

# BIM and Concrete Formwork Repository

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This paper discusses various applications of a concrete formwork repository developed through a Building Information Modeling (BIM). The concrete formwork repository can be used for different applications during various phases of the concrete formwork lifecycle. Some of the applications of the concrete formwork repository include visualization of design loads through a 3D model, material quantity takeoff, alternative design analysis, constructability analysis, and automated shop drawing production. BIM characteristics such as easy access to the information, visualization, and simulation capabilities also facilitate the development of an interactive knowledge repository, which in turn can foster a conducive learning environment. This knowledge repository allows the students to discover strengths and weaknesses of their learning practices and improve accordingly. It facilitates students to learn at their own pace by providing interactive access to the repository through 3D models. This paper discusses the feasibility of developing a concrete formwork repository through BIM and its applications for learning and teaching different aspects of concrete formwork.

**Key Words:** BIM, formwork, learning environment, 3D, repository

## Introduction

Students have different learning styles. Based on learning styles students can be identified as auditory, visual, and kinesthetic learners. Auditory, visual, and kinesthetic learners learn through hearing, seeing, and doing respectively (Marvin, 1998). Teaching construction engineering and management (CEM) courses by addressing students' different learning styles is a challenging task. Traditional lecture is one of the styles which is widely used for teaching CEM courses. In these lectures two-dimensional (2D) drawings are used to facilitate visual learning process. Sometimes, the lecture format style is complimented by including construction site visits. This teaching style provides an auditory and visual learning environment. However, inclusion of site visits within the course schedule is not always feasible due to reasons such as unavailability of construction sites meeting the class needs, class schedule conflicts, and safety issues (Haque et al. 2005). The interpretation of 2D drawings by students varies based on their educational background and previous practical experience. Students are required to develop three-dimensional (3D) models mentally by visualizing the different components of the project. Students with little or no practical experience often face challenges and spend more time in developing 3D visual models. With increasing complexity of present-day projects, even experienced professionals can misinterpret the 2D drawings. Additionally, lack of laboratory and training facilities are impeding the creation of kinesthetic learning environments. Sometimes traditional lecture teaching style also falls short to serve as an effective communication tool for transferring knowledge to students. Due to the lack of a conducive learning environment, which stimulates auditory, visual, and tactile senses, currently CEM students are unable to gain the required skills to solve real world problems in the construction environment. A user-friendly interactive knowledge repository that provides a conducive learning environment is needed to enhance students' learning capabilities. Building Information Modeling (BIM) facilitates development of a knowledge repository and fosters conducive learning environments. BIM is a process that provides a framework to develop data rich product models. In this process, real world elements of a facility such as beams, columns, and slabs are represented as objects in a 3D digital model. In addition to modeling, it provides a framework that fosters the integration of information from conception to decommissioning of the constructed facility.

BIM serves as an excellent tool for data management. It facilitates easy and fast access to the information stored in a single centralized database or in different databases held at various locations through the 3D model. The 3D model helps to comprehend complex details easily through better visualization than 2D drawings and promotes visual learning environment. Some of the BIM characteristics such as easy access to the information, visualization, and

simulation capabilities provide auditory, visual, and kinesthetic learning environments. These environments allow the students to discover strengths and weaknesses of their learning practices and improve accordingly. Any time and interactive access to the repository through a 3D model creates learning environment beyond time and space boundaries and facilitates students to learn at their own pace. This repository also helps as an effective knowledge transfer and communication tool. Development of these environments is part of ongoing research at Virtual Construction Instructional Laboratory of Construction Management Department at Southern Polytechnic State University. The objective of this study is to explore the feasibility of BIM for developing an interactive formwork knowledge repository which in turn can be used for teaching formwork courses. The BIM software used to develop the repository for this study includes Autodesk's Revit structures and Autodesk's Navisworks Manage. The study will be conducted in two phases. The first phase focuses on the development of interactive concrete formwork knowledge repository through BIM. The second phase focuses on the use of the developed knowledge repository in teaching concrete formwork processes. The paper presents an overview of the steps involved in the first phase of the research and discusses various applications of the developed repository. The second phase scope is not included in this paper.

