Analyzing Capacity of BIM Tools to Support Data Use across Project Lifecycle

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ABSTRACT: The lifecycle of a building project, from design through inception and facility management, comprises multiple project management processes where data and information are defined and generated. This information is often only developed and stored in a format and at a level of detail sufficient for the process that it was created, leading to the reworking of information to support later project processes. In order to support processes throughout the project lifecycle, there needs to be a method of structuring and storing information that takes into account information needs at later project processes. This paper examines the use of BIM tools and the methods used to record, recall, manipulate, and generate information to support processes through the project lifecycle. The benefit of a structured information system based upon process information needs is explored as to how it can enhance the use of information within a BIM to support lifecycle processes.

1 INTRODUCTION

Lifecycle management can be defined as a process that incorporates all phases of a project from design through facility management with information exchange and communication between all parties (Guo, et al, 2008). Through the lifecycle of a building project, large amounts of information are produced at various project phases (design, estimating, planning/scheduling, etc.). This information is often fragmented and is mainly used during the project it was created for. This causes lost time and use of resources needed to regenerate the same information for other project phases. Deng, et al. (2001) indicated that time and money are wasted in construction projects due to poor communication and inadequate information exchange between parties.

The use of Building Information Models (BIMs) conceptualizes lifecycle management principles with the use of information-rich digital models to exchange information between parties in support of the lifecycle of a project. The United States' Association of General Contractors (AGC) (Ernstrom et al, 2006) defines BIM as "*a data-rich, object-oriented, intelligent and parametric digital representation of a facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility*." The use of BIM within the construction industry is expanding but the primary uses remain 4D simulation, costing data/estimates, and collision detection (Young et al, 2008). These uses are valuable for saving time and money in coordinating information and reducing change orders, but they are far from the full potential that BIM has to offer in supporting the lifecycle of the project.

Current research efforts dealing with the enhancement of information management within the construction industry do little to enhance information management in support of lifecycle management at the project scale. Digital models and BIMs have been used to manage information during individual project processes through 4D models, simulations, and other virtual prototyping techniques for reviewing plans and schedules (Koo, et al, 2007; Hu, et al, 2008). They have also been used to aid in information coordination between trades (Leicht, et al, 2008) and tracking production performance in terms of cost and delays (Zhang, et al, 2008;Staub-French, et al, 2003; Norberg & Olofsson, 2008). These efforts are valuable for individual processes but leave the remaining project processes fragmented from one another.

Lifecycle processes within this research are defined as processes that require the review, manipulation, or creation of information such as estimating, scheduling, and material procurement by different project players. In order for BIM to truly support the project lifecycle and facilitate information communication across various project phases, two main objectives need to be accomplished.

1. Information needed to support communication among project players at various phases of the project lifecycle should be indentified

and categorized using a standardized classification system that is mapped to project assemblies within a hierarchical system. This framework can then be integrated into the various BIM applications to provide a framework for defining project information.

2. Project data, generated or input by users, should be defined at a level of granularity that would allow for flexible tracking and retrieval of information across the lifecycle of the project without the need for regeneration or reformatting of the information.

This paper investigates concepts for improving information usage through the lifecycle of a project. The linking of information to project assemblies and information processes as well as the importance of indentifying formatting needs are discussed. This paper also investigates the capacity of three common BIM software packages (AutoCAD™ REVIT, Bentley™ Architecture, and VICO™ Constructor) to meet the two objectives set forth above. The study aims at indentifying and reviewing the data structure of these tools and features related to defining and linking project data to CAD objects and the flexibility of defining the information at various levels of granularity to allow for ease of retrieval and use during other project management processes downstream. The limitations of these applications in their support of lifecycle processes are also identified.

2 INFORMATION FRAGMENTATION

Currently, there is no standard framework that integrates project assemblies with lifecycle processes and project information for the A/E/C industry. An example of such framework would link each lifecycle process with information to support that process for a given project assembly (Figure 1). For instance, various pieces of information associated with steel rebar in a reinforced cast-in-place concrete assembly would vary for different lifecycle processes. For estimating, a quantity and unit cost of steel is required. For scheduling, a quantity of an area of the assembly as well as the production rate from the crew is required. For material procurement, each quantity of rebar size needs to correspond to a work task within the schedule to ensure that the proper quantities are ordered and delivered on time. This example shows that each lifecycle processes require different information for making decisions. These different information requirements need to be stored with links to the associated lifecycle process under each project assembly.

