122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #12956

Using BIM to support Habitat for Humanity: A case study

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Abstract

This paper documents a graduate level research project intended to enable students to gain experience with Building Information Modeling (BIM) in the context of a "real-world" project. The project was structured to assist a local chapter of Habitat for Humanity with project estimating and scheduling by utilizing BIM in two primary ways. The first was to use the BIM model to generate cost estimates for projects using a pre-designed housing prototype. The second was to use the BIM model to assist in helping volunteer laborers to better visualize the construction sequence. This required the development of atypical modeling and cost estimating strategies. The paper documents the evolution of the project, modeling strategies that were employed, and the final project outcomes. It also identifies further refinements that can be made to scale the project to adapt to a wider range of Habitat projects.

Introduction

Habitat for Humanity, often referred to as Habitat, is an international non-profit organization that builds and repairs housing for low income families by utilizing the labor of volunteers and partner families, donated materials and professional labor, efficient building methods, modest house sizes, and no-profit loans. Founded in Americus Georgia, Habitat has more than 1,400 affiliates in the United States and around the world. The organization has built over 800,000 homes and shelters. According to Habitat, the "houses are simple, decent and affordable to low-income families around the world, and, whenever possible, build sustainable, energy-efficient and healthy housing" [1].

As part of community outreach efforts, members of a graduate seminar course in construction technology at Bowling Green State University contacted the local chapter of Habitat in order to determine ways in which skills they were developing could be applied to assist them in accomplishing their mission. The design services for the chapters' projects were typically donated by a local architectural firm. In most cases the design was utilized in multiple locations throughout the region. However, while the house design was the same for multiple locations, projects, cost for labor and materials differed based on what was donated, what was purchased, and what work was done by Habitat volunteers, all of which was to some extent unique for each individual project.

After initial meetings with chapter representatives, the following needs were identified::

1. Computer-based cost estimating techniques that are aligned with the Habitat project delivery model.
2. Digital visualizations (renderings and animations) documenting construction sequences and assemblies in order to assist unskilled laborers and volunteers in understanding construction processes.
3. Energy efficiency assessment processes in order to assist Habitat in optimizing energy efficiency in the projects.

The utilization of Building Information modeling (BIM) was determined to be the optimal technology to use to meet these goals in order to meet the organization's needs. While BIM functionality has been considered to be best-suited to larger projects, others have proposed that BIM can be utilized effectively for smaller projects as well [2]. Additionally, utilizing BIM as the central technology for the project would provide Habitat with the ability to uti1ize the deliverables from the class for future projects. After assessing the project requirements, the skill set of the students, and the available software applications, two specific applications were selected. Autodesk Revit was selected as the BIM platform. Autodesk Navisworks Manage was selected for scheduling and construction sequence visualization.

Building Information Modeling Overview

The first implementation of digital applications in the AEC industry was referred to as Computer Aided Design and Drafting (CADD). According to Howell and Batcheler, "the original premise of CAD was to automate the task of drafting" [3]. Similarly, Kensek (2014) proposed that "CAD adoption was heavily based on the direct substitution of existing practice modes," resulting in 2dDvector-based electronic versions of manual drafting [4]. As technology advanced, applications were developed to produce 2D and 3D representations of buildings that were based on 3D vector-based wireframes, raster imaging, and surface modeling. However, these representations had little to do with the knowledge required to actually design and construct a building [5]. BIM, based on parametric object-oriented modeling, is a significant technological advance from previous AEC software platforms. According to Smith and Tardi a BIM application more closely resembles a relational database than vector-based CAD applications. They proposed that BIM more readily "understands" that the objects created by users represent real world components of an actual building [5]. Additionally, they stated that "a genuinely comprehensive building information model would encompass not only geometry but all of the information about a building that is created through its useful life" [5]. According to Kensek, "BIM is a natural progression in the evolution of computer supported practice" [4].

BIM has been defined as a "project simulation consisting of the 3D models of the project components with links to all the required information connected with the projects' planning, construction or operation, and decommissioning" [6]. It is a digital representation of physical and functional characteristics of a facility providing accurate 3D representations of a building and the capability to affiliate attributes and data to the components and objects that form the model [7]. Similarly, the National Institute of Building Sciences published the following definition:

> "Building information models, or BIMs (*are*) digital, easily managed and shared representations of physical and functional data that define buildings throughout their life cycles—are increasingly seen throughout the public and private real estate and construction sectors as a way to control cost and performance problems associated with inaccurate and incomplete communications" [8].

Central to these definitions is the concept that BIM is as a database made up of interrelated files organized within or linked to the 3D digital model. The concept of BIM is to construct a building virtually, prior to constructing it physically, in order to resolve and simulate any potential design conflicts [9].

In a document entitled The Contractors Guide to BIM, the Association of General Contractors stated that the while “the number one use of BIM is visualization”, trade coordination through spatial coordination and clash detection” is another key advantage. Clash detection analyzes the 3D model geometry to determine if there are interferences between building components or systems. BIM enables such testing and coordination can be utilized early in the design process and continued throughout project life-cycle including design, construction, and facilities management [10].

However the AGC also discusses BIM in terms of 3D, 4D, and 5D functionality:

> 3D: Three-dimensional. In the context of BIM, it is used to describe a model that expresses the spatial geometry of a construction project, its permanent components, certain of its environs and certain temporary components in a static form.
>
> 4D: Four-dimensional. The fourth dimension is time. In the context of BIM, it is used to describe a model that has its components displayed sequentially in “screen shots” to reflect the order in which these components will be assembled during the construction process. Such a model can be utilized to study alternative sequences, erection coordination and actual progress. Direct ties to scheduling software can be made, connecting scheduling activities to model components to “drive” the model.
>
> 5D: Five-dimensional. The “fifth dimension” generally describes quantity and cost information that is derived from or applied to a BIM model. Current software allows many quantities to be generated directly from a 3D model. Other quantities can be generated utilizing application software that adds additional information to the model representing quantification of finishes, insulation and other “non-modeled” components. Cost information can be added directly to the model through additional software integration or externally through exporting of quantification to “standard” estimating programs. The use of the fifth dimension is independent of whether time (the fourth dimension) is embedded or used in the model [10].

