Preliminary Requirements for the Use of BIM tools in the Design and Construction of Formwork in the Mexican Construction Industry

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Abstract

Cast-in-Place Reinforced Concrete is a very common construction method in the Mexican construction industry. Formwork is a process that in general lacks standards for design, construction and use. In the majority of the projects, it is the general contractor's responsibility to identify means and methods to design and fabricate the formwork. This is a highly labor intensive process for which quality is difficult to control leading to undesirable aesthetic and performance results in the final cast-in-place concrete product.

The use Building Information Modeling tools in the construction industry have increased worldwide in the last years. The 3D object-oriented and parametric characteristics of these tools allow designers and builders to explore several alternatives resulting in more creative designs as well as cost efficient and constructible solutions. Because of BIM tools capabilities to create 3D visualizations, rich information data base, quantification capabilities and interoperability with scheduling, cost estimating and computer oriented automated fabrication methods, general contractors and subcontractors are finding the use of these tools of great help in the design, planning and control their production processes.

One of the key elements in the effective utilization of BIM tools is the development of a BIM Execution Plan in which the expectations and uses of the model are clearly identified and properly defined. This plan also defines roles and responsibilities of the BIM collaborators and establishes the workflow mapping all the steps of the process.

This paper, presents a preliminary approach to establish formal requirements for the use of BIM tools in the design, construction planning and control of job-built plywood formwork for cast-in-place reinforced concrete in the Mexican industry. Information about the contractor needs has been collected from ply-wood and other material suppliers, local design and construction specifications and codes, as well as from direct need assessment from six regional contractors in the Yucatan Peninsula, Mexico. The paper proposes specific uses of the model, object properties and attributes and proposes workflow maps for effective process implementation.

Keywords

Building Information Modelling, Formwork Design and Construction, BIM and Formwrok Design and Construction Planning,

1. INTRODUCTION

This paper presents a preliminary review of the current management practices for the use of wood formwork for Cast-In-Place (CIP) reinforced concrete in the Mexican construction industry. The research involved a focus group and a workshop involving managers of six local construction firms in the Mexican southeast region having extensive experience in this area and who also are aware of Building Information Modeling (BIM) and have a positive outlook about its potential benefits in the CIP industry. As a result of these interviews it was possible to assess the current situation and to propose the use of Building Information Modeling (BIM) as a tool to improve existing practices.

The group analyzed current practices through the different stages of formwork lifecycle from the design until material disposal. All the different actors who typically participate in this process, their corresponding technical/administrative actions as well as the impacts of these actions were identified. This analysis also included discussions on the potential benefits of BIM tools used along the process. The group reviewed the results of a recently conducted survey indicating that 76% of the respondents consider that the use of BIM has a potential positive impact in the industry (Suermann, et al., 2007). The group also reviewed specific studies indicating that implementation of BIM tools could allow designers and builders involved in cast-in-place (CIP) construction to build product models at the early design stages facilitating constructability reviews and promoting better lifecycle construction planning, execution and maintenance (Barak et al. 2009). Finally, the group participated in the development of process flow diagrams in which actors, objectives, tasks, responsibilities and sequences of execution were explicitly identified.

2. CURRENT SITUATION

Casting concrete in place involves laying/erecting steel reinforcing bars, setting the formwork in place, pouring and vibrating the concrete. Once poured, the concrete cures for a length of time that depends on the type of concrete that is used and on the selected curing methods. The formwork is then removed/ stripped so the solidified concrete element is produced in its final form. Studies conducted on small structures produced in a repetitive fashion show that all the tasks that are necessary to prepare for the pouring of concrete use 57% of the total worker hours involved in the production of CIP element. These tasks are supplementary to the main production process and do not reflect value added to the project (Corona et al. 2000). Placing the concrete only requires about 10% of the total labor. All together these tasks use 67% of total labor. A significant part of the supplementary/preparatory work is dedicated to formwork implying that improved efficiency in these tasks may lead to cost reduction and value added from labor work. This observation was used to further analyze potential contributions of BIM technology to improvements in the overall process

