Building Information Modeling for Quality Management in Infrastructure Construction Projects

Namhun Lee[1], Talat Salama[2], and George Wang[3]

[1] Assistant Professor, Manufacturing & Construction Management Department, Central Connecticut State University, New Britain, CT 06050; PH (860) 832-2624; email: leen@ccsu.edu
[2] Associate Professor, Manufacturing & Construction Management Department, Central Connecticut State University, New Britain, CT 06050; PH (860) 832-2619; email: talats@ccsu.edu
[3] Associate Professor, Department of Construction Management, East Carolina University, Greenville, NC 27858; PH (252) 737-1887; email: wangg@ecu.edu

ABSTRACT

With the growing use of Building Information Modeling (BIM) for vertical building projects, the use of BIM in infrastructure projects steadily increases. Construction companies that build infrastructure facilities are expecting the adoption of BIM since they have observed high return on investment (ROI) resulting from BIM for vertical building projects. In this paper, the focus is placed on the utilization of BIM for quality management in highway and bridge construction. A review of the literature on quality information model and quality control process is presented. The application of BIM for quality management is described. The results of pilot study by the authors on the model-driven approach to quality assurance (QA) and quality control (QC) is reviewed. Finally the issues and obstacles to BIM implementation in the infrastructure sector are discussed. Discussions in this paper are the critical aspects of the utilization of BIM for quality management in infrastructure construction project. Based on the results of this study, great potential of using BIM for quality management in infrastructure projects has been identified. Nonetheless, only limited amount of literature on this topic is currently available. It is believed that this study will set a stepping stone to future research and practice for promoting BIM technology in horizontal construction projects.

INTRODUCTION

Construction projects generate a large amount of complex information during its lifecycle, which is generally stored in document formats. Such information provides important potential for future use. The use of the information and knowledge produced during the construction process becomes more and more important in construction management.

The concept of computer product modeling originated in the 1970s. It is a set of interacting policies, processes and technologies generating a “methodology to manage the essential building design and project data in digital format throughout the building's lifecycle" (Penttilä 2006). In recent years, BIM has been proposed as an information integration platform to facilitate construction project management. It is critical to realize the integration between BIM and other information platforms applied in construction management since various information formats are actually being used. To support the integration of construction information, BIM data sharing and information exchanges among different formats/software should be standardized. Currently, the Industry Foundation Classes (IFC) standard has been commonly used (Froese 2003). Using the IFC standard, building products data can be expressed and exchanged.

BIM has been widely used in commercial building construction to not only virtually build a facility prior to its actual physical construction, but also simulate and analyze potential impacts (Smith 2007). However, very little information is available on using BIM in infrastructure construction projects. According to the 2012 McGraw Hill SmartMarket Report, several terms have already been coined for BIM for infrastructure, such as "Civil BIM", "Civil Information Modeling", "Horizontal BIM", and "Heavy BIM". Regardless of terms, the main objective is to utilize model-based technologies and processes in the infrastructure sector. One of the utilization scenarios would be the use of BIM as a tool for quality information integration for highway and bridge construction. Construction companies which build heavy, civil, and transportation facilities are expecting the adoption of BIM in their projects since they have observed high ROI resulting from BIM for vertical building projects.

BACKGROUND

The purpose of project quality management is to achieve the conditions of products or services that meet or exceed the customer's requirements and expectations. Information resources include the sequence of operations, controls, and checks that have to be implemented during construction. Prior to the commencement of construction work, general contractors are required to prepare specific project quality management plans which detail the control procedures. The quality management plans must comply with applicable ISO 9000 standards and/or technical specifications for a project. In addition, they must demonstrate the ability to deal with the principles and practice of product and service quality assurance and quality control.

Quality planning should focus on identifying quality standards relevant to the project, implementing quality policies and procedures, and managing responsibility for continuous process improvement. Moreover, inspection and test plans must be developed to verify if the product complies with the contract document. When planning conditions controlled for construction activities, a careful consideration should be given to the following:

- Specific jobsite environments
- Construction means, methods, techniques, sequences or procedures
- Materials, equipment and workmanship for the work
- Quality standards for the work
- Product characteristics, tolerances, and requirements
- Clear responsibility for the quality of the portion of the work

- Control Procedures for inspection and test as well as nonconformities
- Records as evidence that the work process controls remain effective

In general quality control process, QA and QC data should be collected from the general- and sub-contractors. For state highway agency's (SHA) highway construction projects, the current practice is that the contractor(s) is responsible for QC and agencies is responsible for QA. The creation and implementation of a model-driven approach which integrates the Product, Process, and Organization (PPO) model with BIM technology for quality management has the potential to facilitate and enrich a collaboration and integration with other disciplines through quality information integration. Responsibilities of project participants for the process and product of construction should be clearly identified and defined. A typical horizontal construction project has a complex web of interrelationships among numerous project participants in organization structures (Bass 2000). Due to this fact, it may be difficult to identify a participant accountable for a quality defect. Therefore, construction quality must be ensured through confirming responsibilities for each participant.