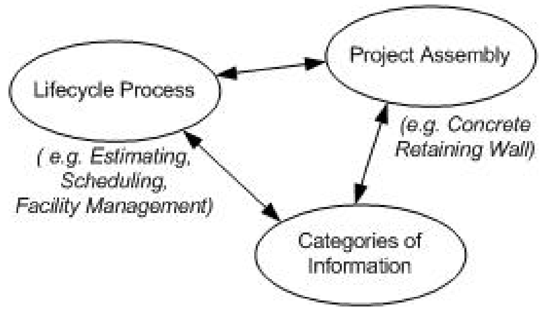


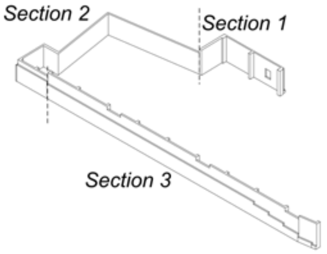
Figure 1. Connected information framework.

If we have the information classification system, then it could be integrated into the database framework of the BIM applications to support user input of information for each project.

A second problem relates to the format in which information is generated during a project management process. It is not uncommon that project management processes may require regeneration of needed information multiple times. This is usually because the format in which information (e.g. material cost) is generated during a given phase and process may not accommodate how such information will be sued during other processes and, hence, must be partially or fully regenerated. Formatting information to allow support of multiple lifecycle processes is needed.

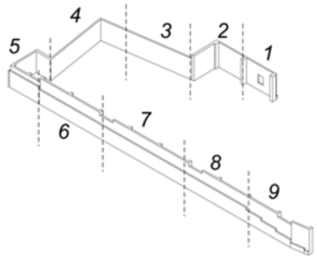
An example of this format fragmentation is how the quantities of steel rebar are calculated and stored for making decisions through the estimate, schedule, and procurement processes. Steel rebar is usually quantified as total tonnage for an estimate. It is conceivable that the estimate of rebar is broken into three sections that match the three sections of the model in Figure 2A as created by the designer. The objective of the estimate process is to calculate a total quantity of steel that can then be multiplied by a unit cost to estimate a total cost. The format in which the steel quantity is generated is therefore not adequate for subsequent processes such as scheduling. To support the scheduling process for calculating durations, the quantity information need to be partially regenerated to correspond to nine separate construction activities that match the nine wall assembly sections used for planning the construction work (Figure 2B). The new quantities are needed to calculate activity durations by dividing the tonnage of steel in each section by crew production rates (tons/day). Similarly, for the procurement process, quantities need to be organized by bar size to allow for ordering, tracking, and delivering material (Figure 2C).

A. Estimate Processes Information



	Tons of Steel
Section 1	5.66
Section 2	8.04
Section 3	11.51
Total	25.21

B. Schedule Processes Information



	Tons of Steel
Section 1	1.82
Section 2	3.82
Section 3	1.92
Section 4	2.20
Section 5	3.91
Section 6	3.86
Section 7	3.09
Section 8	2.50
Section 9	2.07
Total	25.21

C. Procurement Process Information
(Breakdown of Section 1 Rebar)

		Tons of Steel
Section 1	#6 Bar	1.08
Section 1	#8 Bar	0.50
Section 1	#11 Bar	0.24
Section 1	Total	1.82

Figure 2. Rebar Information needs for processes.

Since the format of the information required for each process is different, the information will need to be partially or fully regenerated to support each process. If information is generated and stored at various levels of granularity while taking into account what other processes (downstream) will utilize, the same information can then be retrieved in any format and be readily usable at any phase without the need to recalculate the information. This would facilitate BIM application to better support lifecycle processes.

3 PROPOSED INFORMATION FRAMEWORK

A Work Task Information Framework (WTIF) is proposed to integrate work flow/work tasks with geometric assemblies and various information categories. As shown in Figure 3, assembly classification in the WTIF is based on RSMeans assembly hierarchy (http://www.rsmeans.com/). Information associated with each assembly is divided into eleven information categories.

