07-010

PROPOSAL OF BUILDING INFORMATION MODEL AIDED READY MIXED CONCRETE DISTRIBUTION

Bettemir, Onder Halis[1]

[1]Inonu University

Adverse weather conditions, poor workmanship and unfavorable incidences during the fabrication of cement may still cause lower compressive strength than the desired one. Building audit systems aims to reduce the adverse effects of weather and site conditions as well as fabrication and human errors. On the other hand, building audit is executed mainly by human endeavor which prevents a faultless inspection. In the present state of building audit and Building Information Model (BIM) executions weather, material and site conditions are not recorded. Consequences of this predicament can be stated as high uncertainty of the compressive strength of the concrete and very limited metadata about the construction phase for a forensic case. BIM can solve the stated problem with a low cost information technology in construction implementation. A data recording device attached to the concrete mixer truck can provide data about the stated items. The reported telemetry data of the ready mixed concrete can be extracted to the BIM software and retrieved whenever necessary. The proposed system not only improves the quality of ready mixed concrete but also provides important data which can be used to solve conflicts during the service life of the structure.

Keywords: *Building Information Model; IT in Construction; Building Audit*

PROPUESTA DE DISTRIBUCIÓN DE CONCRETO MEZCLADO LISTO PARA AYUDA CON EL MODELO DE INFORMACIÓN

Las condiciones climáticas adversas, la mano de obra deficiente y las incidencias desfavorables durante la fabricación del cemento pueden causar una resistencia a la compresión inferior a la deseada. La construcción de sistemas de auditoría tiene como objetivo reducir los efectos adversos del clima y las condiciones del sitio, así como la fabricación y los errores humanos. En el estado actual de las auditorías de construcción y del modelo de información de construcción (BIM), el tiempo, el material y las condiciones del sitio no se registran. Las consecuencias de este predicamento se pueden expresar como una alta incertidumbre de la resistencia a la compresión del concreto y metadatos muy limitados sobre la fase de construcción para un caso forense. BIM puede resolver el problema mencionado con una tecnología de información de bajo costo en la implementación de la construcción. Un dispositivo de registro de datos conectado al camión hormigonera puede proporcionar datos sobre los artículos indicados. El sistema propuesto no solo mejora la calidad del hormigón preparado, sino que también proporciona datos importantes que pueden utilizarse para resolver conflictos durante la vida útil de la estructura.

Palabras clave: *Modelo de información de construcción; TI en construcción; Auditoría de construcción*

Correspondencia: Önder Halis Bettemi; onder.bettemir@inonu.edu.tr

1. Introduction

Ready-mixed concrete has extensive usage in the construction sector not only because of legal rules and regulations but also for being easy, economic, and swift. Ready-mixed concrete has higher compressive strength than in situ mixed concrete with the same concrete mix design. However, adverse weather conditions, poor workmanship at the construction site and unfavorable incidences during the fabrication of cement may still cause lower compressive strength than the desired one. Building audit systems aims to ensure fulfillment of safety and design criteria by preventing the adverse effects of human errors, poor quality material, unfavorable weather, and bad site conditions. On the other hand, building audit is executed mainly by human endeavor which prevents a faultless inspection. Failure of avoidance of mistakes and omissions through out the inspection may end up with inadequate compressive strength of concrete.

Building Information Model (BIM) has high potential to improve the effectiveness of the building inspection and life-cycle management. However, the improvement is contingent on the size of the project, communication of the project members, and team members' familiarity with BIM (Barlish and Sullivan, 2012). Smaller firms have tendency of implementing BIM as 3D modeling, on the other hand larger firms utilize BIM for the management of design and construction as well as cost and schedule (Ghaffarianhoseini et al., 2017). According to a Survey conducted by Eadie et al., (2013) 55% and 52% of the BIM implementations are in the design and pre-construction stages respectively. BIM implementations are limited to 35% in the construction phase at United Kingdom.

Building inspection requires examination of many work items. Lack of experience of the inspectors, collection of the data and registration of the data in different media may cause inefficiency and data falsification (Ma et al., 2016). For this reason automation of inspection of concrete structures is an up to date subject (Koch et al., 2014). Borrmann et al. (2012) introduced a BIM based Life-cycle management system for the assessment of the condition of the structural elements of the reinforced concrete buildings. Motamedi and Hammad (2009) proposed data collection method by RFID tags for a life-cycle management system.

