UNIVERSITY OF CAMBRIDGE

Transforming construction: impact case study

Benefits to industry: improving project control and efficient progress monitoring through modern mobile technology; timely detection of scheduling discrepancies

Automated progress monitoring using mixed reality

The challenge to industry

Surveys suggest that less than a fifth of construction projects are completed on time, within budget and in accordance with the required quality standards. Delivering a project to these criteria is a great challenge for managers. Time and cost overrun caused by delays in project execution is a significant problem for the construction industry.

Around 60 per cent of British construction project organisations face time and cost overrun on at least 10 per cent of their projects. Characteristic examples include the Scottish Parliament Building, estimated to cost between £10m and £40m in 1997, which by 2004 had reached £430m. The development cost of the Olympic Stadium in Stratford, London, UK, was increased from an initial £280m to £701m by the time it was finished.

Poor and inadequate construction project monitoring and control lead to cost and time overrun. Progress monitoring is critical to successfully delivering a project on time and within budget but is made difficult due to the complexity and interdependency of activities. Inspection in indoor environments is even more challenging due to the interconnectivity of tasks and their complexity making it one of the biggest challenges that a project manager needs to overcome during a construction project.

Despite the importance of project control, the construction industry does not have efficient monitoring systems compared to other industries. Current practices are mainly manual and based on visual inspections, which are error prone and time-consuming.

Better project control

A real-time solution that needs no prior processing and provides a fast, automated comparison between the as-built and as-planned conditions would benefit the progress monitoring inspection. Efficient progress monitoring practice can reduce overruns by up to 15 per cent and improve costs by over 10 per cent.

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Emerging mobile devices can provide both images and 3D information of an environment in real-time. However, the potential of leveraging this captured real-time data with the design data on-site for addressing both the registration problem and the comparison of the as-built and as-planned data for developing a real-time automated progress monitoring inspection solution, is yet to be explored. Efficient methods for progress monitoring of multiple tasks, especially for indoor environments that are more complicated, are currently lacking. Hence, a real-time, automated, and efficient solution is needed that ensures easy data acquisition, automated information retrieval, and progress assessment of several tasks while providing direct visualisation of the results.

Augmented reality in construction

Efficient visualisation and communication of the results is essential to an effective progress monitoring system. Augmented Reality (AR) offers such a means to visualise the progress of a construction project. AR could also facilitate the inspection process itself by displaying useful information in the inspector's view. Augmented reality is a technology which supplements real-world observations with virtual computer-generated objects. Successful AR systems must combine real and virtual objects in real environments; run in real-time; and align real and virtual objects. Additionally, Mixed Reality (MR) has recently been introduced, mainly by Microsoft. This is a technology where virtual and real worlds are merged and co-exist.

The challenge for application of AR in construction, particularly for inspection, is in tracking the position of the user and accurately aligning virtual with real data on a mobile device.

Overcoming the challenge

Various methods, both static and mobile, have been proposed for registering the as-planned data to the real data and for tracking the position of the user for augmented reality applications.

Static AR methods have mainly been used for visualising the detected progress status of a building under construction. These use spatial information for aligning the 3D as-planned model with the 3D on-site as-built data and processing is performed at the office and not in real-time on-site.

Mobile-based AR methods have also been proposed for facilitating inspection. Methods that accurately register the virtual and the real data have been developed, but they either use heavy and cumbersome equipment that needs to be placed on a tripod at a fixed location, or use a static camera for capturing photos and augmenting them with building information modelling (BIM) information. Those methods, though, lack mobility and reduce the usability of the AR system. Wearable AR devices were developed but have been found to be limited in their utility.

In order to overcome this, marker-less mobile AR systems for facility management purposes must be explored. Additional marker-less mobile AR methods proposed in the last decade have not yet been implemented and tested thoroughly with (BIM) models and on a job site. The dynamic nature of construction site environments could result in additional challenges.

Currently there is a lack of marker-less solutions for inspection and mobile augmented reality inspection systems do not perform any comparison between the planned and the real status of a project under construction to automatically identify progress.

The answer could lie with the relatively cheap and portable mobile devices used in our everyday lives. In the case of progress monitoring inspection of buildings under construction, mobile devices have been used mainly for data management, completing reports and capturing photos of the site conditions.

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Wearable devices to facilitate inspection

Augmented reality has now started to be part of our lives and is a tool that allows the user to have useful information in his view and interact with it. During an inspection, design and schedule information of the project under construction is needed to perform the inspection. The idea of using mobile-based augmented reality stems from the fact that the required design information could be overlaid in the inspector's view for the area that is under inspection. That would save the inspector from having to extract data from 2D drawings, improve efficiency, and reduce the time of inspection. While the inspector moves through the building under construction, the position of the camera will be tracked and the required 3D design information for the area under inspection will be automatically projected in his view.