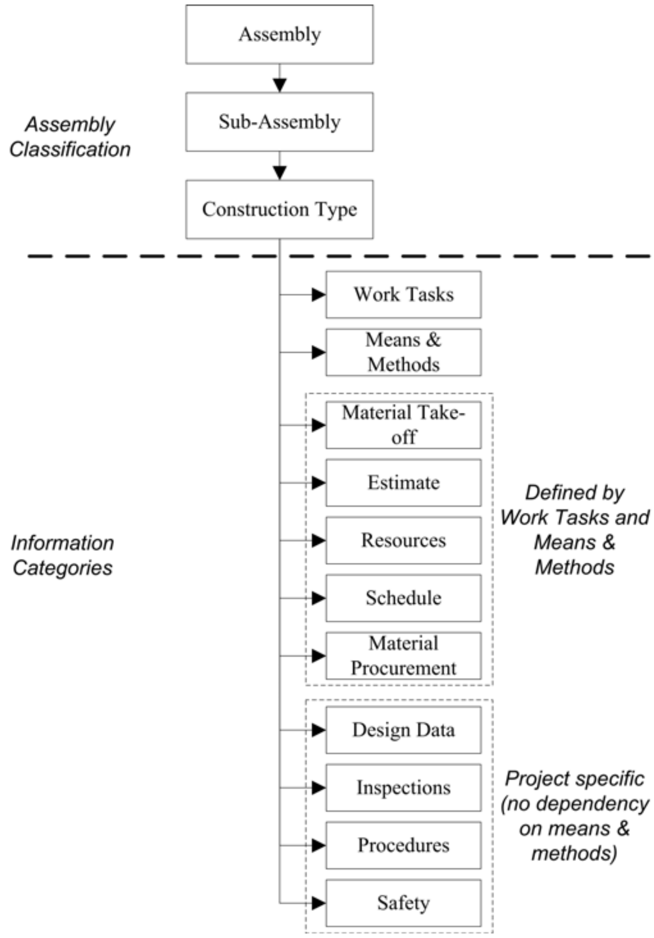


Figure 3. Work Task Information Framework (WTIF)

The assembly classification consists of three levels: Assembly (e.g. Foundations), Sub-Assembly (e.g. Footings and Foundation), and Construction Types (e.g. Cast-in-Place Concrete Walls). There are twelve assemblies (Foundations, Substructures, Superstructures, etc.). Each assembly has a series of sub-assemblies, the quantity vary based on the category. Similarly, each sub-assembly comprises of various construction types associated with it. For each Construction Type, a hierarchy of information categories is defined.

The information categories for each Construction Type are the same, though the information they store may vary. Categories include: Work Tasks, Means & Methods, Material Take-off, Estimate, Resources, Schedule, Material Procurement, Design Data, Inspections, Procedures, and Safety.

Work Tasks and Means & Methods help define the items of information in each category and the structure of sub-categories. The Material Take-off, Estimate, Resources, Schedule, and Material Procurement categories organize information based upon the Work Tasks that are associated with the construction type classification. The Design Data, Inspections, Procedures, and Safety categories are specific to the defined assembly and do not vary based upon the chosen Means & Methods.

The Material Take-off category holds information associated to each item associated with each work task and separated by type, size, or specification.

Estimates are where material, labor, equipment, and overhead and profit costs are stored.

The Resources information category connects a crew designation to each work task. Each crew designation contains the labor and equipment make-up and the production rates associated with the crew.

The Schedule information has sub-categories that consist of the various work tasks associated with the assembly. It holds logical dependencies for each work task, their relationships, task durations, and task dates.

Material Procurement stores related procurement information for each work task consisting of supplier information, costs, material specifications, quantities ordered, order dates, and delivery dates.

Design Data contains information from the architect and engineer related to the design of the assembly. It contains reference standards as well as plans, sections, specifications, and shop drawings.

The Inspections category lists each inspection that is required for the assembly during the lifecycle of the project. It contains the procedures, results, completion date, and responsible party for each inspection.

The Procedures category contains information for contractual procedures associated with each work task. This includes permit, certificate, submittal, and approval information including the associated dates and responsible parties.

The Safety information category consists of information for hazardous materials, a project safety plan, general (company) safety plan, and Occupational Safety and Health (OSHA): safety and health regulations.