As this project required implementation of all three of these functions the AGC description of BIM was particularly relevant. Therefore, the following section discusses the techniques used to generate cost estimates, scheduling, and construction sequence visualization with the selected software applications.

Application specific implementation of 3D, 4D, and 5D BIM

Two applications were selected for the project activities, Autodesk Revit and Navisworks Manage. Revit is an exceptionally robust building information modeler which can export geometry directly to Navisworks for 4D functions (scheduling and construction sequence visualization). The software also includes interference checking features as well as the ability to export geometry for energy analysis.

In Revit, cost estimates and quantity take-offs are generated from the BIM model using schedules. Cost estimating uses either unit costs (object quantity take-offs) or material costs (dimensional unit take-offs). Quantity costs are generally associated with building components that are built or assembled off-site, such as doors, windows, light fixtures, and plumbing fixtures. Costs are embedded in the BIM object itself as a parameter in the "Type Properties" of the object (Figure 1). However, the unit costs do not differentiate between the cost of the building component and the labor required to install it or finish it. Material costs (dimensional unit take-offs) are embedded in the properties of a specific material that is assigned to an element in the BIM model such as concrete masonry units or flooring material (Figure 2). Costs assigned to a specific material can be based on linear units (i.e. cost per lineal foot), area units (cost per square foot or square yard), or volume (cost per cubic foot or cubic yard), depending on how the estimating is planned. As with unit costs, labor costs are not differentiated. Therefore, estimates must include labor costs as part of the material cost, or be set up as "materials only" take-offs. Schedules provide pre-defined field parameters dependent upon the type of schedule being generated (Figure 3 and 4). A wide range of materials are accessible from Revit's default material libraries and customized materials can also be created. Formulas can be added as unique customized fields that are added to schedules to provide operations such as converting a square foot to a square yard or a cubic foot to a cubic yard assuming the material costs are embedded in the materials with the appropriate unit value. Formulas can also reference values from other fields and incorporate them into mathematical equations (Figure 5).

Materials in Revit include thermal properties (Figure 6). These can be customized but in most cases the default properties are accurate for energy efficiency analysis. Revit also supports location-based analysis. The BIM model can be exported to web based analysis services. An external application such as Ecotect can be utilized for energy analysis by exporting the Revit geometry as a GBXML file. Revit can also be used to detect interferences in model geometry using the Interference Checking tools.

Scheduling and construction sequence visualization is not available in Revit in a practical form. Therefore, in this project Navisworks was utilized for these activities. 3D geometry cannot be generated in Navisworks. Revit geometry can be imported directly and updated from within Navisworks should the original Revit geometry be modified. While Navisworks provides a range of visualization tools, including "avatar-based" walk-throughs in which the user can navigate through the model from a first-person perspective in real time. Navisworks includes a robust construction sequence visualization feature that can be based on either and internally or externally generated project construction schedule. The schedule can be adjusted as necessary from within Navisworks or updated if an eternal schedule is utilized. The visualization is based on the tasks associated with the schedule, enabling it to display a linear sequence of construction activities, and can be displayed in months, weeks, days, or even hours. Material costs can be embedded and a running total of the costs expended to date can be displayed in the visualization. Construction sequence visualizations can be exported to conventional file formats. The duration and quality of the visualization can be adjusted without altering the associated schedule for each construction task.

Habitat for Humanity Project Delivery Model

With conventional commercial or residential construction projects, construction activities are coordinated by a general contractor (GC) or construction management firm (CM) hired by a client. Their role is to manage project scheduling and coordinate the activities and responsibilities of subcontractors who perform the actual conduction activities. In some cases the GC or CM may provide some of the actual construction services in addition to the management services provided. In many cases projects are one-off designs unique to a specific site or client. The project architect is hired by the client or, in the case of design-build, by the GC or CM. Particularly in the case of larger projects the design firm will generate cost estimates at various stages of the project.

With conventional commercial or residential project costs can be estimated based on assessing research of current or historical labor and material cost data. The estimates and subsequent bid submissions can be based on a variety of unit costs. For example, an interior wall bid could be based on a cost per lineal foot or cost per square foot. Similarly, a cost estimate and bid for concrete slabs could be based on cost per square foot or cost per cubic yard. Typically, in conventional commercial or residential construction projects material and labor costs are included in bids and estimates. However, the responsibility for the methodology used to generate an estimate remains with the subcontractor. The GC or CM assemble the estimates submitted by subcontractors to provide the basis for the total project cost.

The Habitat project delivery model differs substantially from the conventional commercial or residential approach. Design services are typically donated by local professionals. The role of project management is handled by Habitat representatives or donated by professionals. The scale of Habitat houses enable the organization to re-use designs in multiple locations. Labor and material costs are also substantially different from conventional housing providers. A key variable between projects is that of donations made by contractors and subcontractors. This may entail donation of materials, labor, or both, and will vary from project to project. Habitat projects rely on community volunteers to supplement either paid or donated labor from construction companies. Additionally, on most projects, Habitat will seek private sector sponsors to provide financial support for a specific project. In many cases the sponsors will often ask their employees to volunteer to serve on construction crews. As this labor is typically unskilled, the extent of contribution of volunteer labor to successful project delivery is a variable that is difficult to estimate. However, the variation in the donations and private sector sponsorship is a primary consideration as it can vary within the same geographic area and even between multiple houses being constructed in that same area.

