# Infra BIM based Real-time Quality Control of Infrastructure Construction Projects

**T. Kivimäki[a] and R. Heikkilä[b]**

[a]Infrakit Oy, Finland
[b]University of Oulu, Construction Technology Research Center, Finland
E-mail: teemu.kivimaki@infrakit.com, rauno.heikkila@oulu.fi


**ABSTRACT**

**The paper introduces a new method for infrastructure construction project quality control, which enables real-time monitoring of project progress and quality.**

**The tradition method for quality control reporting in construction projects is measuring the built surfaces via total station or GNSS rover and then using surveying CAD software to produce cross section images, which show difference between measured points and 3D design surfaces. The cross section images are then printed on paper and stored. This method of reporting requires a lot of manual labour using CAD software, and due to this reports are often created weeks or even months after the construction work has been completed. The delay in quality reporting causes errors and prevents effective communication between the constructor and project owner.**

**In the proposed new method, 3D design surfaces are produced and stored on a central collaboration cloud system. All measurement devices used on the site are integrated to the collaboration cloud via internet connection. Typically, geometric measurements on a construction site can be done by using total stations, GNSS rovers or machine control systems. All measurements made are immediately transferred over the internet to the cloud and automatically compared to designs to find height**

**differences and colour coded based on required tolerances. The measurements are available for viewing and approval on a map display, using regular web-browser on PC or tablet devices. The new method has been tested on several pilot projects in Finland during 2014. Pilot projects have shown the proposed new method to significantly improve project quality reporting speed and provide unprecedented transparency and situation awareness to all actors of the project, resulting in gains in project predictability and profitability.**

**Keywords – Infrastructure; BIM; Cloud Collaboration; Real-time; Quality Control; Transparency**

# 1 Introduction

## 1.1 Background

Traditional infrastructure construction project has been estimated to have up to 57% waste in labour costs due to construction errors, lack of up-to-date information, suboptimal planning and information flow.

For example, the traditional the method for quality control reporting in construction projects is measuring the built surfaces via total station or GNSS rover and then using surveying CAD software to produce cross section images, which show difference between measured points and 3D design surfaces. The cross section images are then printed on paper and stored in folders. Because the large amount of data involved, there can be thousands of pages of documents, which makes finding relevant information time consuming. In addition, this method of reporting requires a lot of manual labour compiling the measurements from different sources, using CAD software to compare them with designs and produce the report pages. Due to this reports are often created weeks or even months after the construction work has been completed. The delay in quality reporting causes errors and prevents effective communication and project planning follow up inside the construction company. It also hinders communication and cooperation between the construction company and project owner.

Generally, while using traditional 2D drawings based construction process model, quality control (QC) has been determined to a process of inspecting and confirming the finished installation or work to be meet the design specifications enumerated in the contract documents. The purpose of QC program is to eliminate all possible defects. However, in practice this objective is typically never achieved. Nonetheless the program management should strive for the "zero defects" goal. In order for a QC program to be effective, there are many critical working tasks set to be accomplished, for example the drawings and associated notes have to be reviewed and understood, only approved shop drawings from the design team will be utilized, all testing equipment must be calibrated prior to starting any work, after installation any defaults noted should be taken care of immediately, and records should be maintained concerning the installation procedures and any problems encountered. [11]

Real-time or dynamic information management and quality control has recently been studied in several recent research project. In these studies, dynamic management or control was determined as flexible, fast and efficient reaction to the control of different working tasks on site. Also that can be information modelling (Infrastructure BIM) based, internet browser-based, independent of different terminals, and utilizes wireless and mobile information transfer. [1], [5], [9].

In a railway construction study in Finland [10], dynamic management of an information model-based railway construction was determined to be real-time and efficient reacting on impulses from construction site and site management that is comprehensive, communal and adaptable and utilizes information models. The efficiency of dynamic management is based on real-time information used in management actions. Gathering continuously real-time observations about the progress on the site can do this. [10]

In hopes to enable the industry combat this inefficiency, among others, the Finnish national Traffic Administration responsible for road and highway construction and operation has decided in spring 2014 to start ordering designs in a recently defined national open infrastructure BIM format called InfraModel3.

Using BIM models on-site for measurements by integrating total station and a CAD system has been explored in 2009, but the prototype system was too complicated and clumsy to use in production and lacked in data communication capabilities. [1]

In recent years, mobile devices such as tablets and smart phones equipped with 3G internet connections have emerged as tools to handle digital information for field workers in the infrastructure construction industry. As cloud computing services have become more and more commonplace in other industries, cloud based services for managing infrastructure construction projects according to the BIM methodology have also emerged. This type of service is called a "collaboration cloud".

## 1.2 Objectives

Objective of the research was to define and test a new method for real-time quality control reporting in infrastructure construction projects utilizing a cloud collaboration system and BIM methodology.