The WTIF will link to a database system that is attached to a 3D model within a BIM application. This linking of information to the 3D model will allow for better BIM applications to better support lifecycle processes.

4 INDENTIFYING INFORMATION FORMATTING NEEDS

In order to better support lifecycle processes, the format in which information is generated and stored should accommodate for subsequent processes.

Each project assembly is analyzed to identify information formatting needs at various project phases. Typically, information that is developed during one process is often only formatted for that project process requiring the same information to be generated for later processes. Using the example of the rebar from above, material take-off information during design phase be conducted three times to support three separate processes; estimate, scheduling, and procurement (Figure 4). Identifying a common format with a high level of granularity to support all relevant lifecycle processes eliminates the need for recalculating and regenerating information (Figure 5). The properly formatted information is stored within WTIF allowing for retrieval of the information to support multiple processes with minimal recalculation.

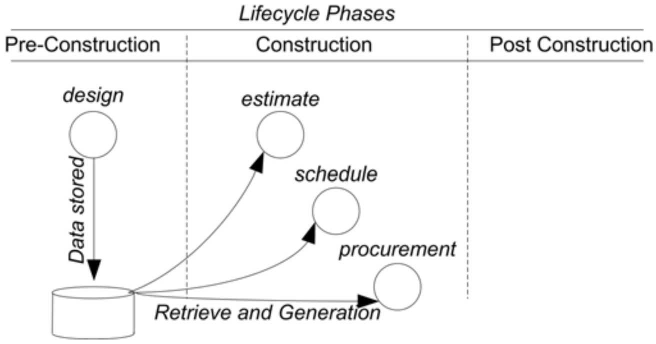


Figure 4. Information is fragmented between processes.

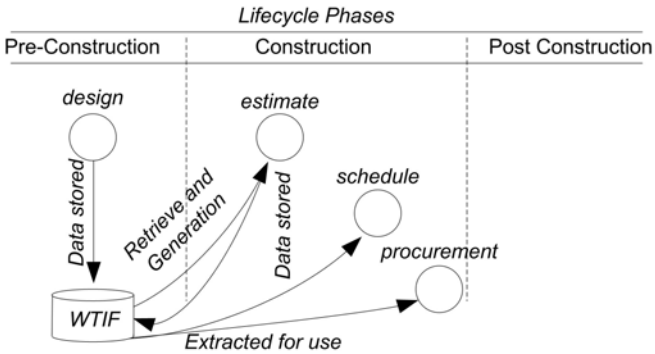


Figure 5. Information is used from earlier processes.

4.1 *Information Exchange*

The proposed information framework will store the information at the granularity needed to support lifecycle processes. The WTIF will allow linking the information within a series of databases to the graphical model. Parameters (e.g. location keys, specifications, construction phases) would be associated to the model objects and used to aid in filtering information. The model and information within the WTIF can then be used during different lifecycle processes. These processes will generate a series of outputs that are used for various purposes during the construction process. The outputs will also be stored back into the information framework at a format that allows for easy retrieval and recall to support downstream processes (Figure 6).

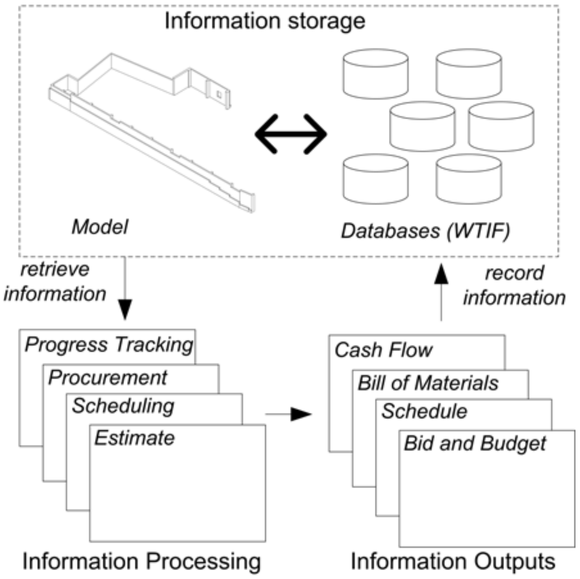


Figure 6. Information exchange method.