### Development of Concrete Formwork Repository using BIM

This section discusses the methodology adopted for the development of a concrete formwork knowledge repository through BIM (see Figure 1). The steps involved in the development process include 3D model development with components broken down to reflect the construction process and integration of information to the 3D model components. The ease of integration depends on the availability and type of parameters in the BIM software. The information associated with the component of the 3D model can be retrieved through parameters of the component. These establish the links between respective files and components in digital format. The 3D model was developed using Autodesk's Revit Structure software. In general, formwork system for concrete consists of sheathing to retain concrete and supporting members necessary to hold the sheathing firmly in place. Members which support sheathing directly are referred as studs in vertical formwork and joists in horizontal formwork. The cross members which support studs and joists are usually referred as wales and stringers respectively. The different components of formwork system were represented by using various Revit Families. To facilitate interaction with the repository through the 3D model, the information is to be integrated with the 3D digital model. The steps involved in the integration of information with the 3D model include creation of new parameters and association of information to these parameters. Some of the newly added parameters include Design Assumptions, Unit Price, Specifications, Construction Video, Quantity Estimation Steps, Typical Section and Construction Photos. These parameters are made to appear under the group name 'Other' in the type parameters list. The URL data format is used for each parameter. This format is useful to establish the link between the respective files and component. The association of information to the model components is accomplished by assigning the file paths of the information to the parameters. This link between the documents through the path stored in the parameter allows easy access to the required information. The information needed was collected through paper format and digital format from various sources. Since BIM needs the information in digital format, the paper-based information was converted into digital format (PDF files) by scanning.

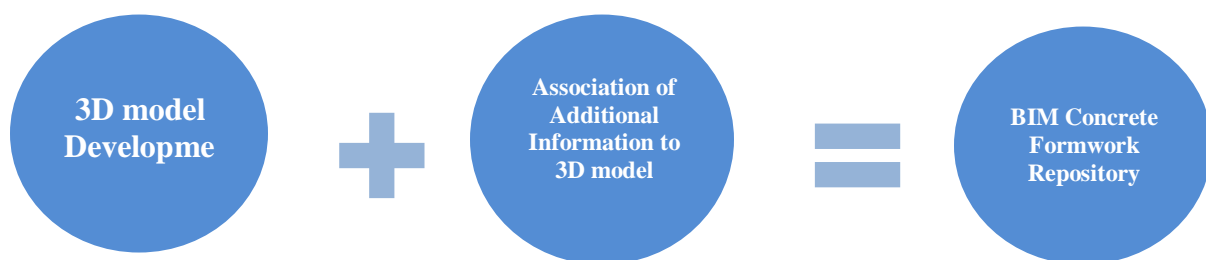


Figure 1: Methodology for BIM concrete formwork repository development

## Applications of Concrete Formwork Repository

Some of the characteristics of the concrete formwork repository such as easy access to the information, visualization, and simulation capabilities make it as an invaluable tool for teaching and learning process. Apart from teaching, concrete formwork repository can also be used for different applications during various phases of concrete formwork lifecycle. Some of the applications of the concrete formwork repository include representation of design loads through a 3D model, material quantity takeoff, alternative design analysis, constructability analysis and shop drawing production automation and are represented in Figure 2. The following sections describe in detail these applications.