2.1 DESIGN

Formwork design in the Mexican construction industry is typically an activity that is based on previous experience the sub-contractor's field personnel and skilled labor force. It involves trial and error and is not a procedure formally documented. Optimized cost considerations are not necessary part of this decision-making process. Solutions used in the past by field staff are typically repeated regardless of the unique conditions that can be found in new projects. For example, in the case of a concrete beam with a 0.30 x 0.50 m cross section, a typical spacing for the support of the formwork bottom flange is 0.50 m. This rule of thumb, gener-

ated from personal past experience, may be used again under new construction conditions regardless of potential variations in the construction loading that may be encountered in a new project. Sometimes, spacing adjustments made based on personal judgment may eventually lead to partial of complete structural failure of the formwork. These decisions do not necessarily explicitly take into account the structural characteristics and behavior of the material being used and in many cases ignores design guidelines as prescribed by ACI 347.

2.2. COST ESTIMATES

Cost estimators typically use historical unit price databases applied to typical formwork assemblies that do not necessary reflect the actual formwork and construction methods used by the field personnel. Therefore the quantities of materials and labor involved are approximate at best leading to variations between the estimates and the actual costs. Assumptions are typically made on the number of uses for the formwork, for example, it can be assumed the formwork will have 6 uses when in fact it may have only 3 uses. These variations between estimates and actual costs may be of significant economic impact since the cost of formwork may range between 40% to 60% of the total cost of a concrete structure (Hurd 1995).

2.3. PROCUREMENT

In general, the amounts of material to build the formwork (plywood, lumber, nails, wire, pins and locks, oil, etc.) that are ordered for the site are not necessarily accurate to the specific needs of the project. Field engineers typically do not necessarily prepare material lists either because it is not part of their job description, do not have the detailed knowledge or do not have reliable detail in the costs estimates prepared by estimators. They order material based on quantities requested by the superintendent or the crew foreman who on the other hand use mostly their past experience and not scientific/accurate methods for this task. Unfortunately, this is an unacceptable but common practice that may lead to unnecessary waste or material shortages producing delays once the work has started. The information provided by the cost estimators is not necessarily reliable to control the handling of these materials on site. These practices also contribute to variations between cost estimates and actual costs.

2.4. FABRICATION

This type of formwork is typically job-built. Pine wood is commonly used for framing and plywood is used to support face concrete. The methods typically used for this formwork construction do not require the use of sophisticated tools. Workbenches are installed on site to prepare assemblies but these do not necessarily built to high safety standards and industrial tools. Steel nails 2-1/2” and 4” long are typically used to fasten the assemblies. These nails are common in the market, inexpensive and relatively easy to supply. However its use lead to undesirable wood splitting, affecting its re-use and are represent a safety risk for the workers. Studies have led to recommendations to discontinue it use (Lee 2009). These are not necessarily followed in the jobs.

2.5 STRIP FORMWORK

Must of formwork fabrication practices are not standardized leading to ad-hoc practices for stripping formwork that do not necessarily promote careful dismantling for further reuse but rather to techniques that favor the convenience of the worker and do not support proper supervision of these tasks. As a result, the damage suffered by the materials maybe significant which reduces its potential for further use. Use of nails to assemble the formwork also makes difficult to extract them without damaging the material

3. PROPOSED IMPROVEMENTS

The analysis of current practices held with the representatives of the six firms who participated in this research together with the review studies which have been conducted in the use of BIM related to its use in CIP industry, led to identification of three stages of the design-construction process in which BIM tools and BIM-based processes could be implemented. It was also noted that in addition to the problems observed in current practices there was a need for training and education of the labor force and for a better integration of the different roles and functions provided by all participants in the process. The three stages targeted for BIM process implementation were: design and construction planning, materials procurement and construction.