## 2 Method

Two separate projects were selected as pilot projects: (1) Riippa-Eskola; a railway construction project in central Finland, also selected as a pilot project by Finnish Transport Agency for model based quality control. (2) Tammitie; street renovation project in city of Espoo, also a pilot project for model based construction. On both projects the cloud collaboration system used was Infrakit.

First, project BIM designs were added to a cloud collaboration service. This means 3D surfaces of structural layers exported from design CAD software in open file formats such as DXF, LandXML or the Finnish national standard InfraModel3.

These designs can then be viewed by anyone using a laptop or mobile device connected to the internet. Designs are also checked automatically for export errors and a visual checking is made by user.

Fig. 1. Photo from Riippa-Eskola railway construction project.

Machine control systems, total stations and GNNS rovers are integrated to the collaboration cloud using available interfaces. These can be either a direct link from device to cloud service online interface link or if this is not available, data is transferred using job-files containing measured as-built points, retrieved from the device.

When as-built measurements are added to the collaboration cloud, the matching design surface is typically found by matching point and surface codes. If this is not available, user selects the design to match the as-built point to when uploading point file. After as-built points have been transferred to the cloud and matching design surface has been determined, they are compared to the design surface to determine difference in height coordinate. Points are displayed on map and coloured based on tolerances defined for the design surface. Black colour means point is within tolerance limits, red colour means point is our of tolerance limits. These results can be examined using a map display and cross sections. Examination can be done using a laptop or, if user is currently on the field, a mobile devices such as a tablet-computer.

The new method was tested on the Riippa-Eskola railway project. As-built measurements were made in cross sections every 20 meters using machine control systems that were directly integrated with the collaboration cloud and validated every 100 meters using total station to confirm the measurements.

A second project was the Tammitie street renovation project in a major city in Finland where measurements were made mainly using machine control systems that were not directly integrated with the collaboration cloud.

Fig. 2. Street renovation site (Tammitie, Espoo).

## 3 Results

In the dual railway construction project Kokkola-Ylivieska, the Infrakit system was tested by general contractor Destia Oy. University of Oulu performed a work study to clear out what kind of experiences the site personnel has met. In the project, the machine guidance was done using Novatron 3D machine control systems. After completing the soil base cutting work, the machine operator measured the as-built points from alignment lines between 20 m intervals using the specific as-built survey functions and tools of the machine control system. The measured points were further through internet connection saved to the cloud service provided by Infrakit Oy. After that site personnel of the contractor were able to see and evaluate the measured geometry of surface layers, and detect and react to the possible deviations in relation to the tolerances in question. According to the contractor, the Infrakit system was used as a part of their Infra BIM based quality control process. The Infrakit has been used for transferring the production models to the machine control systems, for checking the models by surveyors and automation operators, and as a tool for site foremen and supervisors. The Infrakit system has worked all the time pretty good and improved the productivity of production and the quality of completed structures.

According to the design office (Mr. Niko Janhunen, Finnmap Infra Oy) of the Tammitie street renovation project, the experiences of the use of the Infrakit collaboration cloud system were mainly positive. During the project, the software developers of Infrakit Oy managed to improve the system capabilities according to the feedback provided, which was evaluated by Mr. Janhunen to have succeeded well. The Infrakit software was found to be very useful. In the project, the information transfer from office to site machines and surveying systems was mainly executed using Infrakit. Main part of the delivered production models were used on site without any later updates or downstream work. The design office also found having the as-built measurements immediately available to be a very interesting experiment. The site was the first experience for the designers where they were able to see, follow and evaluate online the direct information flow and results from the as-built structures.

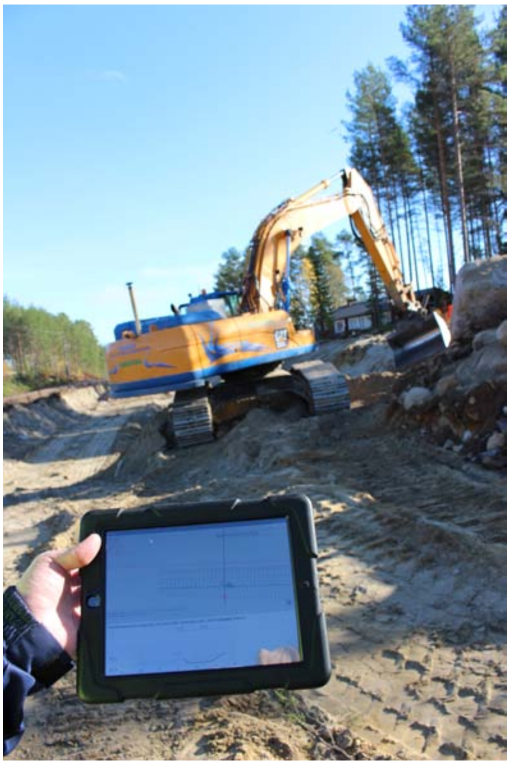

Fig. 3. Real-time quality control under testing in the railway construction project (University of Oulu).