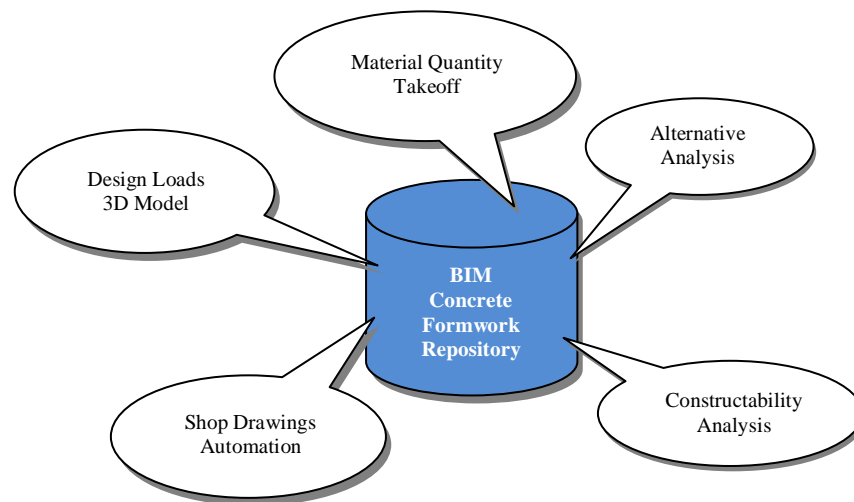


Figure 2: Applications of BIM concrete formwork repository

### *Design Loads 3D Model*

Formwork for concrete has to be designed to support all applied vertical and lateral loads until these loads can be carried by the concrete structure itself. In general, formwork system consists of sheathing to retain concrete and supporting members necessary to hold the sheathing firmly in place. Members which support sheathing directly are referred as studs in vertical formwork and joists in horizontal formwork. The cross members which support studs and joists are usually referred as wales and stringers respectively. Though they are referred with different names all acts as structural beams about vertical or horizontal plane. These need to be analyzed by using beam formulae for different vertical and horizontal loads. Vertical loads include weight of reinforced concrete, weight of forms, and live loads imposed during construction due to material storage, workmen, and equipment. Lateral loads include lateral concrete pressure, wind loads, and impact loads due to starting and stopping of equipment. Most of these loads are distributed over an area and these need to be converted as linear loads acting on beams. Elucidating to students the distribution of loads over an area through two-dimensional (2D) drawings is a challenging task. Traditionally, distribution of vertical loads on sheathing for slab formwork and wind pressure on sheathing for wall formwork is explained by using 2D drawings (see Figure 3a and 3b). The interpretation of 2D drawings by students varies based on their educational background and previous practical experience. Students are required to visualize and develop three-dimensional (3D) models mentally. Students with little or no practical experience often face challenges and spend more time in developing 3D visual models (Irizarry & Meadati, 2009). BIM can be used to produce 3D views of the design loads acting on different components of the formwork. The 3D views provided by BIM facilitate the students to visualize and corroborate real world elements easily. The loads such as point loads, linearly distributed loads, loads distributed over an area can be represented by using point, line, and area load features available in Revit Structure. Some of the 3D views of the formwork components developed in the repository include the distribution of vertical and horizontal loads on sheathing for slab and wall formwork (see Figure 4a and 4b).

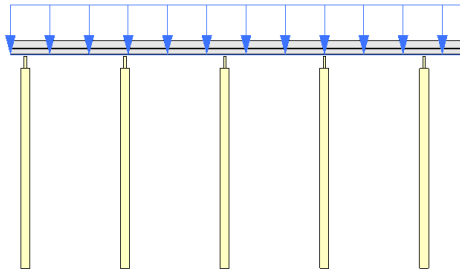


Figure 3a: 2D view of vertical loads acting on sheathing of slab formwork

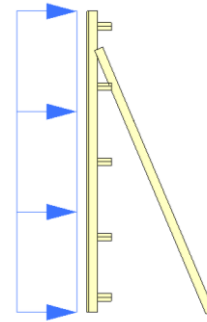


Figure 3b: 2D view of wind pressure on sheathing of wall formwork

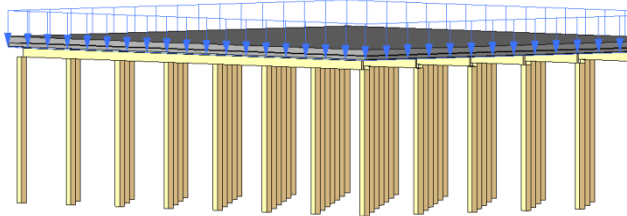


Figure 4a: 3D view of vertical loads acting on sheathing of slab formwork

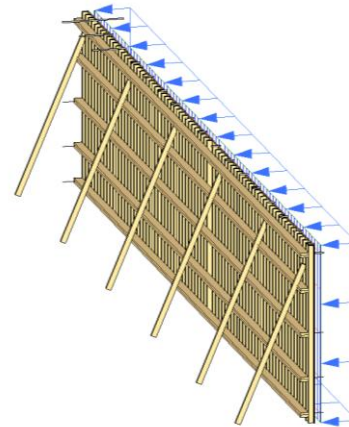


Figure 4b: 3D view of wind pressure on sheathing of wall formwork

### *Alternative design analysis*

The most immediate benefits of BIM for formwork design are better designs and increased efficiency and productivity. Because design and construction documentation are dynamically linked, the time needed to evaluate more alternatives, execute design changes, and produce construction documentation is reduced significantly. The ability of BIM software to automatically coordinate between drawings and details from a model eliminates errors and improves the accuracy. Alternative design analysis can be accomplished by using the Design options and schedule features available in Revit Structure. For example, a cost comparison between two design alternatives for stringers and shores for slab formwork (see Table 1) was accomplished by addition of a cost parameter to each component. The resultant total cost for each option can be calculated instantly by incorporating formulae in the parameters.