BIM can record, store, and retrieve the attribute data of the materials and the objects used at construction; therefore BIM can enhance the effectiveness of building maintenance and inspection (Tsai et al., 2017, Lou et al., 2017). Tsai et al. (2014) proposed a BIM enabled system with office and site modules. The sections to be inspected are entered via office module and the inspectors execute the ordered tasks by using the site module and enter the data related with the inspection by hand held devices. Lin and Su (2013) proposed a BIM based model for facility maintenance management system which can be executed with hand held devices. Chen et al. (2015) lists the possible technologies for automated data integration for BIM implementations as laser scanning, Auto-ID technologies, cameras, augmented reality, GPS and GIS, and sensors. Automation of site-to-BIM data transfer significantly reduces the deficiencies of BIM implementations (Hamledari et al., 2018).

BIM was mainly used for preplanning, design, and construction. However, recent studies are concentrated on the maintenance, refurbishment, and demolishment of existing structures (Volk et al., 2014). Literature survey conducted by Ding et al. (2014) represents that, researches on BIM lack quality, safety, and environmental management applications. However, researchers pay attention on the building inspection. Ma et al. (2018) integrated indoor positioning technique to detect the objects on site and their corresponding abstraction in the BIM model. This lowers the possibility of missing target objects during the inspection and makes sure that each check task is executed.

Researches on the quality control with BIM are limited with the confirmation of the execution of the inspection tasks. The previous studies ignore the righteousness and consistency of the inspections. Concreting is an error-prone process since it requires execution of many tasks properly. Allowable time interval between the delivery and placement of the fresh concrete is very limited (Liu et al., 2014). Ready mixed concrete producers do not send many truck mixers to construction site to prevent queuing up of mixer trucks. This wastes the equipments of the concrete deliverer (Park et al., 2011) but increases the risk of cold joint. Concrete should be delivered uninterruptedly; otherwise cold-joint may occur (Yan and Lai, 2007). Both cases have adverse consequences for the contractor and the concrete deliverer (Graham et al., 2006).

2. Statement of the Problem

In the present state of building audit and Building Information Model (BIM) applications factory of the cement, production date of the cement, how long the cement stored, average particle size of the cement, concrete mix design, when the concrete mixer added water to the dry mixture, how long the fresh concrete mixed in the mixer truck, how many times and how much water was added to the fresh concrete, result of the slump test, amount and kind of concrete additives, duration of concrete pumping, interruptions during concrete pumping, metadata of concrete specimens, outside temperature-humidity-wind velocity, and weather conditions during the curing period are not reported.

Construction sites at the city center may also cause traffic problem and the truck driver may not predict the arrival time correctly. If the truck driver mixes the dry concrete mixture with water earlier than the right time, concrete mixer may not reach the destination on time because of traffic jam and the fresh concrete may be over mixed. This event would never be reported at the present state of the building audit system which causes ineffective execution of building audit system and inefficient usage of ready mixed concrete. Consequences of this predicament can be stated as high uncertainty of the compressive strength of the concrete and very limited metadata about the construction phase for a forensic case.

BIM can solve the stated problem with a low cost information technology in construction implementation. A data recording device attached to the concrete mixer truck can provide data about the stated items. The reported telemetry data of the ready mixed concrete can be extracted to the BIM software and retrieved whenever necessary. Furthermore, a navigation system supported with GPS and GSM system can provide real time position of truck and traffic data. This data can be used to determine when the water should be added to the dry mixture to avoid over mixing. In addition to this, arrival time of the truck can be predicted by the site staff and concrete can be placed into the formwork with higher job efficiency. The proposed system not only improves the quality of ready mixed concrete but also provides important data which can be used to solve conflicts during the service life of the structure.

3. Proposed System for the Data Acquisition

Data to be acquired can be classified as given in Table 1. Data class column represents the data of specific attribute about concreting task. Data to be acquired column represents the related data of the data class.