Establishing Project Goals

Project goals were established in the initial meetings between the project team and Habitat representatives. First, as a non-profit with very limited construction budgets for each house that was built, mechanisms for tracking project costs was established as a priority. Second, developing visualization tools to enable unskilled laborers to understand the construction sequence associated with a specific project would provide a supplemental training resource and assist Habitat in making better use of the volunteers from the community and sponsoring organizations. Lastly, by conducting a basic energy analysis, Habitat could begin to consider energy-cost tradeoffs in determining the benefits of increasing energy performance in order to seek out optimal solutions intended to meet the organizational objective of “whenever possible, (building) sustainable, energy-efficient and healthy housing.”

In terms of the applicability of BIM, the projects constructed by Habitat provided advantages and disadvantages for structuring courses activities. Development of the BIM model geometry is typically fairly simple compared to larger scaled projects. The “re-use” of the same house prototype meant that the project would need to be modeled only once and would be applicable to multiple sites. If needed, minor adjustments to project geometry could be easily made by adjusting dimensions once the constraints and parametric relationships were sufficiently embedded in the 3D model.

Disadvantages included the variations in labor and material costs for each project. For example, on one project the labor and materials for the foundation work may be donated, on another only one or the other may be donated, and on another one or both may be provided at a discount requiring the expenditure of project funds albeit at a reduced rate compared to a commercial project. Costs can also vary with the role of volunteer labor which can vary significantly between projects. Additionally, given the skill set required to use the software, local Habitat chapters would likely not have the expertise on staff to manage the BIM model for future development.

Given the scope of the class activities, the decision was made to divide the project into two phases. In Phase One, two goals were established for the deliverables to be provided at the end of the project. Goal one was the creation of the BIM model, including cost estimating schedules. Goal Two was the development of construction sequence visualization which would assist volunteers to better understand the construction sequences. Although the material properties would be embedded with the geometry in objects and materials, the energy efficiency analysis would be developed as part of a second phase which would be out of the scope of the original class project.

At the start of the project, the local Habitat chapter provided a set of 2D drawings of the house to be used to construct the project (Figure 7). This same house was to be used in at least four locations throughout the region. The documentation was generated with 2D AutoCAD, so no 3D geometry was available to import or use as a starting point to produce the BIM model.

Discussions with Habitat regarding practices for establishing cost and material estimates and assessment of strategies for optimizing the BIM model for their operations yielded several decisions regarding the development of the class project. First, the model geometry would need to support variations in geometry to optimize estimating. While this would not be required for all elements in the project, certain key elements such as walls would need to support geometric variations. For example, the BIM model would only need to support estimates based on assemblies that could be estimated using an area or volume cost that was based on all the assembly components. As an example, this would be effective if there was a single source for the floor and subfloor which would enable the estimate to be derived from a per-square-foot cost for the floor or a contractor or supplier estimated walls at a per-square foot or per-linear-foot cost inclusive of framing and dry-wall. However, the BIM model would also need to support alternate estimating methods in order to accommodate alternative material and labor supply options. This would require more detail than typically be developed for a smaller scale project. Second, although the completed houses may be nearly identical, the variations in labor and material costs between projects highlighted the inherent shortcomings of cost-estimating tools that do not itemize labor cost and material cost for a construction activity or component installation. Therefore, in order to enable Habitat staff to use the BIM model to estimate a project, a simplified interface that enabled itemization of materials and labor could also be used by staff that did not have BIM skills. This was to be included as Goal Three in Phase One.

Developing the BIM Model

The BIM modeling strategy utilized Revit's Design Option feature. This feature allows a user to store multiple variations of the model geometry that can be retrieved as needed. For the initial design option, primary elements were modeled with a lower level of detail. Modeling geometry preceded using default thermal settings for materials with costs embedded in objects and assemblies as the project was developed. Costs were based on research and past projects completed by Habitat. The scale of the project required only a limited number of door and window types. For the doors, the Revit library contained appropriate geometry that could be used directly in the Habitat model. For the windows, the mullion configuration required using a manufacturer's online resources to match the windows shown on the drawings. In this case, the manufacturer-specific data was overwritten as needed to match project specifications and costs. Where necessary, building components were created using generic models that were customized to enable cost and manufacturer or supplier data to be embedded. Examples of this included the roof trusses, roof rakes, roof vents, and down spouts (Figure 8). As the BIM model progressed, the geometry was linked to a Navisworks file. The enabled students to begin to develop familiarity with Navisworks operations. The link was updated as the BIM model was further developed.

However, in order to accommodate alternative cost estimating schemes as well as more informative visualizations, design options using more detailed modeling that more closely reflected real-world construction assemblies were developed. The floor joists, rim joists, and subfloor were modeled as discrete components. Interior and exterior wall framing was modeled separate from the wall assemblies. This included studs at 16" on center, doubled studs at each side of the openings, and door and window headers (Figure 9). Horizontal wall sill plates and wall double top plates were also modeled as separate entities. This required customization of horizontal wood beam components in order to generate new structural members that were oriented with the wide part of the component horizontal as opposed to the default vertical orientation (Figure 10).

The exterior wall assemblies were developed to "wrap" the framing. The wall assembly core thickness of 5 ½" was assigned a thermal resistance value of R-19 to match project specifications. At the exterior of the wall, the assembly included vinyl siding over 1" rigid insulation, and ½" OSB sheathing. The interior of the wall assembly incorporated ½" gypsum wall board over a 6 mil vapor barrier. The total exterior wall assembly R-value was approximately 26. Interior walls assemblies were developed to "wrap" the 2X4 core with ½" gypsum wall board on both sides. For the design options foundation wall plates were also modeled as discrete elements. The completed BIM model is shown in Figure 11. Estimates generated to provide cost estimates included door and window quantity schedules, itemized wall schedules, framing schedules, footing and foundation wall concrete schedules, flooring material schedules, dry wall schedules, roof framing schedules, and roofing material schedules.

