Near Real-Time Monitoring of Construction Progress: Integration of Extended Reality and Kinect V2

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Abstract –

Construction progress monitoring and visualization have recently undergone advanced development. However, the data exchange process between construction offices and jobsites still lacks automation and real-time data records. Furthermore, an information gap between construction offices and jobsite activity persists, and progress inspectors still need to visit jobsites to check progress and assign quality ratings. Therefore, this research proposes a near real-time construction progress monitoring system called (iVR), which integrates 3D scanning, extended reality, and visual programming to visualize interactive onsite inspection and provide numeric data. The iVR system contains four modules: 1) recording jobsite activity through 3D scan (iVR-scan); 2) processing and converting 3D scan data into a 3D model (iVR-preparation); 3) immersive virtual reality inspection in the construction office (iVR-inspect); and 4) visualizing inspection feedback on the construction jobsite using augmented reality (iVR-feedback). In other words, 3D laser scanners first capture an activity point cloud and the iVR-preparation algorithm processes and converts the point cloud into a 3D model that is sent to the construction office's BIM cloud. Then, the proposed VR mode in iVR-inspect enables a quality assurance inspector to trace workflow, compare current project progress with blueprints, measure objects, and add text or design notes to 3D models to improve the site management and decision-making quality. Finally, iVR-feedback sends inspection reports to jobsite workers, who can visualize them in an augmented reality mode integrated with graphical algorithms. An experimental laboratory trial is presented in this paper to validate the concept; the iVR system for progress monitoring successfully generated the required results. The proposed system has the potential to help progress inspectors and workers complete quality and progress assessments and decision making through the development of a productive and practical communication platform. It compares favourably to conventional manual monitoring or data capturing, processing, and storing methods, which have storage, compatibility, and time-efficiency issues. Moreover, iVR minimizes physical interactions between workers and QA inspectors, thus creating healthier construction jobsites that are characterized by minimal human interaction. Finally, the same approach can be applied to more complex construction activities with movable natures.

Keywords –

Kinect Camera; Augmented Reality; Virtual Reality; Building Information Modeling; Progress Monitoring

1 Introduction

Building Information Modelling (BIM) technology, a recent trend in the construction industry, is an exciting solution for achieving automation in construction project progress monitoring. BIM is a rich source of 3D geometry-related information, such as architecture, structure, and MEP; furthermore, it enables knowledge sharing and interoperability over a building's lifecycle [1–3].

Engineers at a construction site find it challenging to manage a complicated BIM model and recognize the necessary attributes in the model [4,5]. Since BIM models are stored on servers or separate computers, they are often not updated synchronously on the jobsite. In other words, the transfer of knowledge from the design office to the engineering office on the construction site is significantly delayed [6]. This delay is crucial in certain projects, such as rapidly tracked projects, where planning and construction occur simultaneously. Slower data exchange results in project slowdown or rework [7]. This implies a need for real-time data exchange between building and planning offices [8]. Therefore, designing a near real-time system for tracking construction projects and closing the distance between jobsite operation and construction offices is necessary.

The aim of this study is to evaluate the degree to which virtual reality systems can be integrated into and affect state-of-the-art construction progress monitoring workflows. This research demonstrates the degree to which mixed reality equipment and 3D laser scanning embedded in visual programming can solve these problems; furthermore, it assesses the effectiveness of the proposed device and framework. We aim to reduce the distance between the jobsite and the construction office, and establish a framework that can provide near real-time progress tracking and data quality control between the construction office and jobsite activities. Therefore, we developed a near real-time progress monitoring system called iVR that consists of four modules: 1) the iVR-scan module monitors jobsite activity using a Kinect scanner, 2) the iVR-prepare module converts captured point cloud data into a 3D model and sends it to the construction office, 3) the iVR-inspect module utilizes virtual reality to help inspectors check activity quality and write review comments, and 4) the iVR-feedback module utilizes augmented reality to visualize inspectors' review reports on jobsites. The iVR system underwent laboratory testing and produced successful results. This system can aid quality inspectors monitor jobsites from construction offices in near real-time, eliminating the need to visit jobsites. Thus, inspectors can monitor multiple activities over a shorter period compared to conventional quality inspection methods. Furthermore, iVR can contribute to a healthier construction environment by reducing human interaction between construction jobsite workers and quality inspectors in the office.

