USING BIM AND MR TO IMPROVE THE PROCESS OF JOB SITE CONSTRUCTION AND INSPECTION

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ABSTRACT

The well-documented construction inspection record is important to the success of the construction project. Along with the development of information technology, mobile devices have been widely employed to record construction inspection. In addition, building information modeling (BIM) is also used to provide information for construction inspection. However, even with the help of mobile devices and BIM, the quality of inspection heavily depends on the information retrieved to examine the on-site condition. Therefore, there is a need to develop a system that can retrieve necessary information and compare it with the on-site condition in real time to improve the process of construction inspection. This research combines BIM and mixed reality (MR) technologies to develop a construction inspection system. Within this proposed system, the construction engineer can employ the head-mounted MR device, HoloLens, showing the BIM model on the construction job site with the exact scale to retrieve the required information for inspecting the jobs in progress. In addition, by employing the function of spatial mapping of the MR device, the construction engineer can also measure and record the on-site jobs to identify the differences between the planned and the actual works in real time. Furthermore, the inspection record can be uploaded to the database on the cloud for better management. The process and quality of the on-site inspection can be effectively improved by employed the proposed BIM-MR integrated system.

Keywords: building information modeling (BIM), mixed reality (MR), construction inspection, constructability.

1 INTRODUCTION

To ensure the quality of the work at the job site and track the progress of the construction project, construction engineers need to inspect the construction work and record the progress of the work items on a daily basis. In recent years, as construction projects become large-scale and complex, construction engineers need to spend more time and put on a lot of effort to record, organize and transfer the data which can reflect the status of the project [1]. In addition, a variety of information is required by the construction engineer during the inspection on the job site. For example, the associated drawings and specifications of the work under inspection. However, construction engineers may have a hard time accessing this type of information, especially if it is not in the digital format. Even the information in digital format, the three-dimensional space is not easy to present on drawings. On the other hand, the daily inspection form can only be recorded in written or in image, which cannot clearly describe the situation on the job site, and all inspection results are not systematically sorted out [2].

Several system frameworks have been proposed to assist construction engineers to inspect construction jobs with mobile devices, which makes the data retrieving and recording construction site data more efficient [3]. For example, cost and material management can be more efficiently carried out through the link to the database [4]. Furthermore, building information modeling (BIM) technology with the capability of the three-dimensional display is also applied in the field of construction inspection [5]. Through the display of the three-dimensional model, it is easier for construction engineers to understand the construction job site situation. Although BIM can contain and provide a lot of information, most of the models

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developed do not connect to work items. Moreover, due to the lack of employing the positioning system in these frameworks, excessive amount of information could still cause trouble for construction engineers to get the correct and necessary information. Consequently, even with mobile device that can retrieve information from BIM, construction engineers could still not obtain the sufficient information when conducting daily inspection for different work items on the job site.

Several new technologies have been proposed to help the construction engineer improve the construction jobsite inspection. Augmented reality (AR) is considered a new technology that can promote BIM information and improve the efficiency of operations on the job site [6]. Augmented reality can superimpose virtual objects in a real-world environment to provide more location-associated types of information. The screened information carried by the BIM model can be presented in the real environment through the AR device according to the location of the user, which can help the construction engineer obtain sufficient and necessary information for inspection on the job site. In addition, the mixed reality (MR) technology that uses environmental scanning devices to obtain environment information can record the local conditions into the system [7]. This new technology can help the construction engineer record the construction site status and compare it with the required work planned. Besides, the head-mounted MR device can let the construction engineer use his or her hands to do other inspection works, which could improve the efficiency and convenience.

Based on the above analysis, there is need to employ BIM and MR to improve the process and quality of jobsite construction and inspection. This research developed the construction inspection system on the head-mounted MR device, HoloLens, showing the BIM model on the construction job site with the exact scale to retrieve the required information for inspecting the jobs in progress. This system displays not only the BIM information in the actual environment but also allows the construction engineer to conduct inspection by measuring work performed at the construction site and complete the required form on the cloud. In the remaining sections, this paper first describes the problems of inspection on the construction job site. Then the research method is explained in detail. Furthermore, a case study is employed to verify the inspection system developed. Finally, the conclusions and future development recommendations are presented.