QUALITY INFORMATION MODEL

The Deming management method has been widely spread in the field of quality management since the early 1980s. The purpose of the Deming management method is to improve the practice of quality management (Deming 1981). The Deming management method consists of fourteen imperative points which are principles of transformation for quality management (Deming 1986). Through the fourteen points, Deming emphasizes the importance of process control (continuous improvement) and organizational structure (internal and external cooperation) for improvement of product (customer satisfaction). From this perspective, general contractors should focus on clearly identifying and defining product, process, and organizational issues (Harmel et al. 2006). Figure 1 illustrates a quality information matrix using the PPO model of quality control.

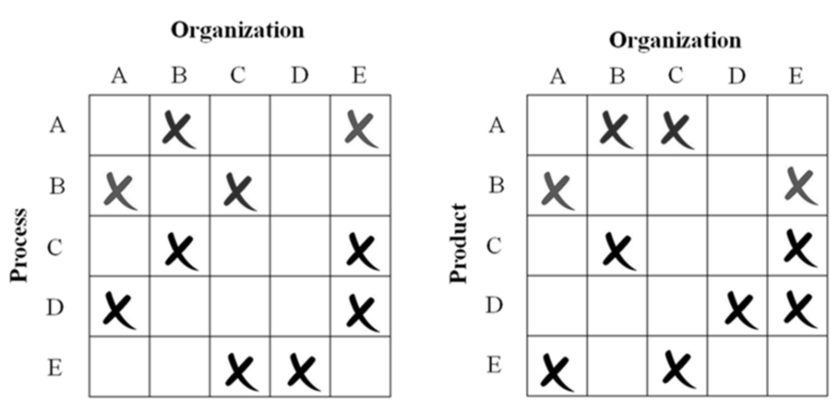

Figure 1. Quality Information Matrix.

During construction, contractors should monitor and control the three aspects through a simple quality visual control tool which uses different color codes to reflect the quality of construction performance. For instance, red check marks mean quality failure, green check marks mean quality pass, and black check marks mean "not started" (Refer to Figure 1). In addition, more color coding may be added to provide other information. For example, a gray background color means "completed", a yellow background color means "on-going", and a white background color means "not started".

In this paper, the term "product" refers to individual component to be controlled for quality in highway and bridge construction projects. Each component has several variables such as material, shape, size, location, and performance characteristics. The term "organization" refers to management structure and personnel who are involved in managing work process controls and rectifying nonconformities, if any. The term "process" refers to methods for quality measurement and analysis and procedures to deal with nonconforming products.

QUALITY CONTROL PROCESS

Quality control process implies a set of practices that integrate methodological approaches into quality management. It is implemented by consistent quality evaluation and control, called PDCA (Plan-Do-Check-Act) cycle (Shewhart 1931; Deming, 1981), in order to monitor and improve a product, service, and process.

In the PDCA cycle, the first step, "Plan" has several elements. General contractors must analyze quality policies, scope statements, product descriptions, and standards and regulations. Then, specific and clear goals must be identified including control procedures, inspection and test plans, and associated checklists. Goals are equivalent to construction specifications in which all the quality requirements including materials and methods to be used and performance features must be specified. The second step is the "Do" step, where the sequence of operations is implemented. The third step is the "Check" step in which the results of the completed operations are analyzed by elements of quality conformance and nonconformance. At some points during or after task performance, feedback should be provided by quality representatives. "Act" is the final step. Such components determined as non-conforming work should be corrected or reworked for quality improvement.

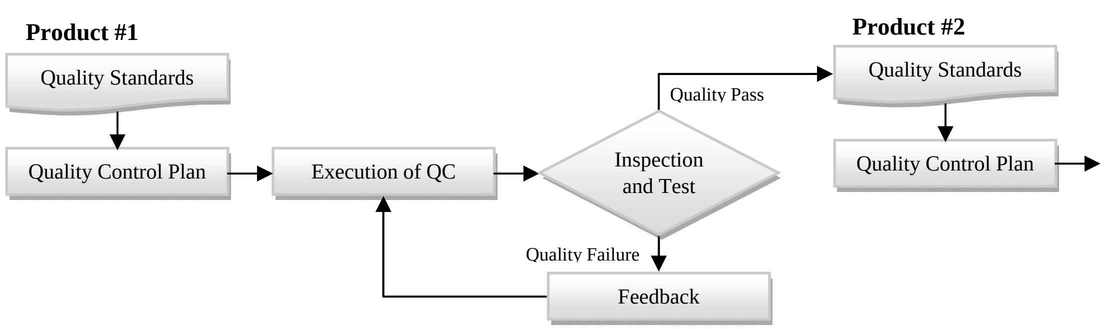

Figure 2. Quality Control Process Flowchart.