On Tammitie site the designers used the table version of Infrakit. The usability was evaluated to been reasonable. Due to the new construction method where no wooden marker sticks were used, the Infrakit tablet use was seen to be very significant. Some new suggestions to the system developers were provided: the folder structure could have more hierarchy, the system could also be expanded to the area of document banks and also to improve the visualization of the different information models in Google Street view in a way that would enable the designs to be viewed in the correct vertical coordinate system.

Fig. 4. Cutting surface design added in the collaboration cloud. Also showing road centreline (red line).

Fig. 5. Several design surfaces on map (blue areas). Surface designs are triangle mesh files.

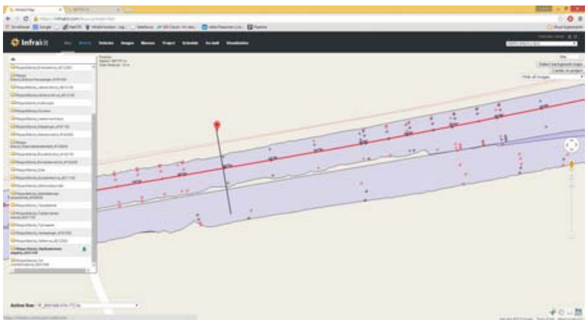

Fig. 6. Lowest cutting surface (blue area) with measured points (black and red crosses). Cross section line in black.

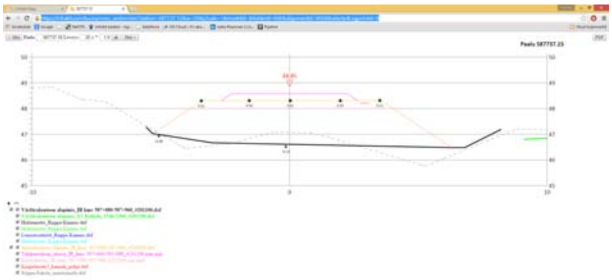

Fig. 7. Cross section from position shown on image x. Shows different layers and as-built points (red crosshairs and crosses) compared to design layers.

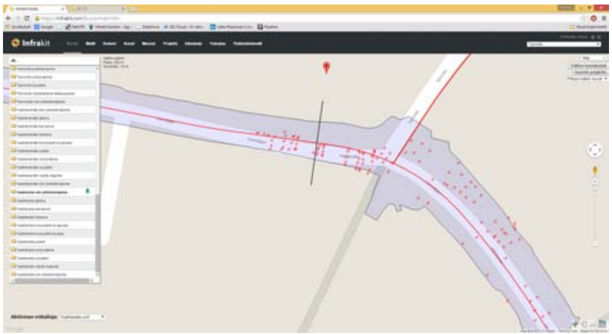

Fig. 8. Measurements of pipe ditch cut in street renovation project shown on map. Ditch was realized in somewhat different form than designed (see cross section below).

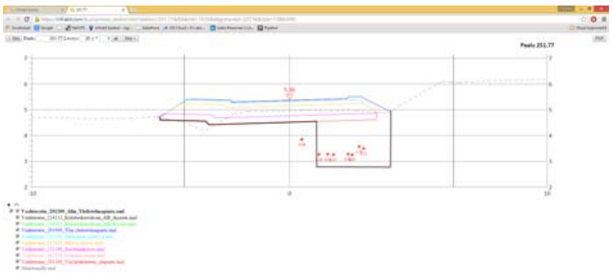

Fig. 9. Cross section of pipe ditch cut designs (black line) and as-built points (red crosses) show a difference in design vs as-built.

According to the contractor feedback (Espoo City), the Infrakit system has enabled better overview and understanding of the site situation as well as the location of the current site operations. The real-time control of site progress has provided a lot of benefits for site foremen. Compared to the traditional site control with 2D drawings, the new method has provided much more versatile abilities to look, compare and check different designed information. Also the available function to check and look at different optional cross-sections selectable freely at any point of the designs was met to be practically useful by site work staff.

Table 1. Total amount of as-built points in the collaboration cloud, both projects about 50% finished.

| Project | Total as-built points so far | Total project alignment meters | Points per meter |
|---|---|---|---|
| Railroad project | 52 176 | 30 000 m | 1,74 |
| Street renovation project | 3 618 | 1 200 m | 3,02 |

Based on the information models and the use of 3D machine control, the amount of information has continuously increased. The Infrakit system has enabled to all of the stakeholders and site workers real-time information service and reasonable version history for the changed files. The quality control according to the new National YIV2014 standard was able to be executed using the Infrakit system.