Using design options provided several key advantages. Where more simplified geometry was sufficient for project estimating, the model could be displayed with the appropriate options. However, if needed, the more detailed design options enabled the components to be estimated by square foot, lineal foot, or unit cost. For example, wall studs could be estimated by unit cost-per-stud or lineal foot, wall plates by lineal foot, gypsum wall board, exterior insulation, sheathing, and siding by cost-per-square foot. Similarly, floor joists could be estimated using cost-per-lineal foot and subfloor using cost-per-square foot. Secondly, the more detailed options supported the development of more accurate and informative visualizations that could better assist inexperienced or unskilled volunteers to understand the projects real-world construction assemblies and sequences.

Project construction sequence animations

As noted previously Navisworks was selected to generate project sequence schedules and visualizations. The final BIM model was updated in Navisworks before the schedule and visualizations were developed in more detail. Navisworks construction sequence visualizations are driven by a Gant-chart style schedule called Timeliner (Figure 13) which provides a graphical representation of the sequence (Figure 13). Timeliner can import project schedules from external applications such as Primavera, a scheduling application widely used in the construction industry. Project scheduling can also be set up within Navisworks by assigning the imported Revit geometry to construction tasks with assigned a start and end dates. Tasks associated with more complex assemblies, such as the wall construction in the more detailed design options, were scheduled with the appropriate sequence needed to reflect real world construction. For example, after the subfloor of the floor assembly was completed the wall framing was displayed, followed by exterior sheathing and insulation, exterior siding and trim, and then interior dry wall. For Habitat, the actual timeframe to assign to each task in Timeliner could vary between projects, depending when in the construction process materials and labor were available. The tasks were organized in an appropriate sequence but the duration of the tasks was treated more generically for purposes of producing more effective construction sequence animations. Once developed and configured with an appropriate duration, the animations were exported as a standard video file that could be edited with a wide variety of PC-based video software. The animations were made available to volunteers via YouTube.

Material Cost and Labor Interface

In order for the project to accommodate Habitat's unique labor and material variables between projects, one of the project goals was to develop a system that enabled Habitat staff who lacked experience with BIM applications to input discrete values for material and labor cost. This would enable the staff to easily identify those costs which were at market value and reflect discounted or donated materials and labor for other components. It was determined that Microsoft Excel, which supports a robust set of export options, was a logical selection as a "front-end" application as Habitat staff were experienced with it and had access to it.

The Project spreadsheet was configured with cells for labor cost and material cost for each building component which were then summed in a cell for a total cost for the material or object used in the BIM model cost and material take-off formulas. Where either labor or materials were donated, a value of "0" was entered into the relevant cell. However, after discussions with members of the computer science department as well as multiple Revit consultants, it was determined that further development of the Excel interface would be beyond the scope of the class. Therefore the decision was made to move this goal to Phase Two of the project.

Assessment and Conclusions

Assessment of project outcomes was based on the extent to which the project goals for Phase One were met. In terms of Goal One, the BIM model with the design options was sufficiently developed for release Habitat and the project architect for their use in current and future projects. In terms of Goal Two, the Navisworks NWD file was used to produce six video clips that documented construction sequences generated with the Timeliner feature of Navisworks. These were prepared to post on YouTube as unlisted media.

However, the technical difficulties encountered in establishing an excel "front-end" for the BIM cost estimating operations resulted in Goal Three not being met but rather being postponed to Phase Two. In terms of immediate results, the construction sequence videos appeared to be the most effective deliverable provided to the Habitat staff. In the absence of staff with some extent of BIM training and the spreadsheet link to Revit to input materials and object costs with discrete values for both labor and the materials, the contribution of the BIM model to Habitat operations may be more limited. Allocating sufficient time to assemble a team with the appropriate skill set and expertise to develop a practical and functional link between applications such as excel and Revit will be necessary for Goal Three to be met in Phase Two.

The project activities identified several strategies for future implementation of BIM with Habitat operations. First, while developing a BIM model with design options would still be required, expanding the role of Navisworks should be investigated. This includes using Navisworks for cost estimates and to generate renderings. Specifically, for cost estimates Navisworks enables labor costs to be separate from material costs. However, this would still require development of a usable "front-end" interface such as Microsoft Excel. Additionally, Navisworks also supports a free application called Navisworks Viewer that enables a user to view Navisworks data and files using a PC as well as a mobile device. This could be utilized by Habitat staff, crews, and volunteers to access key project information while on-site. Lastly, assembling a team of students, faculty, and Habitat staff charged with the task of developing a regional Digital Documentation Standard, of which BIM standards are a critical subset, for Habitat project management could provide a framework for future project delivery. Based on the extent to which this was developed and implemented regionally, opportunities for expanding the standards to other chapters of Habitat would provide not only a valuable service to an organization structured to meet a much needed societal need, but also provide unique and valuable learning experiences for students and faculty alike.

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Appendix: Figures referenced in text.