In order to accomplish the use of BIM to support lifecycle processes, it is necessary to develop tools that allow for manipulating information while working with the information framework. Past research efforts that deal with manipulation of information do not effectively tie back the information to the model in a structured method for future use and modification.

The proposed WTIF is intended to work with the BIM (model) to allow the information and model to be processed and manipulated through process applications. These process applications will include model based scheduling and visualization, estimation tools, procurement tools, design to manufacturer tools, facility management support tools, and others. The tools will work with the model and information in producing needed outputs used in making decisions. A model-based scheduling and planning process application, the Virtual Construction Environment (VCE) (Lucas et al, 2008), is one possible example of an application that will tie into the WTIF.

The outputs of each process will be available as inputs for later processes and stored within the information framework at a level of granularity useful to future processes downstream. The information framework will use the IFC schema when able, though is more complex in nature by connecting associated work tasks and non-modeled information in a structured framework with the key goal of supporting lifecycle processes. Current software applications fall short of supporting multiple lifecycle processes and often only support one or two processes. Each one being useful in its own right in supporting the construction industry but falling short of taking advantage of the potential of BIM.

5 BIM APPLICATION REVIEW

Three current software platforms that are publicized as BIM software were analyzed to identify capabilities of each tool to support project lifecycle processes. This included Bentley Inc.'s Bentley Architecture (Bentley, 2009) and Autodesk's REVIT (Autodesk, 2009). Both applications were originally developed for use in the design phase of project, so there are limitations for their use within the construction industry. The limitations listed are not necessarily flaws within the application, but limitations to its use in aiding the construction industry in completing lifecycle processes. The third application reviewed is VICO Constructor (VICO, 2009) which is developed specifically for use within the construction industry.

5.1 *Bentley Architecture*

Bentley Architecture is an IFC compatible application that offers parametric modeling features and BIM capabilities in identifying and assigning selected information to graphical objects. The user interface consists of a ribbon of toolboxes that allow for defining and inserting objects into the 3D environment. The user can view the graphical information through different top plan, side elevation, isometric, and 3D rendered views (Figure 7).

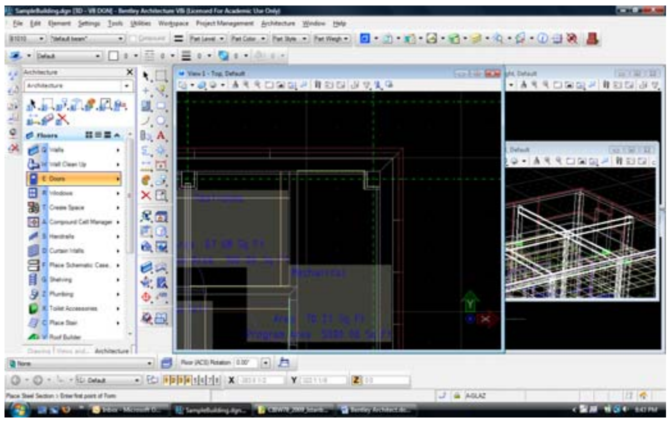


Figure 7. Bentley Architecture user interface

There is a catalog of objects that are defined by the application. These objects consist of windows, doors, wall systems, ceilings, columns, and many other assembly types that are used in designing a building. Each object is part of a family, a type, and has its own type ID. Each one of the objects that is placed within the modeling environment is given a unique ID number and carries the designated properties of the object type. The properties associated with the object depend upon the object definition (i.e. door, wall, beam). Selected materials and properties can be viewed and organized in schedules.

The categories of information that are predefined for each object are targeted to fit the needs of the designer and not the construction needs. The categories that are typically needed for the designer to create schedules for their drawings are included, while information that would aid in construction planning is limited.

Walls, windows, and doors allow for storage of more property values, most of which support the needs of the designer. Defined walls are given properties of material make-up, structural use, fire rating values, and acoustical information. Dimensional values are also stored. Windows and doors allow input for dimensional values, materials, hardware information, manufacturer, and model numbers (Figure 8).