2 Literature Review

Point cloud has been used in different phases of the construction industry for planning and design; production and development; operation and maintenance; etc. [2]. During the planning and design process, point cloud helps in the reconstruction of 3D site models and existing buildings [2,4]. Suitable data acquisition process and devices for construction work include 3D laser scanning, photogrammetry, videogrammetry, and RGB-D and stereo cameras [3].

The Kinect 3D scanner uses the same technology that a mid-range 3D scanner, projector, or infrared camera might use to measure the depth of, and around, an object [9]. The two cameras of the Kinect enable it to scan almost every item in 3D with good precision. The Kinect cameras have been used in the detection and evaluation of construction sites, product identification, materials and labor [2,10], safety monitoring [11] and reconstruction [8]. Many simultaneous localization and mapping (SLAM) programs have used sparse maps to identify and concentrate on real-time monitoring [7]. Other approaches have been used for point-based reconstruction [5]. Kinect cameras reconstruct surfaces more reliably, based on real-world geometry; thus, they exceed point-based representations [7,8].

Immersive modeling increases the understanding of complex construction processes and facilitates the assessment of project situations at reduced costs and interference levels [12,13]. Furthermore, it enables synchronous cooperation between different stakeholders in planning and design [14,15]. The use of virtual reality during the design process has yielded significant improvements in design, which increase workers' safety during construction [16,17].

Laser scanning data are commonly used for dimensional and surface quality assurance in several civil applications and project quality management [18–20]. We propose a precise and effective laser scanning-based technique to reduce the distance between office and construction worksites by combining Kinect 3D scanning and extended reality for a near real-time dimensional and surface quality control approach.

3 Methodology

The research methodology's design and selection were divided into three steps. First, we analysed the current best practice in construction jobsite progress monitoring and selected the best technologies to achieve its objectives. Second, we developed a progress monitoring system called iVR. Finally, we validated the system with a laboratory test and analysed the results for development (Figure 1).

This research proposes a progress monitoring system, iVR, using extended reality and laser scanning. The proposed system consists of four modules: site model capture using 3D laser scanners (iVR-scan); conversion of point cloud into 3D mesh (iVR-preparation); Quality Assurance (QA) inspection and feedback report generation using VR (iVR-inspection); and visualizing inspection feedback on the jobsite using AR (iVR-feedback) (Figure 2).