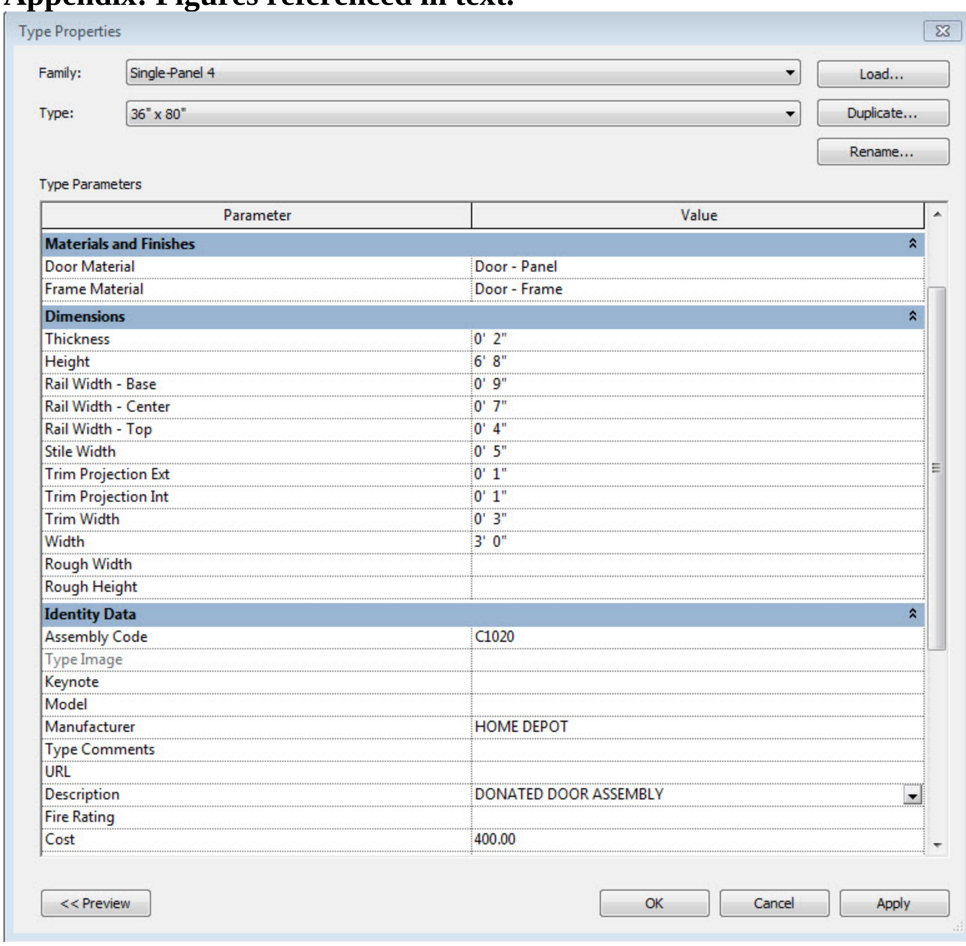

Figure 1. Type Properties for entry door with embedded cost and supplier information.

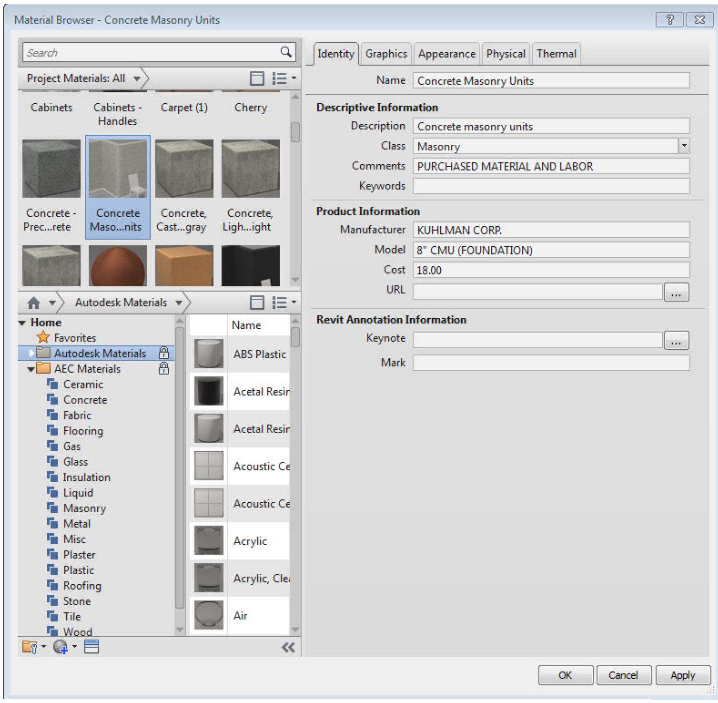

Figure 2. Material Properties with embedded cost.