2 ON-SITE INSPECTION

The well-documented construction inspection record is important to the success of the construction project. However, as the scale of the project becomes large and the design of engineering is more and more complicated, the workload of the construction engineer to perform inspection increases as well. Therefore, how to improve the progress of the construction inspection to reduce the workload of the construction engineer but maintain the necessary steps of inspection is the essential issue to engineering management. To analyze the process of the construction inspection, several factors that affect the quality of the on-site inspection work are identified as follows.

2.1 Inspection form

The inspection form is used to help construction engineers record each necessary task when performing inspection on the job site. An inspection plan must be developed before the project begins to ensure the integrity and effectiveness of the auditing [8]. In addition, the format of the form will affect the performance of the inspection. A concise form can help the construction engineer perform inspection, but an overly succinct form could increase the chances of making errors by the construction engineer [9].

In general, all the construction daily reports and inspection records need to be properly kept for future reference. Through the database, this type of information can be classified and accessed more efficiently so as to improve the process of data transfer between different users [10]. A construction daily report with completeness and accessibility is the key to the success of the construction project.

2.2 Information required

In the process of construction inspection, a lot of information needs to be transferred, exchanged, and processed between different participants. The construction engineer looks for the building plan, details, relevant specifications and other related materials according to the work items under inspection. On the other hand, tracking the progress of the job performed requires different input data according to the work item. Therefore, the information required for both inspection and progress tracking should be carefully identified. In addition, completing the traditional paper form is a time consuming and cumbersome task. With the merge of employing the mobile device in recent years, the construction engineer can use digitalized form over the cloud environment, which can be timely and reduce the cost of data transfer as well.

2.3 New technology

In order to improve the efficiency of construction inspection and progress tracking, augmented reality technology has been proposed to help engineers understand the space situation on job site to develop a construction plan. On the other hand, the 4D BIM model combining BIM model with time-related information has been employed to effectively reduce conflicts and the rework [12]. In 2013, Park et al. [13] proposed a system framework that combines BIM and AR technologies to conduct construction inspection. With the help of the proposed system framework, problems in construction jobs can be immediately discovered. Along with the development of augmented reality technology, mixed reality technology providing environmental perception function was also proposed for construction inspection. The environmental scanning can make the size of the model more in line with the actual scale as well as record the status of the space by collecting environmental information [7].

3 RESEARCH METHODOLOGY

The research procedure of this study is shown in Fig. 1. First the construction inspection is analyzed to identify: (1) the information required for employing BIM during inspection; and (2) the functions needed to perform inspection by using MR devices. Then the BIM for inspection is built with work item data according to information needed. In addition, the required functions of the inspection system on MR device are developed. Finally, the integrated system for the MR device is developed.

3.1 Demand analysis

The regular construction inspection form serves for multiple purposes. Therefore, several work items are usually listed within a single form, such practice causes confusion in identifying the progress and quality of the work items and presents difficulties for subsequent classification for records. Therefore, before the system development, the format of the

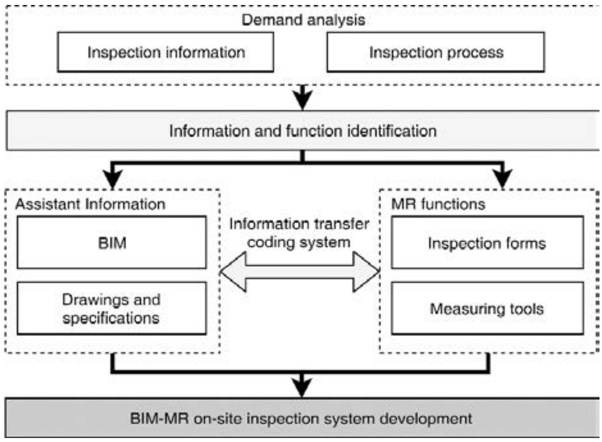


Figure 1: The research procedure of the construction inspection system development.

inspection form needs to be analysed first so that only the data input in line with the on-site inspection needs. In addition, this research also analyzes the inspection process to determine the demand of measure tools and develop several functions to improve it.