The PDCA cycle essentially emphasizes continuous improvement in quality management. Through this cycle, contractors must deal with the tasks and risks involved with quality control process. Figure 2 illustrates a flowchart of fundamental quality control process.

Quality control of highway pavement and bridge construction has been studied from various perspectives. In the quality management plan, applicable quality standards such as ISO 9000 and performance specifications must be identified. In addition, control procedures must be specified in detail and personnel responsibilities and authorities must be clearly defined. More recently in the construction industry, general contractors are expecting the adoption of BIM for quality management in infrastructure construction projects since they have observed high ROI from utilizing BIM in vertical building projects.

BIM FOR QUALITY MANAGMENT

A model-driven approach to QA/QC combines the PPO model with BIM technology to improve the quality of highway and bridge construction. Typically in highway and bridge construction, poor quality results from (1) misunderstanding of quality standards and control procedures for highway pavement and bridge components, (2) ambiguous responsibility for defective or nonconforming work, and (3) neglect of continuous quality improvement.

Using BIM technology for quality management, quality information integration can be embodied in a 3D model. Different layers on the 3D model can provide essential information about the quality of building components, the quality of materials and equipment, quality standards, and control procedures within a single information platform. In addition, clear and specific information about the responsibility assignment can be connected to the 3D model. In this way, project participants can better communicate about the progress of construction work. All project participants including owners, architects, engineers, contractors, suppliers, and subcontractors should have access to the 3D model and collaboratively proceed in the construction work faster and smoother, considering all aspects of quality requirements.

Parametric-oriented 4D BIM models can simulate the specific or entire process of highway and bridge construction to identify design errors, reduce uncertainties, and improve level of quality. Furthermore, other information such as schedule, safety, and resource can be added to the 3D model. Therefore, the successful application of the model-driven approach to QA/QC has great potential of communication, coordination, and collaboration in horizontal construction projects.

SURVEY AND RESULTS

To understand the current practices and viewpoints on using BIM for quality management in highway and bridge construction, a pilot study was conducted. Eleven BIM professionals in U.S. construction firms were asked to fill out a questionnaire intended for this initial study. The response rate was 45.5% with five individuals. Among them, sixty percent reported having worked in the construction industry for over five years. All respondents were from larger companies with an average annual revenue of over $500 million and 250 or more employees.

Question 1: "What would be the on-site QA/QC tasks?"

- Review and analyze specified quality standards, testing and inspection procedures, and quality control practices
- Develop and monitor the QA programs of the organizations involved in construction operations, including personnel qualifications and training, when applicable
- Perform field testing and inspection
- File documents and records to document management systems to keep evidence

Question 2: "What would be contributing factors to noncompliance?"

- Poor communications
- Poor engineering designs
- Improper quality control practices
- Failure to adhere to the code of professional ethics

Question 3: "Do you think a model-driven approach to QA/QC would be effective? If yes, why?"

100% responded that a model-driven approach would be effective to quality improvement. One respondent succinctly stated, "Using BIM is very effective because it provides us visual representations of the work process. This results in better job coordination as well as better communication." Another respondent summarized, "Accuracy of construction designs and information will increase because BIM can be used as an analytical tool to ensure compliance to quality standards." A third respondent described, "The BIM model supports the inspection progress by connecting quality information such as inspection and test plans or quality standards to the model." In addition, the rest of the respondents mentioned that BIM decreases complaints from suppliers and subcontractors, and reduces change orders and rework.

ISSUES AND OBSTACLES TO HORIZONTAL BIM

One of the main issues and obstacles to BIM implementation in infrastructure projects may be the competitive bidding process. Most highway and bridge projects are initiated by the public sector, most likely, the state highway agencies. The contract is usually awarded to the contractor who submitted the lowest bid. In this bidding process, there may be no room for BIM costs to win the bid. BIM technology usually takes initial costs even though it ultimately provides cost savings by the end of the project. Moreover, the public sector has had low interests in taking risks involved in the adoption of BIM technology, investing money in infrastructure development.