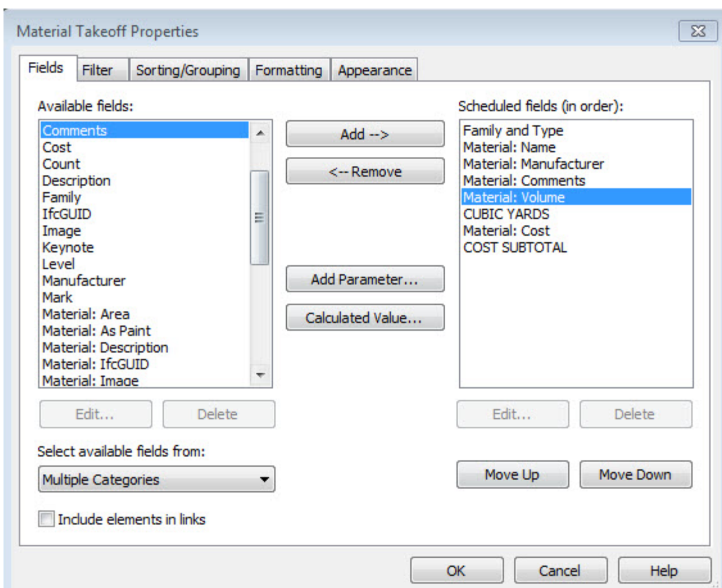

Figure 3. Schedule Fields

<CONCRETE FOUNDATION MATERIAL TAKE OFF>

A	B	C	D	E	F	G
Family and Type	Material: Name	Material: Manufact	Material: Comments	CUBIC YARDS	Material: Cost	COST SUBTOTAL
Basic Wall: 8" Foundation Wall						
Basic Wall: 8" Foundation	CONCRETE_Cast-in-Place gray	KULMAN	LABOR - MATERIAL DONATED	1	12.00	$7
Basic Wall: 8" Foundation	CONCRETE_Cast-in-Place gray	KULMAN	LABOR - MATERIAL DONATED	0	12.00	$6
Basic Wall: 8" Foundation	CONCRETE_Cast-in-Place gray	KULMAN	LABOR - MATERIAL DONATED	1	12.00	$6
Basic Wall: 8" Foundation	CONCRETE_Cast-in-Place gray	KULMAN	LABOR - MATERIAL DONATED	0	12.00	$5
Basic Wall: 8" Foundation	CONCRETE_Cast-in-Place gray	KULMAN	LABOR - MATERIAL DONATED	1	12.00	$18
Basic Wall: 8" Foundation	CONCRETE_Cast-in-Place gray	KULMAN	LABOR - MATERIAL DONATED	3	12.00	$31
Basic Wall: 8" Foundation	CONCRETE_Cast-in-Place gray	KULMAN	LABOR - MATERIAL DONATED	1	12.00	$17
Grand total: 7						$90

Figure 4. Schedule Fields Displayed

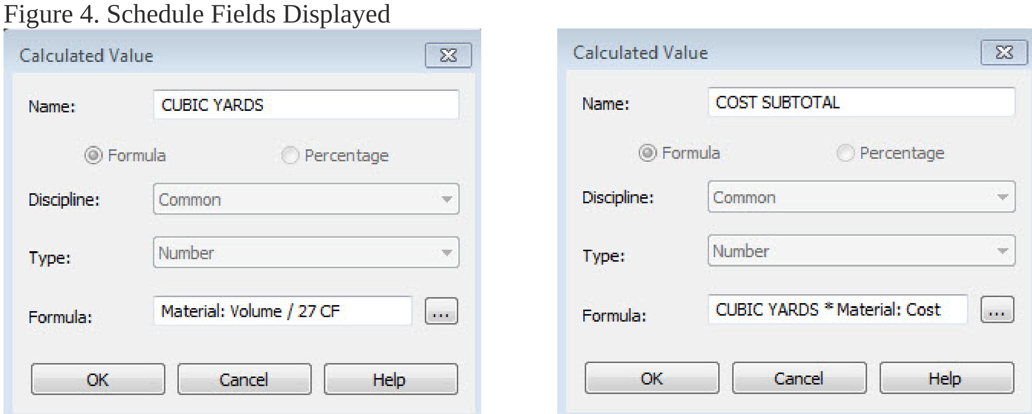

Figure 5. Examples of customized fields with calculated values formulas

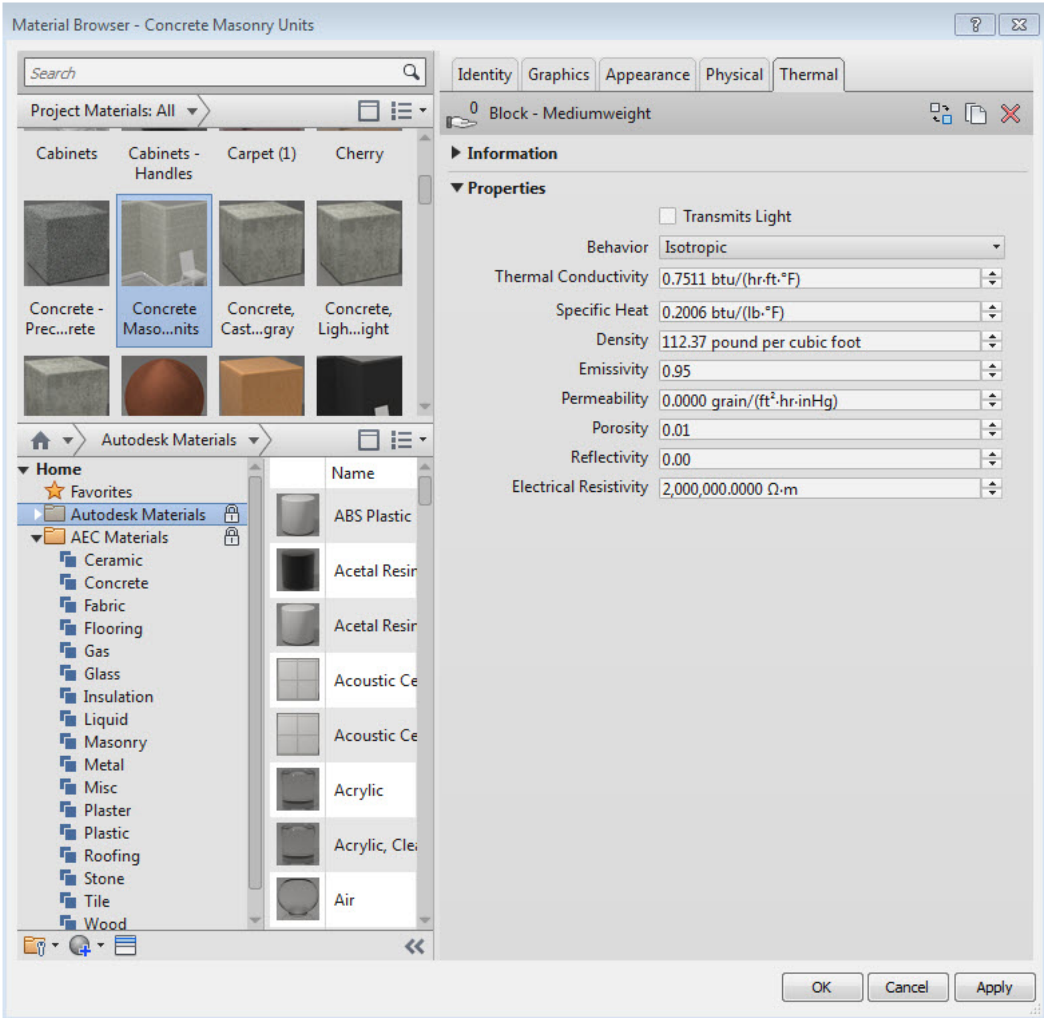

Figure 6. Material thermal properties (CMU example)