3.1.1 Progress tracking and inspection information

To better understand the information needed for inspection, this research analyzes the measuring unit of work item to design a more efficient format of the inspection form used on the MR device so that the data collected can accurately show the work progress. For example, Table 1 shows the regular unit used for several work items. In the work items "structure-column-concrete", volume is used to indicate the progress. Although the construction engineer usually records the volume of the concrete poured by tracking either the order to the ready mixed concrete plant or the volume of the concrete mixed on the job site, the volume of the concrete can be be recorded by multiplying the section area and height obtained by the MR device. An alternative way of measuring actual amount of concrete poured. However, the weight of rebar is hard to measure on the job site. Instead of measuring the weight of the rebar, the detailed allocation and arrangement of rebar can be identified by employing BIM. Therefore, if the progress of rebar related work item is going be identified by using MR device, the stage of the rebar completion can be defined in advance so that by counting the number or the set of the correctly installed rebars can determine the progress of the rebar related work items. For the finishing work items, such as "window frame" the progress can be recorded as completed or not depending on the set of the windows installed. by the set.

Table 1: Unit information for progress tracking.

Type	Element	Work item	Unit	Information need
Structure	Column	Concrete	Volume	Section area/height
	Column	Formwork	Surface area	Section perimeter/height
	Column	Rebar	Weight	Count or set
Finishing	Wall	Painting	Surface area	Wall height/width
	Window	Window frame	Perimeter	Window perimeter
	Window	window glass	Set	Completed or not

Table 2: Information required for inspection.

Work item	Inspection item	Information examined	Inspection type
Column rebar	Material property	Type SW420D	T
		No rust on the surface	T
	Section size	Length and width	L
	Main rebar	Quantity	C
		Size	D
	Stirrups	Spacing	L
		Size	D
	Stirrups arrangement	Staggered	T
		Standard hook > 75mm	T
		Tightening	T

Inspection type: T = Toggle box, L = Length, C = Count, D = Drop-down list.

In addition, the regular form for inspection is designed for hand writing or typing. However, with the help of using MR device, several types of data input can be automatically recorded to simplify the process of inspection. Table 2 is a typical inspection information required for the rebar of the column. The material property and the tying situation of the rebar can be recorded by applying toggle box to indicate if the job is completed or not. To inspect the correct number of main rebars installed, the count capability of the MR device can be employed. As for obtaining the length of inspection items, such as section size and spacing of the stirrups can be determined by using the measuring tools of the MR device. The drop-down list can show the type list, such as rebar size, arrangement type. Through classifying different types of information required, the inspection form can be recorded more efficient.

3.1.2 Inspection process

To better understand the function required for the on-site inspection. This study also analyzes the process of the inspection work. Fig. 2 indicates the traditional construction inspection flow. First, the construction engineer should prepare the associated information, such as the associated drawings and specifications and forms needed, for the inspection before going to the job site. Nowadays most of construction engineers can acquire the digitalized data to review the associated information with the mobile device. However, the construction engineer still needs to obtain the right information for inspection, sometimes, this searching process could be troublesome since the construction engineer has to screen out the information in advance before conducting the inspection job. For the large-scale construction projects, the positioning device is usually used to help the construction engineer to quickly find the area where he or she conducts inspection. Similarly, the positioning device can be used to assist the construction engineer to obtain the information more efficient to improve the process of the construction inspection. In addition, the construction engineer needs to use various tools to measure distance, quantity, horizontal level and vertical degree during the inspection. Furthermore, all associated information and forms required should be accessed through the cloud. From the above inspection process analysis, it is evident that the MR device can employed to provide all necessary functions and acquire the associated information according to the location of the construction engineer through the positioning capability of the MR device.