Table 1: Design Options Details for slab formwork

Component	Option-1	Option-2
Deck	$\frac{3}{4}$ " Plywood	Plywood
Joists	1 $\frac{3}{4}$ x 14 Plywood Web Joists	1 $\frac{3}{4}$ x 14 Plywood Web Joists
Stringers	Plywood Web Joists 1 $\frac{3}{4}$ x 14: 5 members spaced at 5' apart	Steel W12x26: 3 members spaced at 10' apart
Shores	Timber (5x5) spaced at 5' apart along each stringer	Steel-Round Hollow Tubular Section(HSS5x0.5) spaced at 10' apart along each stringer

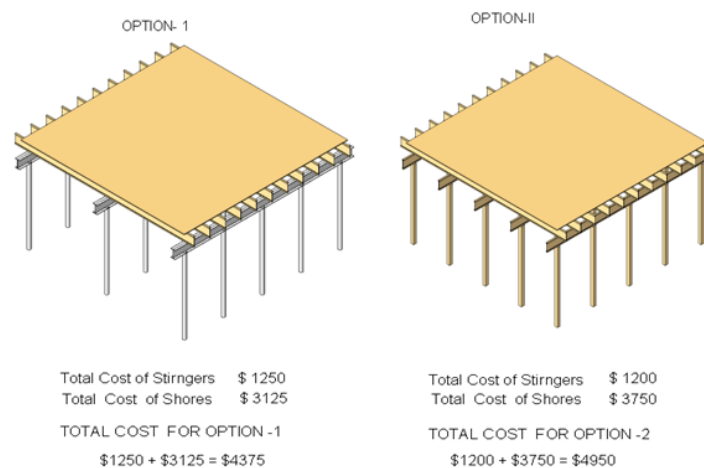


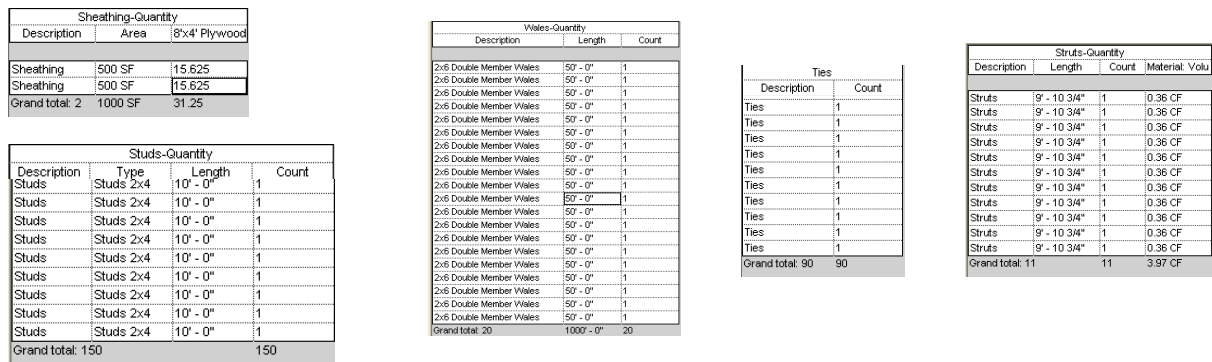
Figure 5: Alternative analysis results

### Material Quantity Takeoff

Traditionally, 2D drawings of different views such as plan, elevation and section view are produced independently and these are used for quantity estimates. Because of this practice and due to human involvement, the possibilities of coordination errors between these different views are high. These coordination errors can be eliminated by using BIM. In Revit Structure, the different views such as plan, elevations and sections are interlinked. The changes made in any view are reflected in other views instantly. This feature reduces human errors and helps to prepare error free quantity estimates. The material quantity takeoff of the different components can be accomplished by using the Schedule feature and Add Parameter function available in Revit Structure. For Example, the required material quantities for sheathing, studs, wales, ties and struts of wall formwork can be calculated through BIM by addition of new parameters using Schedule feature (see Figure 6).

### Constructability Analysis

Traditionally, the construction sequence is taught by using two dimensional (2D) drawings and critical path method (CPM) bar charts. Students need to develop 3D models about the construction sequence in their minds to correlate the relationships between different components of the project and schedule activities. Lack of 3D model visualization skills limits the students' ability to comprehend the construction sequence (Messner et al. 2003). The short comings of these traditional methods can be addressed by using four dimensional (4D) modeling (Koo & Fisher, 2000; Kang et al. 2004). BIM facilitates integration of 3D with schedule for 4D modeling. This can be accomplished by using the phase feature available in Revit. This feature is useful for creating a static visual simulation based on the project schedule and helps to develop a feasible schedule instead of using 2D drawings (see Figure 7). Dynamic simulations can be accomplished by integrating 3D models and schedules through Autodesk's Naviswork Manage software. These simulations help to explain and communicate the construction process better than 2D drawings and CPM bar charts.



