such as costs estimation and component descriptions can be included in the quantity table. A sample output is presented below for a simple quantity take-off. With this table, the proposed project cost estimates for the structural components can be derived. If the IFC data with regards to geometry data are accurate the bill of materials derived from the system would be useful for cost calculation and analysis, determining the number of precast components, calculating the volume and weight of components, and so forth.

It is also extendable to include filtering of the information report types to provide different views of quantitative reports. An example is shown in Figure 8.



Component Type	Description	Method	Length	Quantity
Project: 1000 + Block: 10				

Level 1				
**********				
Column	Concrete-Rectangular-Column 300 x 450mm	Precast Column	3000	1
Column	Concrete-Rectangular-Column 300 x 450mm	In-Situ Column	3000	11
Column	Concrete-Rectangular-Column 300 x 450mm	In-Situ Column	2700	20
				TOTAL = 32
Slab	Floor Generic 300mm	In-Situ Slab	0	3
				TOTAL = 3
Wall	Basic Wall Generic - 200mm	In-Situ Wall	3000	16
Wall	Basic Wall Generic - 200mm	In-Situ Wall	2700	16
				TOTAL = 32
Level 2				
**********				
Beam	Concrete-Rectangular Beam 300 x 600mm	Precast Beam	3000	56
				TOTAL = 56
Column	Concrete-Rectangular-Column 300 x 450mm	Precast Column	3000	12
Column	Concrete-Rectangular-Column 300 x 450mm	Precast Column	2700	20
				TOTAL = 32
Slab	Floor Generic 300mm	Precast Slab	0	1
				TOTAL = 1
Level 3				
**********				
Beam	Concrete-Rectangular Beam 300 x 600mm	Precast Beam	3000	56
				TOTAL = 56
Column	Concrete-Rectangular-Column 300 x 450mm	Precast Column	3000	12
Column	Concrete-Rectangular-Column 300 x 450mm	Precast Column	2700	20
				TOTAL = 32

Figure 8: Bill of Quantities for Precast and Cast-In-Situ Concrete Component Types

Practical Application

The prototype was modeled using the workflow diagramming and presented in

Figure 9:

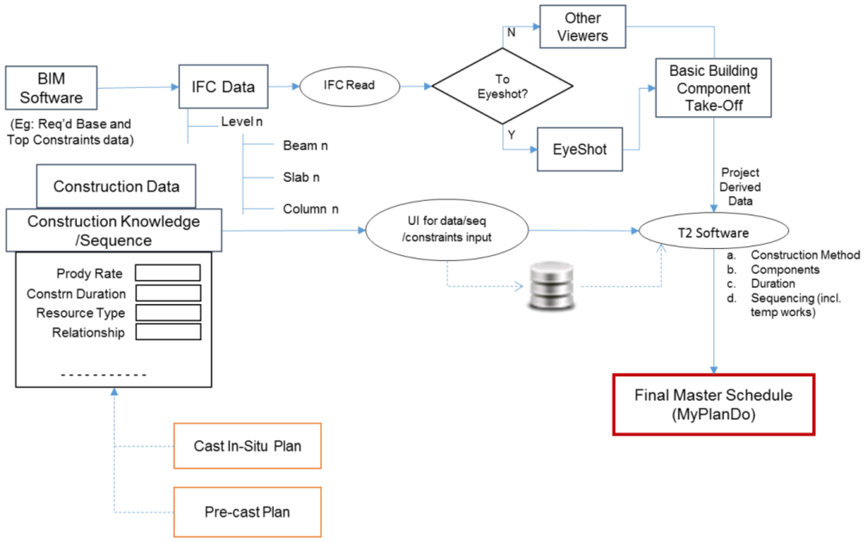


Figure 9: Prototype workflow diagram

It is established that this workflow can govern how the project can be routed from one stage to another providing a quick approach to establish a proposed project with a master project schedule generated automatically, to perform and compute quantity take-off for its building components, to analyze the costs for the project main building components taking into account the pre- and post-construction activities, and to consolidate the number of precast components to order or make. Any other project schedule analysis can be carried out within MyPlanDo.