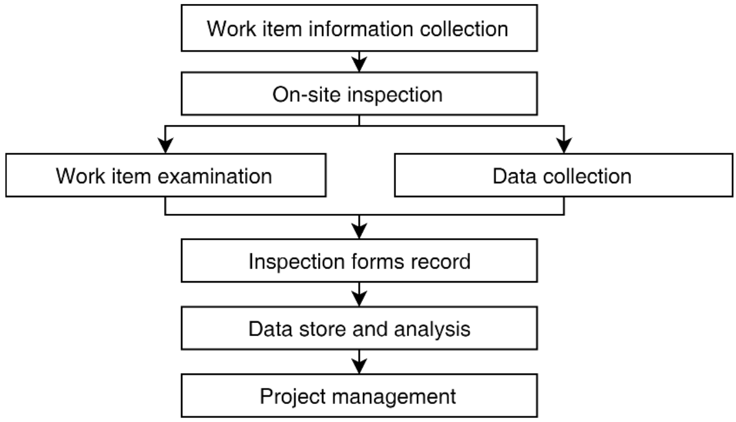


Figure 2: Traditionally inspection flow.

3.2 Information and function identification

Through the above analysis of the information needs and the inspection process, it is clear that BIM and MR are the suitable technologies used to develop an innovative inspection system to improve the process of construction inspection on the job site. As indicating previously, BIM should be developed according to the information needs for inspection. The procedure and the requirements for BIM development is described in the following section. In addition, the MR device should provide the functions needed to help the construction engineer perform inspection. The function identification is also presented in the following section.

3.2.1 BIM

This study employs BIM as the information integration platform to obtain the necessary information for inspection. Autodesk Revit 2018 is used to develop the BIM needed of this study. Since Revit is element-oriented authoring software, as shown in Fig. 3, the attributes of an element are important features for determining the quantitative information needed for

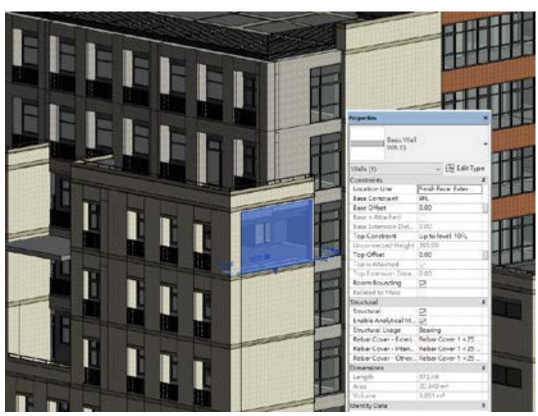


Figure 3: The information of BIM elements.

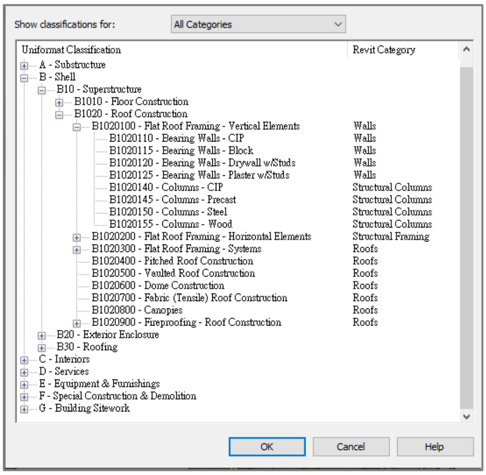


Figure 4: The Uniformat II coding system in Revit.

the work items. For example, the geometry properties of the BIM element have length, width, height, thickness, area, volume, and etc. These properties can be used to calculate the quantitative information needed for the work items. In addition, structural properties such as covering thickness, coating, interlayer and core layer thickness can be added to the structural elements.