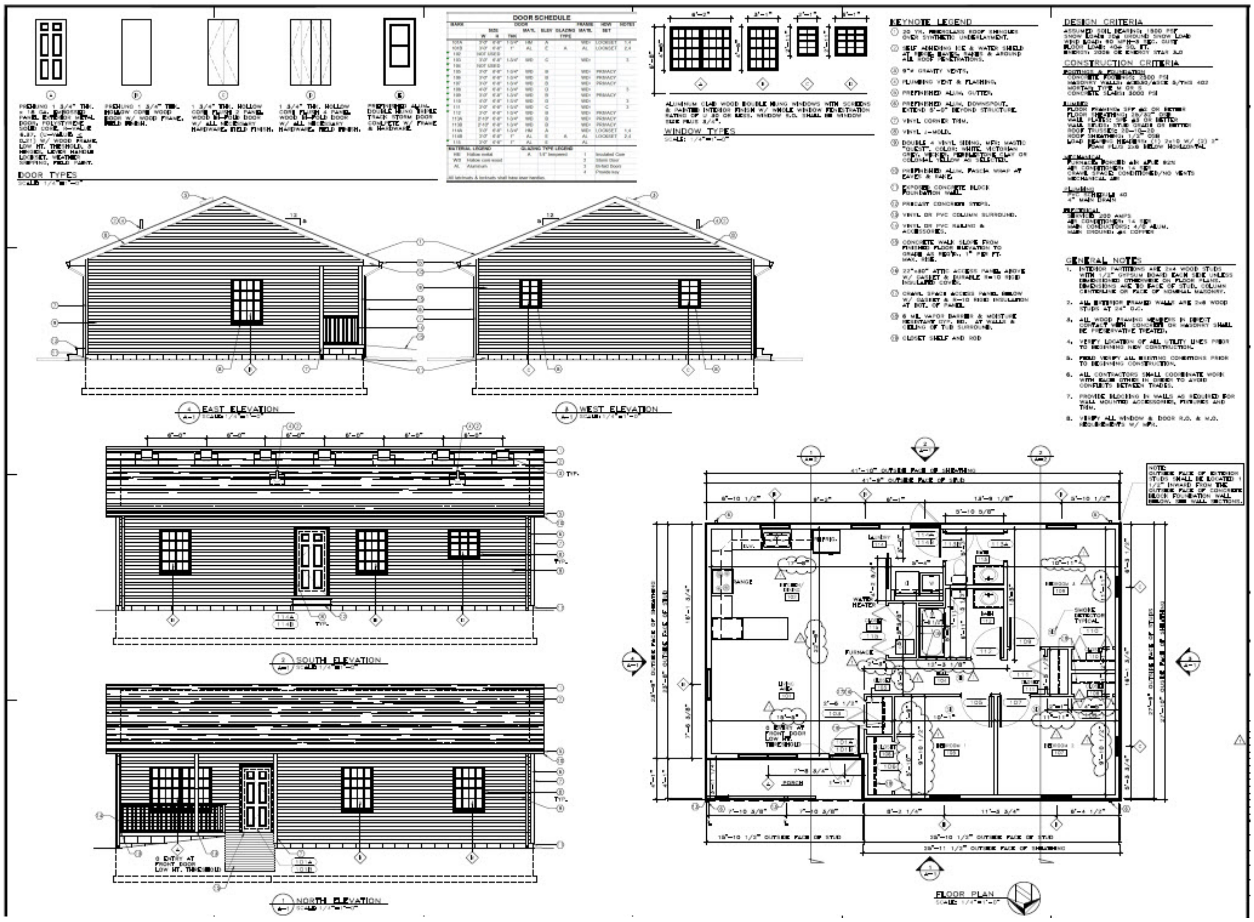

Figure 7. Sheet A 1 of the 2D documentation provided at project start.