Table 1. Data about concreting

Data Class	Data to be Acquired
Metadata of cement	Factory of the cement type of the cement production date of the cement how long the cement stored at concrete plant average particle size of the cement Storage of cement: Packed or Unpacked
Metadata of concrete	Concrete mix design, amount and kind of concrete additives how many times and how much water was added to the fresh concrete, result of the slump test,
Metadata of delivery	when the concrete mixer added water to the dry mixture? how long the fresh concrete mixed in the mixer truck?
Metadata of pumping	Duration of concrete pumping interruptions during concrete pumping amount of pumped concrete
Metadata of specimens	Which batch does the specimen belong to? When the specimen was taken? Where the concrete was poured?
Metadata of weather	Outside temperature-humidity-wind velocity during concreting weather conditions during the curing period

3.1 Metadata of Cement

Cement can be delivered to the concrete plant by two ways; packed and unpacked. If the cement is packed metadata of the cement except for how long the cement stored at concrete plant can be acquired by an RFID tag system. Right after the arrival of the cement bags, barcode of each bag should be read by a laser scanner and the related information with the cement should be recorded. Arrival time of the cement will be equal to the scan time of the cement bag. Each cement bag should also be scanned before they are unpacked and the reading time is recorded as departure time of the cement. The storage duration will be computed by considering the arrival and departure times.

The proposed method requires important amount of workmanship. Fortunately, most of the concrete plants obtain unpacked cement. Therefore, this proposal would be valid for a limited number of concrete plants.

If cement is delivered as unpacked situation, the carrying truck should have an RFID tag. The cement attribute data would be loaded at the cement factory. This attribute data would be loaded to the data management system of the concrete plant when the truck arrive the concrete plant. The arrival time of the truck is also recorded. The cement is stored at cement silo where the cement amount is managed by the first in first out principle. The departure of the cement would be predicted by this situation. However, different batches of cement may be mixed at the silo but this would not cause a significant uncertainty. Metadata of the cement is loaded to the RFID tag of the mixer truck.

3.2 Metadata of Concrete

Concrete mix design gives the ratio of amount of cement, fine aggregate, coarse aggregate, water and cement additives. This information is important to have an idea on the expected compressive strength of the concrete. Concrete may contain certain additive in order to increase its workability, retard or accelerate its setting, prevent freezing, reduce or increase air voids. Each additive has special effect on the concrete and its containment should be recorded. During the service life, the building would be exposed to freeze-thaw cycles, sulfate or acid attack, or any abrasive effect. The durability of the concrete can be predicted by the ingredient of the additives.

Concrete aggregates have direct affect on the compressive strength of the concrete. Therefore, metadata of the aggregates should be stored. Results of sieve analysis of both fine and coarse aggregate should be stored in the RFID tags. In addition to this, location of the quarry where the aggregates are obtained and the geological formation of the aggregates are also important.

Water-cement ratio of concrete is significantly important since it directly affects the compressive strength of the concrete. Water is added from the water tank on the mixer truck and the amount of water has to be recorded by a recording device. If the slump of the concrete is low, the workability of the concrete lowers and placement of the concrete into the formwork becomes very difficult. Therefore workers may insist to add more water to the concrete to increase the workability. If the control on the construction site is not adequate, truck driver may add water and the final compressive strength of the concrete significantly lowers. For this reason, amount of water and when the water is added to the concrete have to be measured and recorded by a digital water meter mounted on the mixer truck.

Slump test is performed in order to measure the workability of the concrete. If the slump value is too low, placement of the concrete inside the formwork becomes very difficult and amount of air voids in the concrete increases. If the slump value is too high, concrete becomes very fluid and segregation of coarse aggregates might occur. Therefore, slump value of the concrete should be recorded.

3.3 Metadata of Delivery

Concrete delivery at city center is significantly difficult because of the variability of the traffic. Arrival time to the construction site can not be predicted correctly by the truck driver. Therefore a navigation system which can obtain real time traffic data via GSM data transfer system would be suitable for the prediction. The system can guide the driver not only for the route to follow but also when the driver should add water to the dry concrete mixture. Adding water on time is also important because over-mixing of concrete may cause crushing of the coarse and fine aggregates, evaporation of water, and loss of workability due to initial setting of the concrete.

The concrete mixer may also weight in the queue at the construction site. If the concreting requires fine workmanship, waiting duration might also be long. Therefore, mixing time should be determined by considering the delivery and queuing. The mixing time will be equal to the time interval between the water is added to the dry mixture and the mixer truck docks on the concrete pump.