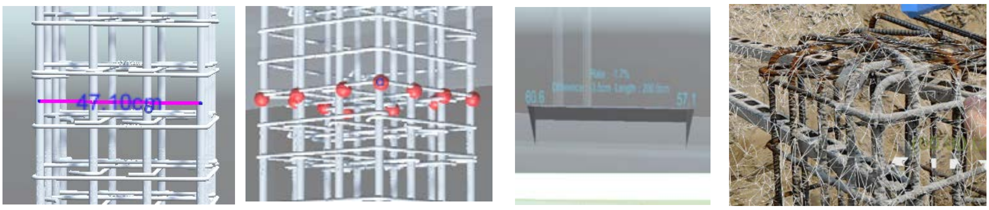
Several important issues should be also pointed out regarding the BIM development. BIM does not contain the information of work items by nature. Several coding systems are used to identify BIM elements and their links to work items. Similarly, the work items of the project should be coded. The work item can be coded according to any cost coding systems preferred by the contractor. In addition, what information that the work item should obtain from the BIM elements should be identified. An additional UNIFORMAT II code [15], as shown in Fig. 4, is required on each BIM element for subsequent data link. Through this coding system, BIM elements can be linked to related work items.

3.2.2 MR functions

Milgram and Colquhoun indicated that the mixed reality can achieve the interaction of virtuality and reality [16]. The MR device can display virtual information in the real environment, and also obtain environmental information through its various sensing functions. MR technology also has many applications in engineering. Examples of applying MR device are information visualization, remote collaboration, human–machine interface, design tools, education and training [17]. This study uses Microsoft® HoloLens as the MR device to operate the construction inspection system. Since HoloLens is a head-mounted MR device, construction engineers can use it while performing various operations by their hands free without any constraints. In addition, HoloLens supports gestures and voice input, providing the versatile and convenient data entry interface. Furthermore, the construction engineer can employ HoloLens to obtain the spatial information of the environment through its scanning capability and acquire location associated information according to his or her the position over the internet.

Fig. 5 shows the interface of the proposed construction inspection system on the HoloLens. The functions of this system are explained as follows:

Figure 5: The functions of MR system.



(a) (b) (c) (d)

Figure 6: MR functions. (a) Length ruler; (b) Counter; (c) Level measuring; and (d) Spatial mapping.

1. Inspection mode: This function presents the virtual model of the work item under inspection on the real construction job site according to the location of the user. The virtual model of the work item can appear with various types of colours as the progress of the work items advances, which helps the construction engineer find the work item for inspection more efficient.
2. Locate: It is a positioning function provided by Vuforia, which can recognize the imagine associated with the BIM model and position the virtual model with the exact scale according to the predefined location.
3. Inspection List: The inspection list shows a list of inspection items on the simplified form. The content of the list changes according to the work item to be inspected.
4. Length: It is a distance measuring tool that can help the construction engineer measure the length of the target, as shown in Fig. 6(a).
5. Counter: The function that is used to identify the virtual object by gestures for counting the number of targets, as shown in Fig. 6(b).
6. Level: A measuring function employed to determine the slope of the selected object for assisting the construction engineer in the vertical or horizontal level inspection, as shown in Fig. 6(c).
7. Scan: The environmental scanning function. Through HoloLens' unique spatial mapping function, the user can scan the actual space condition, as shown in Fig. 6(d).

3.3 Development of the BIM-MR on-site inspection system

Fig. 7 shows the information links of MR on-site inspection system development. BIM model is integrated with the information of the work items through the coding systems, uniform II and cost item codes. The work item related information, such as detail drawings, specifications and forms are linked by acquiring data from the cloud. HoloLens carries the MR operation functions developed by this research to load the virtual model to the location of the construction engineer.