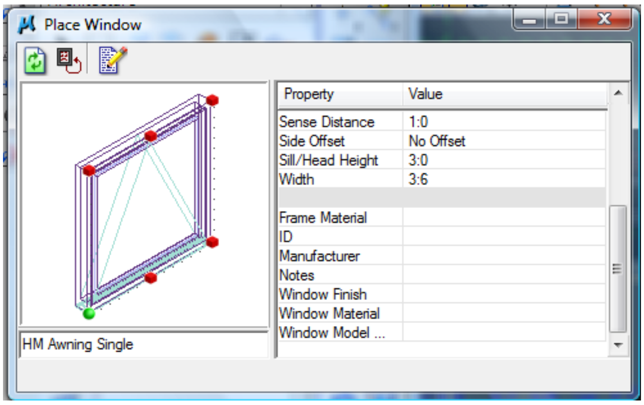


Figure 8. Dimensional and information input for windows

Other objects within the application, such as steel for columns and beams have limited information attachments. Inputs available for steel members are limited to steel member section, categorized by section type.

5.1.1 *Program capabilities*

Bentley Architecture allows for the quantifying of materials through the creation of quantity reports and schedules. The quantity reports, by default, identify each individual component and compute dimensional, area, and volume values. Formulas can be applied to customize the quantity reports. The material schedules are automatically created and include columns for each information property defined to the objects.

Schedules are also automatically produced based upon a chosen object type. The fields for a schedule are editable and include material properties as well as organization by phasing. Digital entities placed within the modeling environment have phasing properties. These phases include New Construction, Existing to Remain, Existing to Demolish, Future Construction, Temporary Construction, Item to be Moved, and Not in Contract.

There are construction planning features available within the application that include 4-d simulation and collision detection. Through the use of the Schedule Simulator, 4-d simulations are created within the program environment. Schedules are imported into Bentley Architecture or can be defined within the applications.

5.1.2 *Program limitations*

Program limitations include the calculations of material weights. This is overcome with the creation of customized formulas within the reports, but for materials like steel where a section of steel has a specific weight and there are multiple sections of steel, it would aid in multiple tasks if weights were easily associated to the objects and automatically quantifiable. Other applications that import the structural information are needed in order to analyze or quantify structural information. Transfer of data is similar to an import/export function of IFC model data.

Other program limitations include the linking of manufacturers, suppliers, and supplier information for materials of steel and concrete. These typically are not concerns to designers though important for contractors. The manufacturer information is connected to objects like window assemblies and finishes since this information is relevant and included within the schedule of materials and material specifications.

5.2 *Autodesk REVIT*

Autodesk REVIT is also an IFC compatible application with BIM capabilities. The user interface is set up with a series of tool groups and icons in a ribbon format. Possible views, levels, sheets, and other information are easily accessed through an information tree organization. The digital model is viewable from above as a plan view, in multiple elevation views, isometric, or walkthrough model (Figure 9).

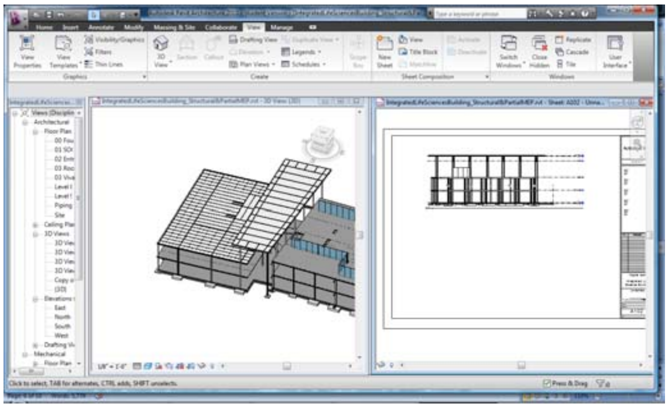


Figure 9. Autodesk REVIT user interface.

Various object types are available through the system to use within the modeling environment. These include walls, doors, windows, and structural information as well as other objects used for representing the design of the building. The wall types are editable to add layers of material to a wall type or create new wall types. The properties associated with each wall are construction properties, graphical properties, and identity data properties. The construction properties include wall layers, materials, dimensional values, and function (interior, exterior, etc.). The identity properties include assembly code information and descriptions as well as the fire coding, costing information, and manufacturer information. Window assemblies have similar construction properties which include dimensions of units as well as offsets in wall and sill thickness. They also have properties for model, manufacturer, assembly details, and costing (Figure 10). Doors have similar properties to the windows.