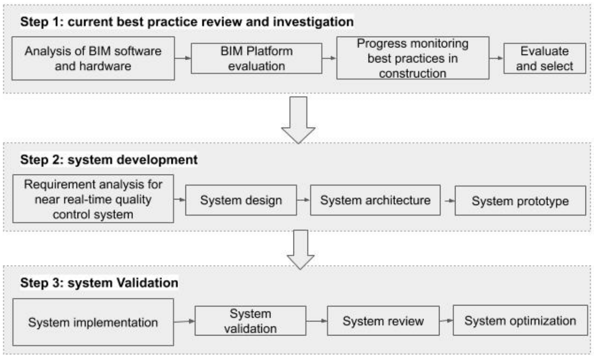

Figure 1. Research methodology design and selection

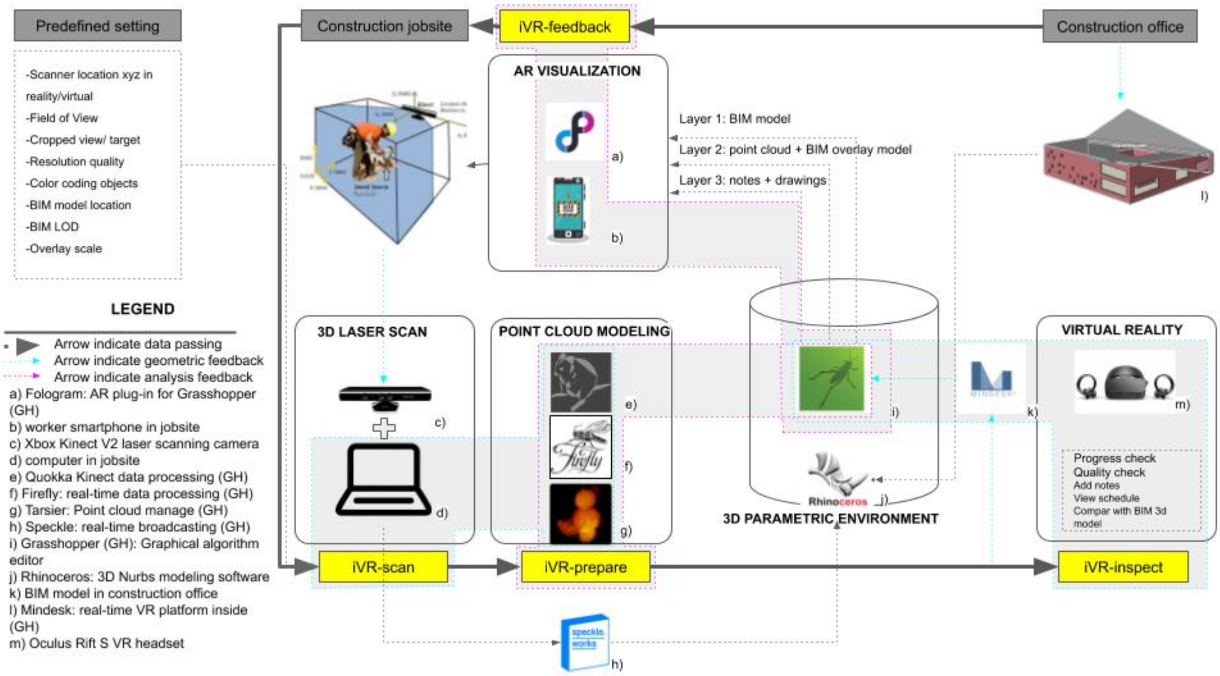

Figure 2. iVR system architecture connection loop between construction jobsite and construction office

3.1 iVR-scan

In this module, a laser scanner installed on the jobsite tracks an operation and sends live scanning data to the building office. This module focuses on the location, path, type of laser scanner, software, and hardware needed to complete this process.

This research used the Kinect V2 [21] [21], offering live scanning, as a 3D laser scanner. (Lidar + photogrammetry = Kinect 3D scan) represents the combination of cameras and sensors for target observation and distance recognition, thus building this research's concept.

The Kinect 3D scanner uses the same technology that is used by a mid-range 3D scanner, camera, or infrared camera to calculate the depth field of, and around, an object. The two "cameras" of the Kinect enable accurate 3D scanning of almost all items.

The scanning process for the target item is as follows: 1) Assign a position for the laser scanner in the BIM area, using the everyday operation optimizer iVR-scan position tool; 2) Set up the laser scanner and direct it toward target objects on the construction site; 3) Connect Kinect V2 to the Grasshopper PC Graphical Algorithm Editor [22,23] in the commercially developed software Rhinoceros [24]. Three point cloud libraries (Quokka [25], Tarsier [26], and Firefly [27]) in Grasshopper manage point cloud data and convert them into point, color, and GPS coordination in order to process the model in real time. Then, the Speckle cloud [28] sends cloud point data from the jobsite to the Grasshopper Rhinoceros in the development office, which gets synchronized and updated per time cycle.

3.2 iVR-preparation

The built algorithm in iVR-preparation processes these data in the construction office as follows, before the inspector gets access to the point cloud data collected from the jobsite: Step 1) Using the Speckle data receiver to receive point cloud data from job PC; Step 2) Building a visual algorithm that coordinates and compares point cloud colours, points, and GPS with the BIM model; Step 3) iVR-crop the selected item from the scanned scene, utilizing colour coding to minimize computational data and the time spent on further measures; Step 4) iVR-preparation uses Alpha shape matching cube mathematical logic [29] and a ball pivoting algorithm [30,31] to convert the point cloud into a 3D mesh object; Step 5) To reduce computational data and time spent, iVR-preparation uses a bounding box to include the produced 3D mesh; Step 6) iVR-preparation contrasts the cloud bounding point box with the BIM model and analyzes the operation's progress.

3.3 iVR-inspect

In this module, 3D mesh is aligned with the BIM model that was developed in iVR-preparation. A progress tracking investigator attaches the virtual reality (VR) headset to the Rhinoceros area and starts reviewing progress details obtained from the jobsite in VR technology. In general, the iVR-inspection module process is as follows: 1) Aligning the 3D mesh with the BIM model that was developed in iVR-preparation; 2) Linking the VR headset to the virtual reality and set layout design, size, and colors; 3) The controller monitors progress checks, building accuracy, and quality checks; 4) The progress monitoring inspector composes notes, highlights items, and draws illustration types as input; 5) Sending a fresh dataset kit back to the jobsite.

The reason we chose the VR inspection method rather than conventional site visits or BIM versus point cloud screen checking is to give the progress monitoring inspector the capability and power of immersive reality, thereby increasing inspection rate, speed, and accuracy.

Finally, after the progress monitoring inspector completes the progress and quality checks, draws illustrations, and writes comments, iVR-inspection sends multilayer data, including the BIM model, overlay model, comments, drawings, and an accomplishment report to iVR-feedback.