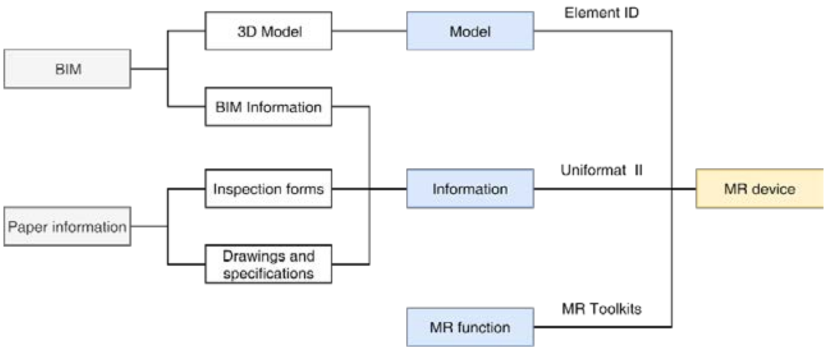


Figure 7: The information link of MR on-site inspection system development.

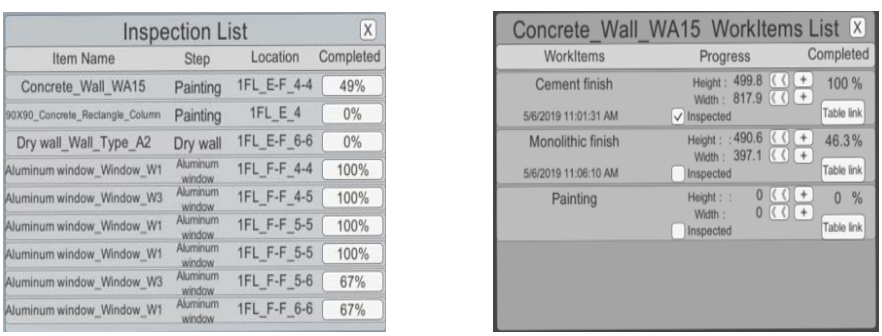
4 RESULT

Two case studies are used to verify the proposed construction inspection system, one is the progress tracking of the interior decoration work items, and the other is the inspection of rebar work.

4.1 Progress tracking

The number of interior decoration related work items for a typical building project is large. Construction engineers usually track the progress of work items by either visual inspection or determine the approximate completion percentage subjectively. Consequently, the actual progress is not tracked and the project manager usually finds the problem of low productivity after the delay occurs.

The proposed construction inspection system allows the construction engineer to the perform the efficient progress tracking operation. When construction engineers arrive at the location they are going to track the progress of work items, the associated work items according to the location can be displayed with the virtual model linked to the information for identifying progress. As shown in the Fig. 8(a), the associated inspection forms pump up once the construction engineer clicks on the virtual model. Different work items require different measurements to determine the completion percentage. Construction engineers can employ the functions provided by the proposed construction inspection system to measure



(a) (b)

Figure 8: (a) Inspection list; and (b) Work item list.

the quantitative data. As shown in the Fig. 8(b), the progresses of three different work items can be recorded automatically after the construction engineer finishing measurements.