3.4 Metadata of Pumping

Concrete pumping is also an error-prone task which can cause adverse consequences. Process of setting of the fresh concrete starts when it is placed inside the formwork. Therefore concrete pumping should be executed without long interruptions. Interruptions may occur when the concrete trucks lose time in the traffic jam, or there might be too much concreting task where some of the mixer trucks are assigned to other jobs.

Interruptions during the concrete pumping can be detrimental if the placed concrete initially sets and hardens a certain amount so that the fresh concrete can not joins the fresh concrete. This phenomenon is called cold-joint. The adherence between the concrete layers becomes inadequate which significantly deteriorates the mechanical properties of the concrete. Usually cold-joints are not determined and recorded by the inspectors; therefore an automated detection system should be implemented.

Pumping logs of the concrete pump should be recorded on a data storage device located on the concrete pump. If a long time gap occurs in the pumping metadata, this gives a clue on the formation of cold-joint. Detection of existence of cold joint is important but location of cold joint is more important. Position of the cold-joint can be determined by a positioning device mounted on the mount of the boom of the concrete pump. The last concreted location before the long interval can be identified as the most suspicious place where the cold-joint might occur. Precise positioning devices are still expensive while bare GPS receiver cannot provide enough positioning accuracy. In the literature there are augmenting systems to improve the positioning accuracy of GPS systems in highly dense urban areas (Lu et al., 2007). With augmented GPS positioning systems placement of concrete can be precisely determined. This can provide useful information if concrete is placed indiscriminately. If concrete is poured by visiting several times at a certain place, then this again causes the risk of cold-joint. This deficiency can be detected by examining the time-location diagram of the concreting task. Amount of pumped concrete is also necessary information for the resolution of the conflicts between the contractor and the concrete supplier.

First concrete mixer truck of the fleet carries a special concrete mix design in order to lubricate the concrete pump. This concrete has more slump value and smaller aggregate distribution than the proper concrete mix design. Therefore, the ultimate strength of the first concrete batch can be lower than the remaining concrete batches. Concreted section of the structure with the first concrete mixer truck should also be reported. Positioning system on the boom of the concrete pump provides the necessary data for this purpose.

3.5 Metadata of Specimens

Inspectors have to take concrete specimens during concreting. The inspectors may not always wait for the whole concreting task and take enough number of specimens from the earlier concrete batch and leave the construction site. This situation may be welcomed by the contractors and the site engineers as well. If this is the case, quality of the remaining concrete batches will be unclear. Concrete specimens are obtained from concrete mixer trucks in the present implementation. The truck first pours some fresh concrete on to the ground and the concrete is filled to the cube forms and these specimens are stored at the inspection laboratory to perform compression tests.

This method of taking specimens prevents the control on the inspectors as there is no evidence about when and from which batch the specimens are taken. If the specimens are taken from concrete pump with a data logger, time and the batch of the specimen can be recorded. A special exit hole with a valve can be attached to the concrete pump. If the valve is opened, the concrete is poured to the outside and the time of this event can be recorded. This enables the recording of the batch of the specimen and when and how much the specimen is taken without human intervention. In addition to this, with the positioning system on the boom of the pump where the concrete is poured can also be detected. The collected data can be very precious for building management.

3.6 Metadata of Weather

Weather conditions significantly affect the setting time of the concrete. Therefore weather conditions should be recorded and the time when the dismantling of the formworks should be decided accordingly. If the formworks are detached earlier than the proper duration concrete section may sag too much or even collapse.

Concrete should be cured within its setting time. Intensity of the cure depends on the temperature, humidity and velocity of the wind. Therefore, the mentioned weather data should be recorded. These data can be recorded on the construction site or can be downloaded from a weather forecast website. This data can be useful for the detection of the causes of the deformation of the concrete throughout its service life.

4 Conclusion

In this study a BIM compatible data acquisition system for the inspection of concreting is proposed. The system aims to minimize the human intervention through the building inspection to prevent errors and ignorance. Moreover, the acquired inspection data can also be used for the management of the facility and prediction of the service life of the structure.

The proposed system can force the construction workers and the ready mixed concrete distributors to execute their jobs properly since the proposed system acquires many data which can detect the causes of the faults. Furthermore, the collected data can be used for forensic cases after a destructive earthquake.