Wearable devices would be even more efficient than a common mobile phone or tablet PC for this purpose as such devices leave the inspector's hands free. Having the 3D design model registered to the real as-built environment and aligned with the corresponding view of the real environment, the next step is to compare captured as-built data from the mobile device against the as-planned 3D model for detecting schedule discrepancies. Colour coding can be used for helping the inspector identify objects that have been classified as behind, on, or ahead of schedule from the system.

Microsoft Hololens tried and tested

A mobile-based AR inspection system could also facilitate the inspector's movement inside the building. Since the system knows from the schedule which areas should be inspected, it could identify the optimum path and guide the inspector inside the building using indicators.

Three groups of devices and methods were deployed in this study:

1. 2D images taken from mobile devices and a model-based AR framework

2. Simultaneous Localisation and Mapping (SLAM) methods which provide both the estimated position of the camera and a 3D map of the scene in the form of a point cloud.

3. RGB-D devices; the devices tested were Microsoft Kinect, Google Project Tango, and Microsoft HoloLens. These devices provide direct information about the position of the user and the 3D reconstruction of the as-built environment. This method proved particularly promising.

Experiments were conducted with data from the Dyson Building at the University of Cambridge Engineering Department. As the Dyson Building has already been built, more columns, beams, and ventilation systems were added to the files, where possible, to also test the algorithm with objects that do not exist in reality.

The overall performance metrics of the proposed solution were: 76.6 per cent precision, 100.0 per cent recall, and 83.5 per cent accuracy. The 100 per cent recall means that all 'built' elements were successfully detected by the developed solution. Some scenes had substantial occlusions due to scaffolding, but the algorithm was still able to detect all 'built' elements.

Microsoft HoloLens performed well on-site. It fitted satisfactorily with a safety helmet and the battery could last for two-hour inspections. Microsoft HoloLens was able to maintain tracking and capture spatial data even during considerably sunny conditions.

Impact and benefits

This research proposed a real-time and automated progress monitoring solution using mixed reality for better accuracy and time and cost efficiency of progress monitoring inspections. The proposed solution allows inspectors to derive instant information about the progress of a building under construction by simply navigating inside the building. This allows them to identify schedule discrepancies between the as-built and as-planned status of a construction project and take timely corrective actions.

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Future prospects

This study marks the first steps towards the automation of progress monitoring inspection using mixed reality. Additional improvements can be considered and functionalities added to offer a more holistic solution to inspectors:

- improvements to the registration process for aligning the 3D design model to the real as-built environment

- improvements to the proposed semi-automated registration process. Currently, access to the HoloLens' IMU sensor is not available which inhibits matching the orientation of the building and the 3D design model. A similar solution could be provided if the device could be connected to a mobile phone and acquire the right orientation through the phone's GPS data

- the correct 3D design model can be loaded on the device using location readings from the phone's GPS in cases where a WiFi network exists on-site. A company with several construction projects can have the design models from all their projects on the cloud and the right model for that specific project would automatically be loaded onto the device when the inspector arrives on-site

- when comparing the as-built and design data for deriving progress status, progress is only detected for big objects with regular flat surfaces; mainly walls and columns. Further research required for performing an automated comparison between the as-built and as-planned data for objects with irregular shapes

- additional improvements to the time efficiency of the proposed solution. The current solution requires the inspector to visit all the areas that are under inspection and gather spatial data for the whole objects. When an object, which is connected with another object, is detected as 'built' that could possibly mean that the other object is also 'built' and the inspector would not need to inspect it

- additional machine learning techniques that would require only a small amount of spatial data for determining the progress status of an object depending on the object type

- an augmented reality navigation assistance functionality could be implemented for facilitating inspection inside a building. It could recognise from the schedule data which areas should be inspected, identify the optimum path, and guide the inspector inside the building using indicators.

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The Laing O'Rourke Centre for Construction Engineering and Technology, in the University of Cambridge Department of Engineering, was launched in 2011 with industry partner Laing O'Rourke to fulfil a shared vision of transforming the construction industry through innovation, education and technology.

Case study

This case study is based upon a Laing O'Rourke Centre for Construction Engineering and Technology Engineering PhD thesis titled: *Automated Progress Monitoring Using Mixed Reality* (2017) by Marianna Kopsida.

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