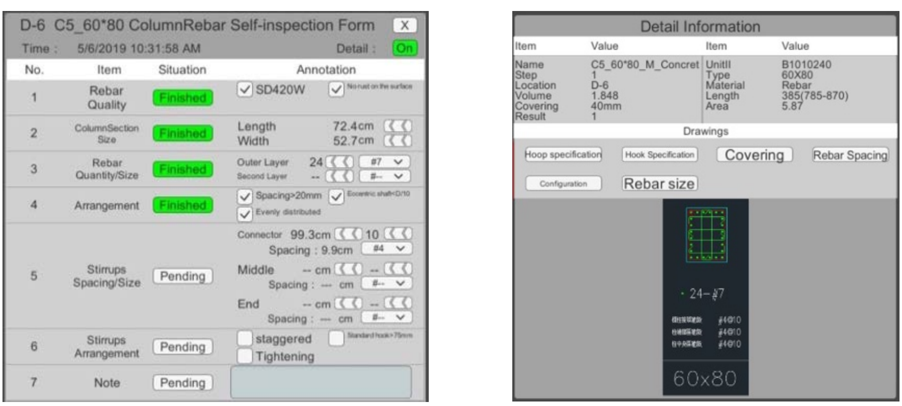
4.2 Construction inspection

The structural work items, as shown in Fig. 9, are used to demonstrate the efficiency of using the proposed construction inspection system. Again, as construction engineers arrives at the place where they need to conduct inspection, the associated virtual models of the wok items appear, they can click on the virtual model to examine the required items. The inspection form, as shown in Fig. 10(a), pimps up and shows the tasks need to be performed. The toggle and the drop-down list can be entered by hand gestures. The measurement of the quantitative data can be performed by using the functions of the proposed construction inspection system. In addition, all the measured data will be automatically recorded into the form. Furthermore, if construction engineers need to acquire any associated information during the inspection, they can click on the specific the work item and the detail information, such as drawings and specifications, can appear as shown in Fig. 10(b).

4.3 New process of the construction inspection and progress tracking

Applying BIM and MR to the on-site construction inspection also changes the process of inspection. Nowadays, most of the projects employ BIM to many stages of the project life.

Figure 9: On-site MR construction inspection.



(a) (b)

Figure 10: (a) Inspection forms; and (b) Assistant information.

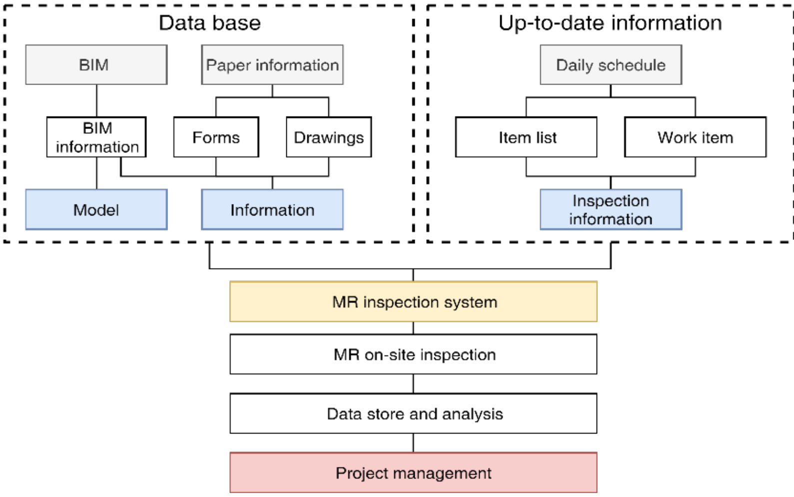


Figure 11: Inspection flow diagram.

BIM is no longer unique but becomes popular and serves as the requirement of the project deliveries. Fig. 11 shows the new process of the construction inspection and progress tracking. BIM linked with the information work items should be accomplished before inspection. The data observed and measured at the construction job site can be performed by using MR device. A paradigm shift of the construction inspection and progress tracking from the traditional approach.

5 CONCLUSIONS AND SUGGESTIONS

In this study, a proposed system that combines BIM and MR is developed to improve the process of construction inspection and progress tracking. Engineers can efficiently perform inspection and progress tracking by using the MR device to compare the difference between design and actual result on the job site. In addition, with the help of the MR inspection tools developed, observing and recording the on-site conditions is no longer time consuming. All inspection related documents can be easily downloaded, recorded and uploaded, according to the location of the construction engineer. Furthermore, automatic recording of the measurement of work item under inspection and progress tracking can reduce the chance of making mistakes and provide better data integrity.

BIM and MR technologies become prosperously applied to the field of construction engineering. The system proposed by this research is mainly for assisting construction engineers to perform inspection and progress tracking operations. However, along with the development of image capture and image recognition technology, there is an opportunity to develop an artificial intelligence system that can be more efficient to conduct inspection and progress tracking on the construction job site in the future. BIM and MR technologies also present a paradigm shift in the project management. It can be expected that the quality and progress of the construction project can be substantially improved as more advanced software of BIM and hardware of MR devices developed.

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