3.1. DESIGN AND CONSTRUTION PLANNING

In the design and construction planning the role of the BIM modeler is proposed. This is primarily a technical role that combines engineering and modeling skills and knowledge. The modeler becomes responsible, among other things, for formwork design to house the reinforcing steel and provide support to the concrete being poured before it cures and hardens. At the same time it was recommended to create a collaborative project team to complement the work of the BIM modeler. The team should include the project manager, field engineer, the job superintendent, the cost estimator and the subcontractor. The design should follow design codes and standard design practices. The cost estimator uses the BIM model to extract quantities of work, prepare more accurate cost estimates and review the economic feasibility of the design. The project manager, field engineer and job superintendent review the constructability of the design through all the steps involved in the fabrication, erection, and removal of the formwork. The design should follow recommendations proposed by Robinson (Robinson 2007) using applications based on .NET and the use of API programming supported by the 3D Object Oriented Parametric software used to develop BIM models (Revit 2011). The BIM model of the CIP structural elements is then used to support the design functions for the formwork according to local design codes and approved construction practices.

As the design is completed with the support of the BIM model, the procurement department uses bill of material to determine purchasing volume and obtain more accurate prices and delivery times from the market. The BIM model can also be used for 3D visualization and to better communicate the design intent to the fabricator and to perform clash analysis and construction trade and material coordination. The information storage capabilities of the BIM model provide long-term memory of the design to the firm which in turn can be used for improved future cost estimating as well as for future training and education of the labor force.

Figure 1 below shows a flow diagram in which participant interaction is mapped out through time during the design and construction planning stage. This stage, should confirm conclusions reached from previous research (Li et al. 2008) which indicate that 3D virtual models promote effective communication among the project owner, designer and builder. It also incorporates their findings indicating a more effective change management and design integrity based on the parametric characteristics and object orientation of the BIM software These improvements accrue to the process regardless of the type of construction whether it is public or private.

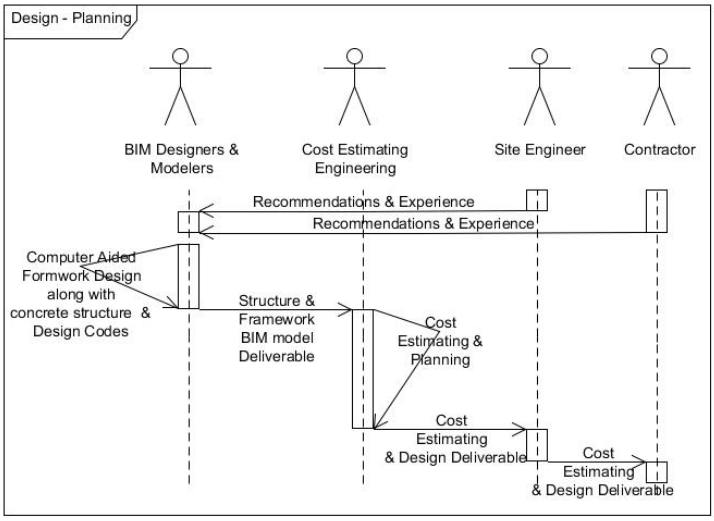

Figure 1.- Design and Construction Planning stage

3.2 PROCUREMENT

The BIM model becomes a tangible deliverable of the design and construction planning stage, as such all quantities directly extracted from the model can be used to prepare bill of materials and purchase orders. It is important to note that this process provides a more reliable source of information for the field engineer eliminating the questionable practice of having to depend on the information furnished by the job superintendent as the sole source of information in this regard.

The field engineer first reviews this information as it becomes available and then transmitting it to the firm's purchasing department who in turn prepares the purchasing orders to be sent to the specific suppliers.

This part of the process is not too different from current practices, the main difference, in this case, is that the information is obtained earlier and is more reliable and accurate. The flow diagram shown in Figure 2 can be considered as a "happy path" implying that no problems are anticipated and all steps of the process are executed as expected. Further research is necessary in this area to confirm these expectations and to discover potential deviations that are not foreseen at the moment.