Structural beams are also an object used within the modeling environment. The beams have structural and material properties. Columns are similar. Both can be quantified in number of pieces and length automatically. Cost can also be associated with a beam.

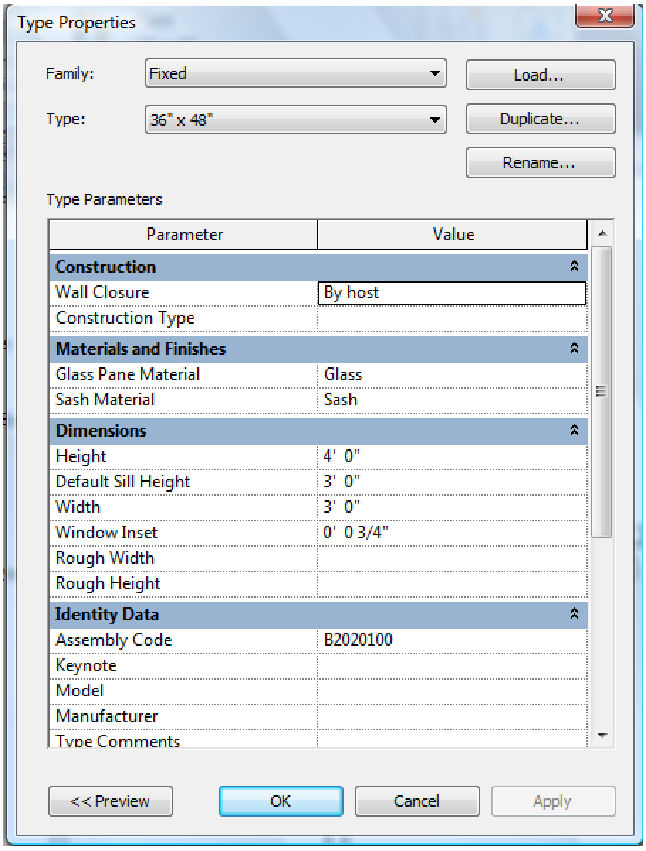


Figure 10. Information input for windows.

5.2.1 *Program capabilities*

Schedules and list of quantities are easily created within the application. The item to quantify is selected. This can be filtered for a phase of the project. Then the fields are chosen to include within the schedule or list of quantities. Quantities of items such as doors are capable of being broken down into door panels, frames, etc. This allows for a more detailed list of items. The schedules and list of quantities can help in developing design document scheduling needs as well as aid in cost schedules, material ordering forms, etc. for construction processes.

5.2.2 *Program limitations*

Supplier information is limited to manufacturer and model numbers. There is no association for other supplier information, delivery dates, and support for other procurement related issues.

There is no capability directly within REVIT that allows for schedule simulation. Autodesk's NavisWorks allows for this function. Data is transferred to NavisWorks through the import function. Also with NavisWorks a previously created schedule can be imported or new schedule activities created. There is also no function within REVIT to allow for collision detection, NavisWorks allows for this.

There is no ability to associate schedule activities, activity dates, or tracking progress of work put in place. The information capabilities available within the BIM application is aimed toward design needs and not construction processes.

5.3 *VICO Constructor*

VICO Constructor allows for the creation of a model and then linking of information and limited modification of the model and information through virtual construction features. These virtual construction features allow for the creation of coordination plans, work flows, 5D planning, estimating, etc.

The modeling capabilities of VICO Constructor allow for the creation of various assemblies (e.g. walls, columns, etc.). However, material definition is not automatically supported. When importing model objects, the parameters defined are limited to dimensions and graphical appearances of the object. There are no associations of materials, supplier information, and manufacturer information associated with these modeled objects (figure 11). Material definition is conducted through the creation of a Recipe (formulas defining information, related work flows, etc.), which works with the estimating and quantity take-off functions. Recipes are stored within a database that is attached to a file and works with each module of the application (5D Simulator, Estimator, etc.).