Proposed data acquisition system is not an expensive system. Total cost of the system is around $1000 including the navigation, positioning, RFID tags and data recording devices. However, the proposed system requires modifications on the concrete pumps to obtain concrete samples. The expected quality improvement is significantly more than the cost of the system. Consequently, the proposed system can be a feasible investment both for the ready mixed concrete distributors and the contractors.

References

Barlish, K., and Sullivan, K. (2012). How to measure the benefits of BIM—A case study approach. *Automation in construction*, *24*, 149-159.

Borrmann, A., Lukas, K., Zintel, M., Schießl, P., and Kluth, M. (2012). BIM-based life-cycle management for reinforced concrete buildings. *Int. Journal of 3-D Information Modeling (IJ3DIM)*,*1*(1),1-24.

Chen, K., Lu, W., Peng, Y., Rowlinson, S., and Huang, G. Q. (2015). Bridging BIM and building: From a literature review to an integrated conceptual framework. *International journal of project management*, *33*(6), 1405-1416.

Ding, L., Zhou, Y., and Akinci, B. (2014). Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD. *Automation in construction*, *46*, 82-93.

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., and McNiff, S. (2013). BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in Construction*, *36*, 145-151.

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O., and Raahemifar, K. (2017). Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews*, *75*, 1046-1053.

Graham, L. D., Forbes, D. R., and Smith, S. D. (2006). Modeling the ready mixed concrete delivery system with neural networks. *Automation in construction*, *15*(5), 656-663.

Hamledari, H., Rezazadeh Azar, E., and McCabe, B. (2018). IFC-based Development of As-built and As-is BIMs Using Construction and Facility Inspection Data: Site-to-BIM Data Transfer Automation. *Journal of Computing in Civil Engineering*, *32*(2), 04017075.

Koch, C., Paal, S. G., Rashidi, A., Zhu, Z., König, M., and Brilakis, I. (2014). Achievements and challenges in machine vision-based inspection of large concrete structures. *Advances in Structural Engineering*, *17*(3), 303-318.

Lin, Y. C., and Su, Y. C. (2013). Developing mobile-and BIM-based integrated visual facility maintenance management system. *The scientific world journal*, *2013*.

Liu, Z., Zhang, Y., and Li, M. (2014). Integrated scheduling of ready-mixed concrete production and delivery. *Automation in Construction*, *48*, 31-43.

Lou, J., Xu, J., and Wang, K. (2017, November). Study on Construction Quality Control of Urban Complex Project Based on BIM. *Procedia engineering*, *174*, 668-676.

Lu, M., Chen, W., Shen, X., Lam, H. C., and Liu, J. (2007). Positioning and tracking construction vehicles in highly dense urban areas and building construction sites. *Automation in construction*, *16*(5), 647-656.

Ma, Z., Mao, N., and Yang, Q. (2016, June). A BIM based approach for quality supervision of construction projects. *Creative Construction Conferece*, 644 - 649.

Ma, Z., Cai, S., Mao, N., Yang, Q., Feng, J., and Wang, P. (2018). Construction quality management based on a collaborative system using BIM and indoor positioning. *Automation in Construction*, *92*, 35-45.

Motamedi, A., and Hammad, A. (2009, June). RFID-assisted lifecycle management of building components using BIM data. In *Proceedings of the 26th international symposium on automation and robotics in construction* (pp. 109-116).

Park, M., Kim, W. Y., Lee, H. S., and Han, S. (2011). Supply chain management model for ready mixed concrete. *Automation in Construction*, *20*(1), 44-55.

Tsai, Y. H., Hsieh, S. H., and Kang, S. C. (2014, June). A BIM-enabled approach for construction inspection. In *Computing in Civil and Building Engineering (2014)* (pp. 721-728).

Tsai, C. F., Xiao, Y. T., Chen, H. S., Ye, Y. X., Wang, C. H., and Liang, T. W. (2017, May). Integration of BIM and GIS to query management on pipeline of building-a case study of dormitory. In *Applied System Innovation (ICASI), 2017 International Conference on* (pp. 944-947). IEEE.

Yan, S., and Lai, W. (2007). An optimal scheduling model for ready mixed concrete supply with overtime considerations. *Automation in Construction*, *16*(6), 734-744.