Figure 8. Generic model geometry

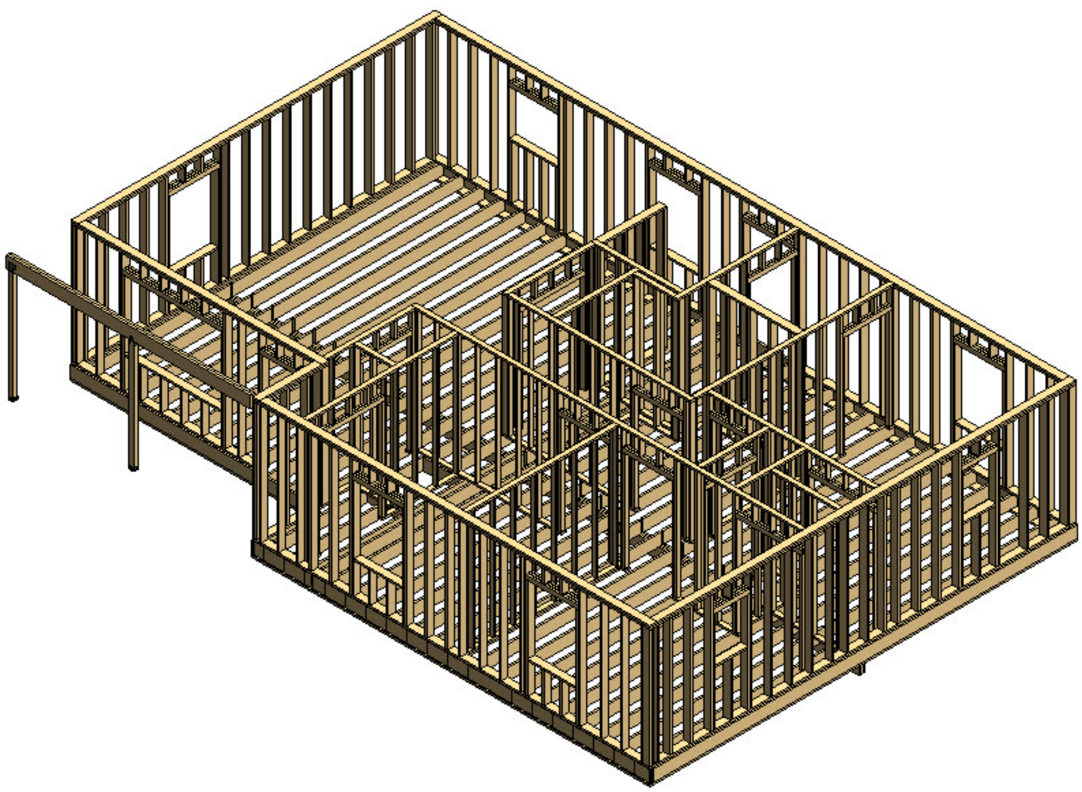

Figure 9. BIM model with wall framing

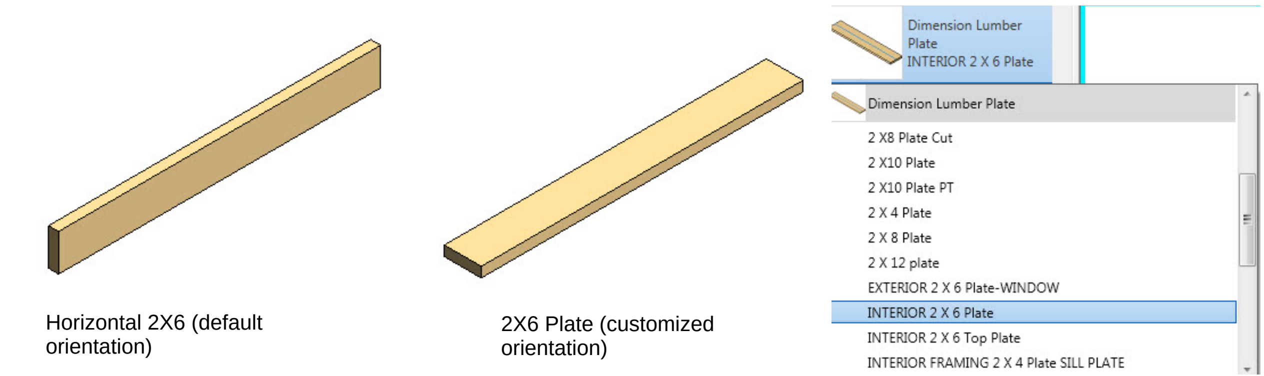

Figure 10. Left: 2X6 Beam and Plate. Right: Custom Family Types for wall plates created for project

Figure 11. Completed BIM Model

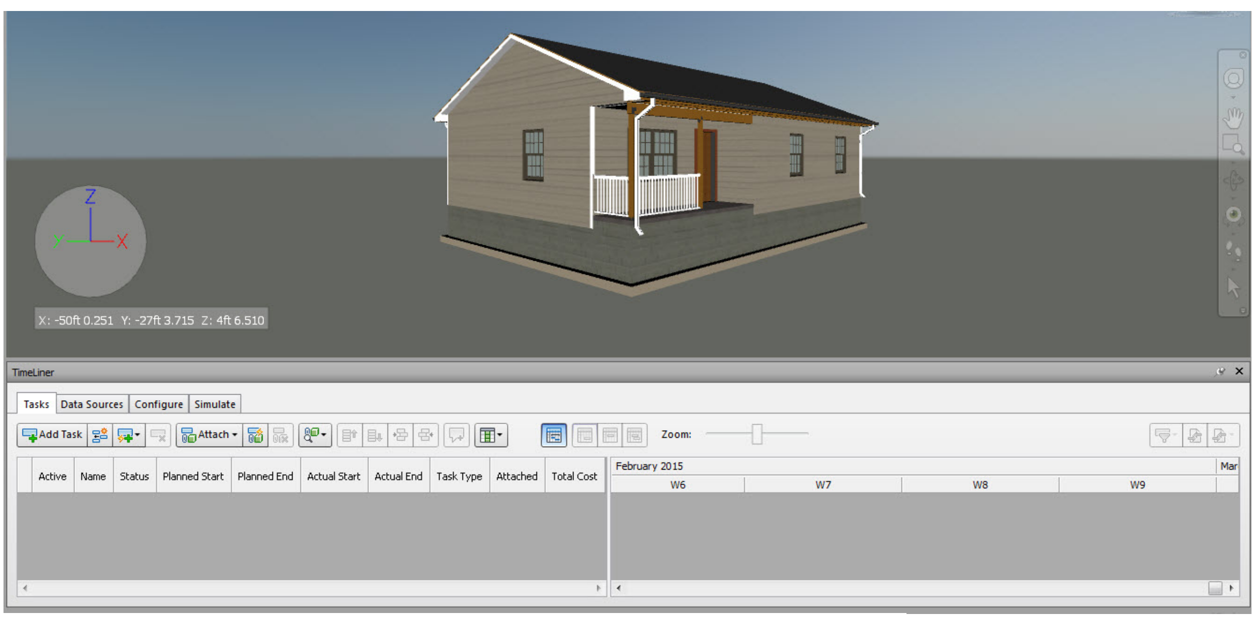

Figure 12. Timeliner interface. Imported BIM model in Navisworks viewport above.