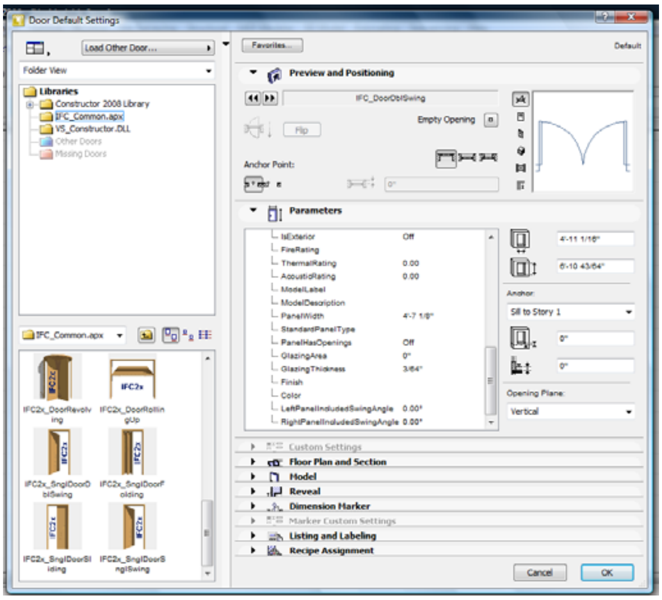


Figure 11. Information input for model objects.

The application does allow for compatibility with VICO Office which is a suite of products that easily aid in estimating and scheduling. These products were not analyzed at the time of publication. Though allow linking of these tools for automatic update of information between schedule, estimates, and design models can prove valuable with the coordination of documents.

5.3.1 *Program Capabilities*

VICO Constructor does allow for the creation of sequencing of work and work breakdown structures. It also allows for estimating and quantifying materials as defined through developed Recipes for work with the system. Any estimating information first needs to be formulated by the user. This allows for customizing information to the needs of the user, though requires the user to have the knowledge and abilities to create the needed formulas.

VICO Office Suite has advanced scheduling, sequencing, and estimate capabilities that are directly compatible with VICO Constructor. These features allow for expanding construction processes.

Quantity take-offs that are created through the application allow for both itemized and total quantities of materials. The materials can be defined through Recipes as to how they should be quantified. The default quantifications are all dimensional areas per side, length and width dimensions, and volumetric dimensions. Through Recipes, limited non-modeled information can be included within both the schedule and estimate information.

5.3.2 *Program limitations*

There is no easy definition of material when placing objects into the environment. There is also no ability to associate manufacturer and supplier information to the objects leaving minimal support to procurement processes during the construction processes. There are also no costs associated to the base model. Cost and scheduling features are available through connected products, however are not directly connected to the original BIM model in one location.

6 DISCUSSION AND FUTURE RESEARCH

Current BIM tools fall short of truly supporting lifecycle processes of a project. They allow for referencing a model and connected information, but do not allow for easily manipulating the information and making decisions to support project processes. A BIM should not be considered a model with connected information to reference when performing a task, but also include processes that allow for the manipulation of that information. Only when the information needs of lifecycle processes are taken into account and non-modeled information related to a digital model is included in a structured way will BIM truly support the lifecycle of a project.

The proposed Work Task Information Framework (WTIF) will improve BIM capabilities. For estimating, there will be a separation of cost values (labor/equipment/material) and links between modeled and non-modeled information for quantity take-offs and cost values. Information will be linked to graphical objects through the BIM that will allow for updating and tracking of changes when the design changes. For scheduling and work flow development the WTIF will allow for automatic association of work tasks with assemblies and methods, this will allow for sequencing and planning from the model and easily conversion into detailed plans. Since connections are made between all processes, costs and resources can easily be added to the schedule. The linking of information to various project processes will also allow for easier development of material procurement schedules. The linking of information with specifications, quantities, and design data will also allow for development of manufacturer and supplier information. Links to supplier information like material quotes and lead times with design and schedule information will allow for quick development of accurate estimates and delivery orders. Process applications will be developed to work with the WTIF and BIM that allow for improved support of the lifecycle of a project.

Future research includes evaluating the structure of the WTIF through the analysis of more case study assemblies. This will validate the information categories and prove the flexibility of the WTIF structure to support multiple assemblies. Another aspect of future research is to develop the database system based off of the WTIF structure and tying that database system to the digital models through the development of process tools to aid in various planning tasks. The future research will also analyze current

IFC schema and make appropriate connections between the IFC schema and the WTIF structure.

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