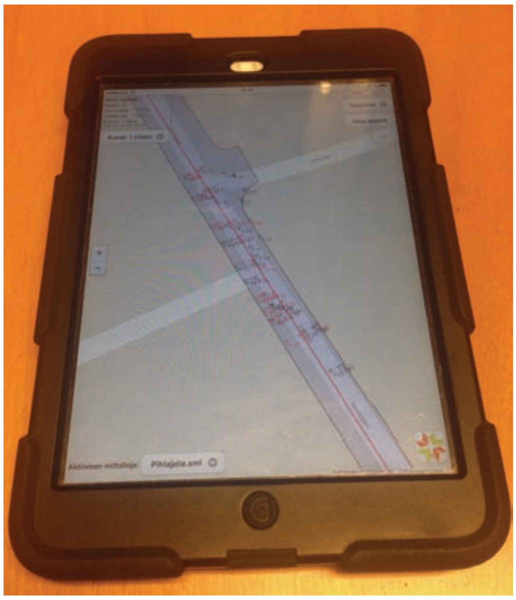

Fig. 10. Street renovation project designs and as-built points visible on tablet device. Device also displays user location on map based on internal GPS receiver. Tablet devices were used on-site by site foremen and installation crews to see designs and track progress.

## 4 Conclusions

Many clear improvements and benefits achieved in the carried experiments reported were observed in the real-time communication and transparency in the railway and road construction projects in Finland. Compared to the traditional quality control, no specials delays in information transfer and utilization were observed in the new method,

In the proposed new method, 3D design surfaces were produced and stored on a central collaboration cloud system. All measurement devices used on the site were integrated to the collaboration cloud via internet connection. All the measurements made in the experimental project part were immediately transferred over the internet to the cloud and automatically compared to designs to find height differences and colour coded based on required tolerances. The measurements were online available for different viewing and approval purposes on a map display, using regular web-browser on PC or tablet devices.

The real-time or dynamic quality control for road and railway construction sites seems to open new possibilities for all of the stakeholders being executing the construction operations. The key is to have continuous abilities to real-time and efficiently gather and react without delays to the different impulses from construction site.

## References


[1] Kivimäki T. and Heikkilä R. Integrating 5D Product Modelling to On-site 3D Surveying of Bridges. In ISARC'2009, The 26th International Symposium on Automation and Robotics in Construction, pages 445-450, Austin, Texas, U.S.A., 2009.

[2] AuthorSurname C. and AuthorSurname D. A conference paper. In *Proceedings of the conference*, pages 12–34, Sydney, Australia, 2014.

[3] AuthorSurname E. *A book*, volume 2(3). The Publisher, Publication address, 2014.

[4] Leavitt N. http://www.hh.se/download/18.70cf2e49129168da0158000123279/1341267677241/8+Is+Cloud+Computing+Ready.pdf

[5] Viljamaa, E. & Peltomaa, I. & Heikkilä, R. & Hovila, J. (2012) Advanced Process Control for Infrastructure Building Processes. The 29th International Symposium on Automation and Robotics in Construction, 26 June – 29 June, 2012, Eindhoven, the Netherlands, Abstract p. 67, Full Paper doi:10.4017/gt.2012.11.02.229.632

[6] Viljamaa, E. & Kilpeläinen, P. & Pentikäinen, V. & Sarjanoja, E.-M. & Heikkilä, R. (2009) On-line Process Management of Pavement Laying Using Wireless Communication Technologies. ISARC'2009, The 26th International Symposium on Automation and Robotics in Construction, 24-27 June 2009, Austin, Texas, U.S.A., pp. 348-356.

[7] Kilpeläinen, P. & Heikkilä, R. & Parkkila, T. (2007) Automation and Wireless Communication Technologies in Road Rehabilitation. ISARC'2007, The 24th International Symposium on Automation and Robotics in Construction, 19-21 September 2007, Kochi, Kerala, India, pp. 35-40.

[8] Current Analysis Inc. Cloud Collaboration Drives Business Value Across Industries. On-line: http://www.cisco.com/c/dam/en/us/products/collateral/unified-communications/7800-series-media-convergence-servers/current_analysis.pdf, Accessed: 27/01/2015.

[9] Heikkilä, R. & Tiitinen, P. (2013) Dynamic Management of Road Construction Operations on Site. ISARC'2013, The 30th International Symposium on Automation and Robotics in Construction and Mining, 11-15 August, 2013, Montreal, Canada, 7 p.

[10] Heikkilä, E. (2013) Developing the Dynamic Control Method for an Information Model based Railway Earth Moving Work (in Finnish). Master's thesis, University of Oulu, 2014, 118 p.

[11] Lambeck, R. & Eschemuller, J. (2009) Urban Construction Project Management.