The diagram illustrates the construction of a wall in four stages:

- Stage 1:** A single vertical panel is shown, representing the initial formwork or a single leaf of a wall.
- Stage 2:** Multiple vertical panels are shown side-by-side, representing the initial formwork or a multi-leaf wall.
- Stage 3:** The wall is shown with horizontal reinforcement (e.g., rebar or mesh) and vertical bracing, indicating the addition of structural strength.
- Stage 4:** The wall is shown with diagonal bracing, indicating the final stage of construction where the wall is fully braced and ready for use.

## Automated Shop Drawings

The different phases of formwork lifecycle include design, shop drawings production, quantity estimates, and constructability analysis (installation and removal of forms). In the design phase based on structural drawings, the design team determines the design loads such as dead loads, live loads, wind loads, and concrete lateral pressure. These design loads are then used to choose the formwork system which meets the flexure, shear, deflection and bearing requirements. The formwork system details determined during the design phase are then represented through shop drawings in the shop drawings production phase. The shop drawings production involves steps such as drafting, reviewing and correction. Traditionally the information between these teams is exchanged through 2D drawings. The number of review and correction iterations between design and shop drawings production teams depends on the reviewer's skills of interpretation and visualization of 2D drawings. These iterations can be reduced by facilitating 3D model exchange between design and shop drawings production teams. This can be accomplished by automating information exchange between design software and BIM software. In Revit, this can be accomplished by using the Application Program Interface (API) (Goedert & Meadati, 2008). An interface is developed using the C# programming language. This helps to produce automated shop drawings, which include the 3D model and the plan and elevation views (see Figure 8). The produced shop drawings are then further used during quantity estimates and constructability analysis phases.

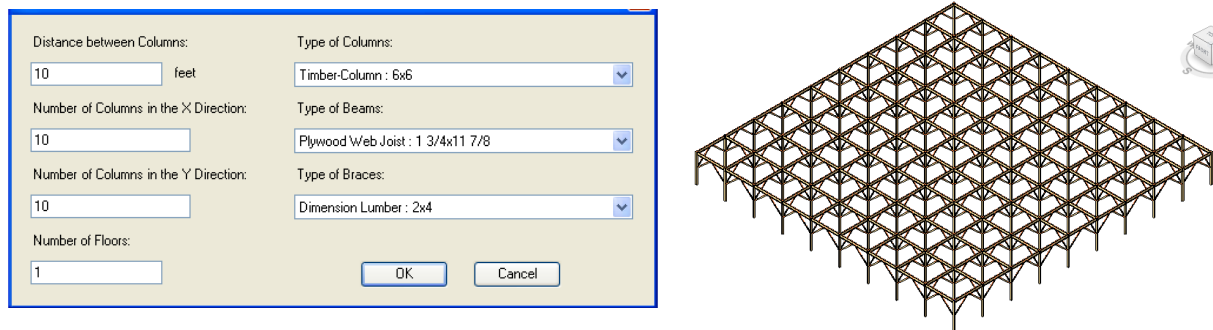


Figure 8: Interface screen and resulting shop drawings

## Conclusion

BIM has a great potential to serve as an effective teaching tool. BIM characteristics such as easy access to the information, visualization, and simulation capabilities provide a conducive learning environment. This environment allows the students to discover strengths and weaknesses of their learning practices and improve accordingly. The methodology discussed in the paper serves as an initial step to develop an interactive formwork knowledge repository that facilitates a conducive environment. Apart from teaching, concrete formwork repository can also be used for different applications during various phases of concrete formwork lifecycle. Some of its applications include representation of design loads through a 3D model, material quantity takeoff, alternative design analysis, constructability analysis and shop drawing production automation. Some of the factors, which govern the repository development process include BIM software, means of information association to the model, and information format (Meadati & Irizarry, 2010). Lack of some features in BIM software can increase the 3D model development time. The steps involved in the association of information include parameter creation and linking. These steps had to be repeated for each component of the 3D model. Depending on the amount of information to be associated, this becomes a time consuming process. Developing some means of automating this process can reduce this effort. Depending upon information format, inclusion of some additional steps affects the repository development process. For example, a document scanning process has to be included as an additional step for converting paper format information into digital format. Many other applications of BIM as a teaching and learning tool can be explored. Visualization of construction processes can be integrated with safety standards, operation procedures, and material or product data sheets. The continuous evolution of computing hardware allows such applications to be used even in mobile platforms. This facilitates any-time access to a knowledge repository and creates a learning environment beyond time and space boundaries. For example, tablet computers can be used to explain workers on site about installation procedures using visual representations developed on BIM software.



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