Due to the nature of infrastructure construction projects, BIM implementation would be difficult. Infrastructure such as bridges and highways is considered less complex than buildings. Nevertheless, many participants are involved in the construction process. A common project goal is well shared, but project participants such as subcontractors and suppliers typically try to retain their own ways in doing their business to maximize their profit.

According to Rowlinson and Walker (1995), there are no QA/QC standards for infrastructure projects due to the nature of one-off production and non-standardized members. Consequently, it takes much more time and effort to create 3D models since there is no official standardized product model. The created 3D models of building components will hardly be reused at other projects.

Finally, Lee et al. (2013) emphasize that there is a lack of BIM skilled personnel and insufficient BIM education and training programs. This would be another major barrier to utilizing BIM in infrastructure projects.

DISCUSSIONS AND CONCLUSION

BIM technology has been used for detecting design errors prior to actual construction and achieving better communication among project participants in vertical construction project. Without a doubt, general contractors who mostly work for horizontal infrastructure projects will have the same benefits from using BIM technology.

We believe that one of the major BIM application areas is to use BIM as a QA/QC tool for highway pavement and bridge components. In the quality control process, QA and QC data are to be collected from general and sub-contractors using Information and Communication Technologies (ICT) to improve the quality control process. The creation and implementation of a model-driven approach, integrating the Product, Process, and Organization (PPO) model with BIM technology, for quality management has the potential to facilitate and enrich a collaboration and integration with other disciplines. With support of ICT and BIM technology, quality information integration can be embodied through different layers on the 3D model to provide essential quality information including quality standards, requirements, and control procedures within a collaborative and integrated information repository.

BIM technology will allow for easy access to data sharing and information exchanges for quality control in infrastructure projects, utilizing an integrated database, providing the dynamic simulation of the construction process, and identifying critical control point deviations from the state DOT specifications. Therefore, the accuracy of quality control process will increase and the overall quality of highway and bridge construction will be improved.

In a typical infrastructure construction project, there are various stakeholders involved in QA/QC. Within the organizational structure of the stakeholders, only a limited number of QA/QC personnel are responsible for an increasingly large workload, managing complex quality control practices. According to Autodesk (2012), a more immediate increase in efficiency is expected from BIM implementation in an infrastructure project, which results in quality improvement and reduction in cost overrun. To ensure the continued quality of rehabilitation of the infrastructure facilities, a model-driven approach should be considered.

In conclusion, BIM technology has great potential as a quality management tool. BIM technology should be adopted to improve the integration and collaboration in infrastructure construction projects. The information integration resulting from the utilization of ICT and BIM technology enables us to enhance the overall project quality and the quality management in accordance with the customer's requirements and expectations.

REFERENCES

Autodesk, (2012). "BIM for infrastructure: a vehicle for business transformation". Autodesk, http://images.autodesk.com/adsk/files/valueofBIM_wp__en_FINAL.pdf (Dec. 8, 2013)

Bass, R. (2000). "Quality control of soil-cement construction for water resources". *Soil-Cement and Other Construction Practices in Geotechnical Engineering*, ASCE, 13-25.

Deming, W. E. (1981). "Improvement of quality and productivity through action by management". *National Productivity Review*, 1(1), 12-22.

Deming, W. E. (1986). *Out of the crisis*. Cambridge: Massachusetts Institute of Technology, Center for Advanced Engineering Study.

Froese, T. (2003). "Future directions for IFC-Based interoperability". *ITcon*, Vol. 8, Special Issue IFC - Product models for the AEC arena.

Harmel, G., Bonjour, E., & Dulmet, M. (2006). "Product, process, and organization architectures modeling: from strategic expectations to strategic competencies." *The 12th IFAC Symposium on Information Control Problems in Manufacturing*, INCOM'06, Saint-Etienne, France.

Lee, N., Dossick, C. S., & Foley, S. P. (2013) "A Guideline for Building Information Modeling in construction engineering and management education.". *Journal of Professional Issues in Engineering Education and Practice*, 139(4), 266–274

McGraw Hill Construction (2012). "The business value of BIM for infrastructure: addressing America's infrastructure challenge with collaboration and technology," *McGraw-Hill Construction SmartMarket Report*, New York.

Penttilä, H. (2006). "Describing the changes in architectural information technology to understand design complexity and free-form architectural expression." *ITcon*. 11, 395–408.

Rowlinson, S. M. & Walker, A. (1995). *The Construction Industry in Hong Kong*. Hong Kong: Longman.

Shewhart, W. A. (1931). *Economic control of quality of manufactured product*. New York: Van Nostrand.

Smith, Deke (2007). "An introduction to Building Information Modeling (BIM)". *Journal of Building Information Modeling*, Fall 2007, 12–14.