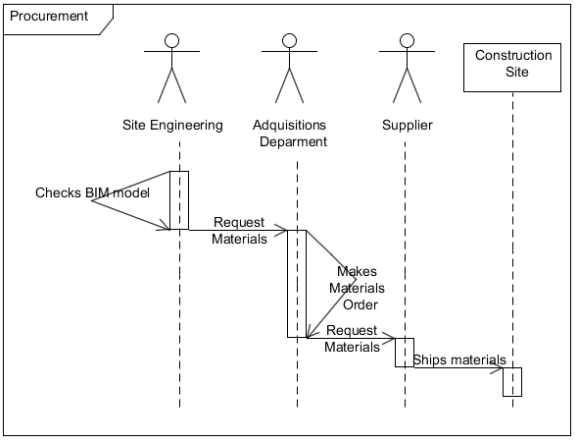

Figure 2.- Procurement stage

3.3 CONSTRUCTION

The field engineer or the project manager furnishes construction specifications to the formwork subcontractor who in turns prepares a material delivery schedule that will guarantee and support the continuity of the production process. This information is also used to plan for site storage according to its capacity and the size of the site. Figure 3 shows the flow diagram at this stage in which all participants and their corresponding interactions and collaboration needs are identified. Again, it is expected that the improved procedures based on 3D visualizations of the virtual model will promote better communication and understanding of the scope of the final product and its intermediate stages, which has pointed out before by previous studies conducted in this field (Li 2008).

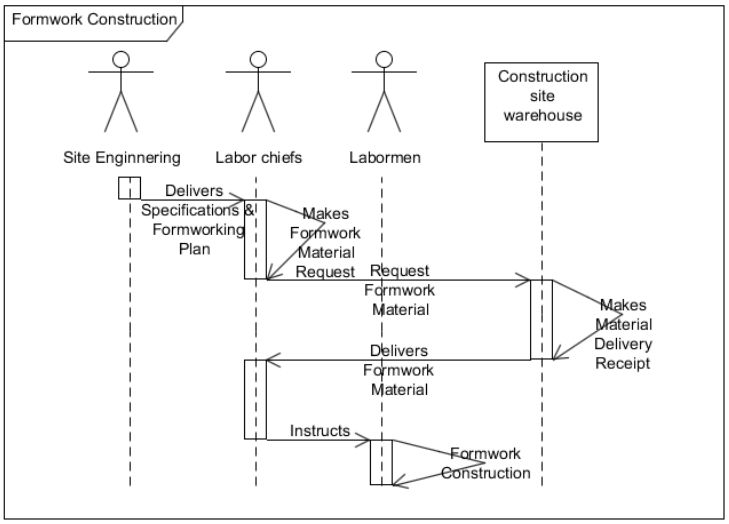

Figure 3 . Formwork Fabrication stage

4. CONCLUSIONS

It is understood that the introduction of BIM technology as proposed in this study requires an investment in software license, training and system support. However, the economic and non-economic benefits derived from these proposed improvements are expected to outweigh the costs and making it attractive.

It is still necessary to collect more specific and in-depth information about the functional requirements for different types of formwork used in the Mexican construction industry. This may lead to an increase in the use of pre-fabricated formwork which by the way it has been observed that with the use of BIM models pre-fabrication of building components are becoming a common trend in the industry. More modularization and standardization are also expected to increase in the design and fabrication procedures of formwork in the CIP industry, thus making the entire process more cost effective.

It is important to start the process of investing in BIM technology and its implementation as suggested in the approach proposed in this paper. In this way, virtual models specific to the Mexican CIP industry can be developed and tested in the context of BIM project teams. The emergence of the BIM modeler as a designer is just a natural outgrowth of this technology in which the software takes the role of creator of coordinated design documentation and 3D visualization tool enabling more effective communications among the members of the project team. Educational and training programs at vocational schools and universities will be also playing an important role in accelerating this change.

The approach herein proposed is primarily based on the opinion and vision of the six firms who were part of this study. They seem interested enough to invest in this field and willing to further promote a more in-depth future study

5. ACKOWLEDGEMENTS

The authors of this paper would like to acknowledge the valuable participation and contribution of the six firms involved in the study as well as to thank them for their partial funding. Due to confidentiality of some information they wish to remain anonymous for the time being.

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