Research Project’s Strengths and Weaknesses

The research carried out in this paper has shown that its strength is its flexibility to use a platform such as EyeShot where an IFC read module is developed to read IFC data. This extracted data becomes the heart of the BIM model in EyeShot as the building components can be assigned to construction methods (precast or cast in-situ) if the original source of the IFC data source does not include them. As a development platform the programming codes can be easily customized to suit the requirements in reading and manipulating IFC data and project scheduling. The research overall strength is the ability to integrate developed modules and connectivity to IFC database as in MySQL or any other database brands. It is also not the purpose in this project to develop a project management software. Thus an export routine to project software such as MS Project via CSV format is developed as part of the environment although not discussed in the paper. MyPlanDo which retrieves the master project schedule is used to verify the schedule generated by the EyeShot platform.

The module developed for the reading of IFC data was integrated by adopting a third-party IFC DLL engine, and adapted in this research with own codes integrating the DLL. After understanding the philosophy of the DLL, its usage became easier than the initial stage of using it.

The research also enables the bill of quantities to be easily consolidated and various reports can be derived such as total and sub-total number of precast elements, for example.

It is not the intent of the research to compete with commercial BIM software and project management software. Instead it demonstrates the usage of an “open” platform to enable planners to apply, hold and manage construction knowledge and applying BIM and IFC standards to generate a master project schedule automatically.

Conclusion

It has been shown that for an IFC data file of a proposed project, the planner can adopt the workflow process to view, inspect and accept the BIM 3D model. Following this the assignment of construction methods that contain their specific activity sequence can be carried out for the building components. This is an important stage as it allows the project planner to assign methods and activity sequence according to their prior or current site experience for setting up as construction knowledge provided by the knowledge and experience of site managers.

These set of construction knowledge and the IFC data can be analyzed and computed with the transformed dataset and write into the database.

As a result, when using a project schedule application (developed or commercial) that reads project data from the database, an automated master project schedule can thus be derived. For further work, the following enhancement can be implemented in the future:

Future work to increase its functions are:

- Enhancement to construction knowledge and precedence diagram concept to provide better project scheduling as currently only the finish-to-start and start-to-start relationships are implemented.
- Importing more IFC data types such as ifcramp, ifccurtainwall, ifcfooting, ifcpile, ifcspace and others for wider scope of coverage.
- Importing IFC data for other engineering disciplines such as MEP, QS and Architecture.
- Comprehensive quantity take-off.

References

David K.H. Chua, Q. T.-W. (2013). PLAN-IT – A game approach to teaching last planner planner methodology and lean construction. *EPPM.*

Eva Mikulakova, M. K. (2010). Knowledge-based schedule generation and evaluation. *Advanced Engineering Informatics*.

Hegazy, T. (2006). Simplified Project Management for Construction Practioners. *Cost Engineering*.

Kim, H. A. (2013). Generating construction schedules through automatic data extraction using open BIM (building information modeling) technology. *Automation in Construction*.

Joseph J. Moder, C. R. (1983). Project management with CPM, PERT and Precedence Diagramming Third Edition. *New York: Van Nostrand Reinhold Company Inc.*

Nawari, N. O. (2012). BIM-Model checking in building design. *Structures Congress.*

Phatsaphan Charnwasununth, T. N. (2013). Knowledge and skill requirements in the installation of prefabricated members. *International Journal of Civil Engineering and Technology (IJCIET)*, 156 – 176.

Industry Foundation Classes (IFC) data model — buildingSMART. 2014. Industry Foundation Classes (IFC) data model — buildingSMART. [ONLINE] Available at: http://www.buildingsmart.org/standards/ifc. [Accessed 15 May 2014].

EyeShot. *3D Graphics and CAD components for the Microsoft .NET Framework - devDept Software S.a.s.* Retrieved from www.devdept.com: http://www.devdept.com/ [Accessed 02 May 2014].