3.4 iVR-inspect

In this module, iVR-feedback uses the Fologram library [32] in Grasshopper Rhinoceros to simulate the inspector's files on the jobsite by utilizing extended reality. The iVR-feedback workflow consists of: 1) A worker's phone is registered with the Fologram tool in the construction office to receive live data; 2) The progress monitoring inspector sends BIM models, comments and sketches, output reviews, and overlay models to a mobile phone on the jobsite via Fologram; 3) A jobsite worker visualizes all the data received via mobile phone in extended reality. Using the parametric models representing the architecture, an immersive holographic instruction set is generated. Fologram synchronizes the geometry created on virtual reality devices through a local Wi-Fi network in a Rhinoceros or Grasshopper file. If a consumer makes improvements to a pattern in Rhinoceros or Grasshopper, those changes will be observed and forwarded to all related extended reality apps, thus allowing users to display digital models in a physical environment and on-scale, while making changes to these models using common, powerful CAD software devices. This tool inspector can also monitor whether a worker uses Fologram to correctly view comments using data from a jobsite; this is a very important benefit of iVR-feedback.

4 Case Study

A laboratory test was designed to simulate a specific activity's quality inspection between the jobsite and the construction office in order to validate the proposed iVR system. All four phases of iVR were introduced in this case study, and the time spent on each phase as well as their accuracy and practicality were reported to facilitate further device growth. The target activity in this research comprised six boxes (20 x 30 x 20 cm) laid in two columns with three boxes on each side of the construction. The target activity was designed in a BIM environment; Styrofoam boxes were used to represent the jobsite (Figure 3) in the laboratory.

The construction site working environment is constantly changing and therefore it is challenging to maintain a constant network between different devices. In the case study one operator runs the iVR-scan that consists of a Kinect V2 camera connected to iVR platform on a portable computer. The computer specifications used in the case study are: (processor: intel core i7 cpu, installed ram 32 gb, graphic card: nvidia GeForce gtx 1060 3gb) which registered 3d point cloud data from target activity in the jobsite. Next, the iVR-prepare cropped the point cloud scene and converted the targeted object into 3D mesh and sent it to the Construction office using Speckle doc cloud synchronizer between two iVR platforms using Wi-Fi internet. After that, the iVR-inspect used VR technology to check quality, insert notes, check progress rate and draw comments and send it to iVR-feedback. In the case study, a smart phone with 4G Wi-Fi was used in iVR-feedback to receive data from the construction office and visualize them in the jobsite. It is essential that both construction offices and iVR-scan are connected to the same wifi host. Finally the worker successfully visualized the inspector report in using AR technology as illustrated in Figure 3.

It takes about 17 minutes to finish one loop of iVR data exchange. It took 23 minutes for the inspector to comment using VR in iVR-inspect and for the worker to provide feedback visualization in iVR-feedback. In total, the laboratory test took about 40 minutes.

First, the laboratory research for the case study began by targeting one pile of boxes for 3D laser scanning, collecting 3D geometry vertices, and documenting the point cloud using Kinect V2 (seconds time). The Qualla library was used to control point cloud resolution to manage the processing and time required for computational data. Next, a cropping box was created containing only selected items (in our case, concrete columns) for the next stage in order to minimize processing time and remove the unwanted items that were scanned from the point cloud, as seen in the iVR-scan module section of Figure 3.

Next, iVR-preparedness monitors point clouds at any interval and updates current point clouds as a loop. In this case study, the interval for updating was set at 17 minutes. As described in the methodology, iVR-preparation used ball pivot algorithms to convert concrete column point

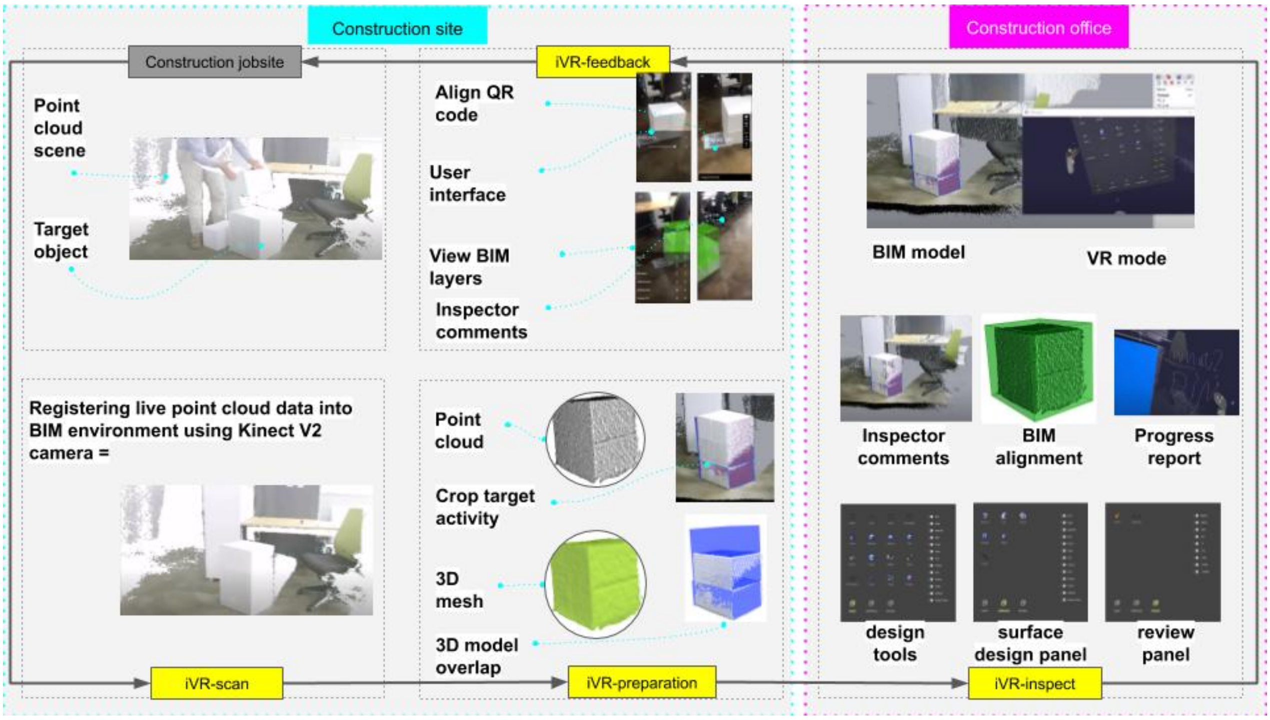

Figure 3. Case study lad test of column monitoring and quality check in near real-time using iVR system

clouds into 3D mesh. Using the Speckle cloud 3D model synchronizing device and overlaying it with the BIM model in the Grasshopper Rhinoceros program as seen in Figure 3, the iVR-preparation module was sent to the development office after the 3D mesh and the point cloud.

After that, progress monitoring inspectors receive point cloud and 3D mesh data in the building office using Grasshopper Rhinoceros and the Speckle data receiver tool. This research used Oculus Rift S [33] [32] to test iVR-inspection. The progress monitoring inspector simulated the 3D model in virtual reality, taking measurements, writing notes, checking development and consistency, taking snapshots of the required information, and producing development reports, as shown in the iVR-inspection module section of Figure 3.

Finally, the iVR-feedback algorithm sends inspectors' progress reports back to the worksite using Fologram's augmented reality platform in Grasshopper Rhinoceros. Workers on the site get progress sheet reports that include BIM models, feedback, sketches, and accomplishment pace, and overlay models. Notice that external details can often be added to progress reports, including job venue, mission independency, timetable, and building methods. In construction offices, workers' phones and receiver Fologram devices should be connected to the same Wi-Fi network for AR operation. In this case study, iVR-feedback effectively visualized input details on the construction site, allowing workers to check observations from the progress inspector in the overlay model and follow up on the relevant revised information requested by the progress inspector, as seen in the iVR-feedback section of Figure 3.

Figure 3. Case study lab test of iVR progress monitoring using extended reality and data exchange between construction jobsite and office.

5 Discussion

The adopted case study to track the concrete columns' progress showed that the new program can accommodate more complex and robust worksite construction. The iVR program successfully captured tracking data, analysed it, produced a progress inspector's report, and returned it to the construction worksite for input. Through iVR-inspect, auditors can harness the power of augmented reality to observe concrete columns from different angles and take samples that are out of the scope of conventional methods. This research argues that using iVR at the progress monitoring stage could improve decision making and result in a better product in a shorter time span and with the lesser human resources. The study also argues that this approach reduces humans' physical contact, which helps maintain social distancing measures to reduce the spread of infectious diseases, such as the COVID-19 pandemic [95]. The innovative methods, algorithms, and technologies developed in this research distinguish it from past research. Hence, this study makes several significant contributions.

First, the 3D laser scanner is directly connected to the

BIM environment in this research. A medium platform is not required, whereas other frameworks developed by researchers need a medium platform to convert scanned data into point cloud or massing geometry.

Second, the iVR system eliminates file format compatibility issues as every hardware and software is connected directly to the Grasshopper Rhinoceros' visual program. Many progress tracking models, on the other hand, involve various scanning tools in a range of formats (xyz, ply, pts, e57, las, and laz) and BIM-type formats (3dm, dwg, obj, ifc, rvt, and nwd); these variations in file format pose consistency concerns and can also trigger data fragmentation or failure due to the need for specific versions or data processing.

Third, data storage in the BIM environment is managed and controlled in iVR. To import or export information, Kinect apps, the VR headset, and Fologram are connected to the BIM environment, which make them extremely light and easy to work with. However, other state-of-the-art data management tracking exists in the scanning business' cloud or on handheld devices, which is inefficient because the customer has to link the processed point cloud data with another data cloud or other BIM applications to track the operation's progress.

In the case study, the accuracy of registered data in the iVR-scan was +- 3 mm compared to the actual measurements. The laser scanned data accuracy depends on various factors including: distance between target object and laser scanner, colour, scale, rotation of the target object, and the lamination of the room. The backside of the target object is not registered by the laser scanner therefore the 3d model of target object misses the backside which is one of the limitations of fixed laser scanners in the jobsite. The point cloud registered in the iVR-scan can is colour coded also which can help iVR-inspect differentiate different objects using associated colour code. The scale factor remained fixed to 1 to 1 throughout the iVR loop to maintain accuracy and data management. There was no data loose during the iVR loop except when iVR-prepare crop the scene point cloud and detach target object from the rest of the point cloud to reduce computation time. The system needs to be tested on a variety of construction activities with different object scales and colour to compare accuracy and efficiency of iVR.

6 Conclusion

Despite critical advancements in 3D scanning and photogrammetry techniques for tracking building progress, traditional quality control and progress testing often entail manual inspection or data analysis, which takes a long time to track and relies on conventional methods. A near real-time project monitoring tool (iVR) has been developed and tested to address this issue. The vital benefits of iVR are summarized, based on the findings, as follows:

(A) The study indicates that the device significantly reduces the information gap between the development office and jobsite; the collection, sharing, and computation of data requires fewer resources and time.
(B) Immersive, interactive, and augmented technologies allow investigators and workers to visualize tasks from perspectives that are unfeasible with traditional approaches; they enable effective interaction and an almost tangible approach to the data by providing investigators and workers with the appropriate means to sketch, report, and add data.
(C) Using iVR, inspectors can monitor several activities in a short period while remaining in the construction office. Furthermore, it can reduce human resources and improve quality and production.
(D) The system can ensure social distancing and minimize human activity among staff and construction officers, which might further mitigate the spread of infectious diseases on building sites during the ongoing COVID-19 pandemic.

To conclude, iVR's potential for progress tracking at the construction level was identified and validated with a laboratory-tested case study. This method will be presented in the future as a tab plug-in to commercial software applications; it will improve the progress tracking inspection process. The methodology's scope in the architectural field is limited to activity geometry, such as construction progress monitoring; however, in the future, it could be expanded to also include progress tracking (photogrammetry + Real 3D scanner), material tracking (GPS, RFID), worker tracking (RFID), and equipment tracking (GPS and distributed sensors). The iVR-scan is currently only applicable to jobsite target activity; however, it can be extended to not only focus on object quality checks, but can also consider human activity, such as human recognition and skeletonizing, to identify human figures and track skeleton images of people moving within the Kinect field of view. In iVR-preparation, generated reports could be integrated with BIM schedule targeted activity reports to give feedback to 4D BIM, facilitating automatic updates and increasing automation in QA inspection.

Data Resources

All of the iVR project's visual program algorithms and datasets are stored in the Mendeley Data repository https://data.mendeley.com/datasets/g2xh9k5yzy/1, and the results that are presented in this paper can be reproduced by following the readme file instructions or the methodology that this paper explained. Case study video footage can be found using these links: https://www.youtube.com/watch?v=jjT40j6UATw; https://www.linkedin.com/posts/ahmed-khairadeen-ali-09631791_cad-digitalconstruction-openbim-activity-6668921608612253696-RBeS; and https://www.linkedin.com/posts/ahmed-khairadeen-ali-09631791_openbim-dynamo-digitalconstruction-activity6674930637192998912-ASWP.

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