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INTEGRATING AUGMENTED REALITY AND BUILDING INFORMATION MODELLING TO FACILITATE CONSTRUCTION SITE COORDINATION

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ABSTRACT: *The construction industry has been evolving to embrace the delicate balance between buildings and the sustainable environment. This has highlighted the necessity to optimize resources to create healthier and more energy-efficient constructions. Likewise, it is vital to determine the viability of architectural design and building process. The application of relevant techniques to achieve this goal is essential. However, the lack of capabilities which immerse clients, end users, and building team members in highly detailed, fully lit environments that simulate the final structure of existing techniques could discourage the development of green buildings. Augmented Reality (AR) technology, which has advanced rapidly in the past few years, could play a key role towards onsite construction coordination. Despite within a Virtual Reality (VR) environment enabling its potential practice for simulated information sharing, this study focused primarily on the applications of AR for reviewing 3D drawings in a real-world interface based on a 2D drawing. Moreover, integration of professional models empowering the accuracy for AR presentation is an inevitable essential during sustainable construction management. The objective of this paper highlights the need for a structured methodology of fully integrating AR technology in BIM to facilitate construction site coordination. This study describes current AR research opportunities and challenges in sustainable construction management and emphasize what they can gain from the adoption of BIM. It is demonstrated that, extension to the site via the AR technology within the BIM platform can develop and visualize project designs, construction plans, schedules, and construction equipment into a real-time interactive and digitally manipulable environment.*

KEYWORDS: *Augmented Reality (AR); Virtual Reality (VR); Building Information Modelling (BIM); Sustainable Construction Management; Green buildings.*

1. INTRODUCTION

The improvement of the cost-efficiency in construction projects has a major impact on nation's gross domestic product and jobs added (Finkel, 2015; Ibrahim et al., 2010; Jaffe et al., 2016; Lu et al., 2015; MBIE, 2014). It is suggested that there is a need to optimize resources to create more and healthier energy-efficient constructions in the Architecture, Engineering and Construction (AEC) industry. In the past decades, computer aided design (CAD) was dominantly used in AEC industry (Aouad et al., 2013; Phiri, 1999), however, coordination among multiple disciplines and complex structures could reduce the effectiveness of two dimensions (2D) method (Aouad et al., 2013). Moreover, three dimensions (3D) modelling provides multi-view drawings, represents the building entities in a more complete way rather than 2D (Watson & Anumba, 1991). Therefore, AEC industry has been focusing on 3D applications for integrating all construction working documentation for projects (Cory, 2001). Although 3D methods hold the potential to deal with complex construction issues, 3D modelling requires more time and cost for training (Aouad et al., 2013; Cory, 2001). Besides, the convenience of 3D method used onsite is also important (Aouad et al., 2013; Cory, 2001). However, 3D packages are limited by the level of interoperability (Aouad et al., 2013). Based on these conditions, this study proposes an AR (Augmented Reality)-based construction drawing to improve the efficiency of onsite construction. The study provides a literature review for the state of the art of 2D and 3D digital drawings and AR technology. Then, this study will detail the technology roadmap for the solution of integrating AR and BIM for onsite coordination for the main objectives. In section 4, the application of the proposed technology into BMW Brilliance Automotive Ltd. Dadong Plant New 5 Series Construction Project Assembly Shop project is introduced, and the results are discussed and final conclusions provided.

2. LITERATURE REVIEW

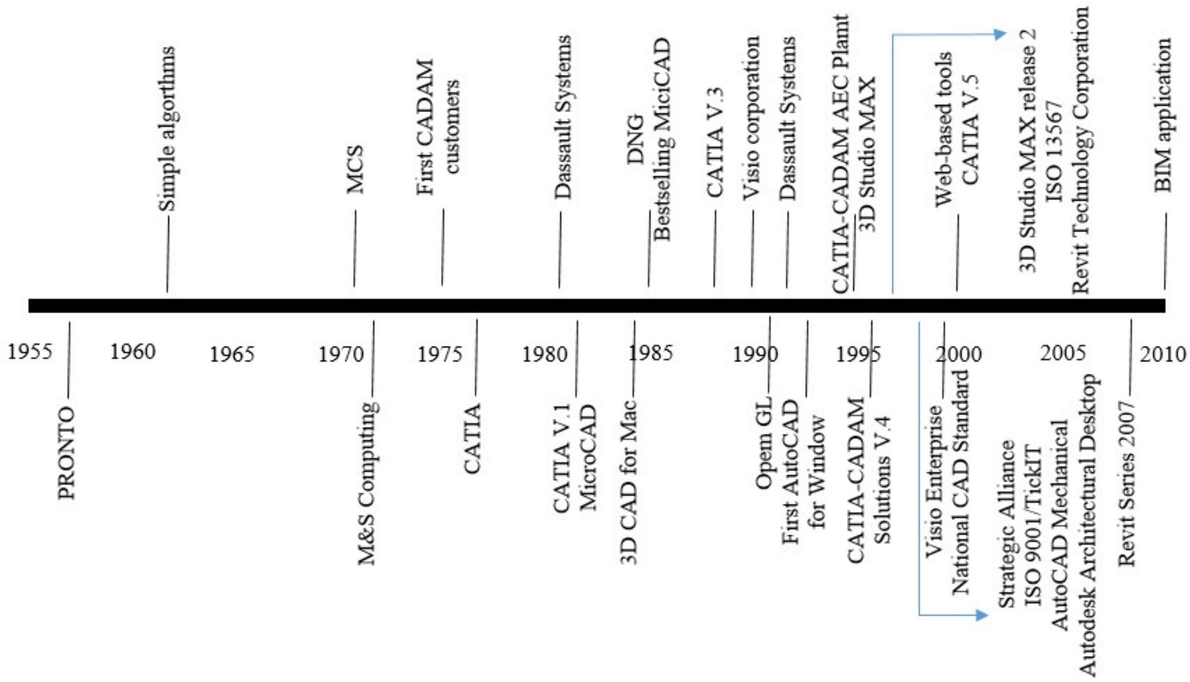
The construction industry is a vibrant and dynamic sector of any country's economy. It is responsible for a major impact on nation's gross domestic product and jobs added (Finkel, 2015; Ibrahim et al., 2010; Jaffe et al., 2016; Lu et al., 2015; MBIE, 2014). However, the sector is believed to have low levels of innovation (Loosemore, 2015; Noktehdan et al., 2015; Suprun & Stewart, 2015; Tajuddin et al., 2015). In addition, low productivity is a common pattern globally in this sector (Chalker & Loosemore, 2016; Loganathan & Kalidindi, 2015; Muhammad et al., 2015; Noktehdan et al., 2015). A breakthrough in technology could play an important role to change these issues as advanced technology could improve the character and nature of the construction industry (Noktehdan et al., 2015; Teo et al., 2015).

2.1 Digital drawing in construction industry

An important adopted innovation technology was the introduction of digital drawing (see Figure 1). It began with the PRONTO development, the first commercial numerical-control programming system, by Dr. Patrick J. Hanratty in 1957 (Martin-Dorta et al., 2013). The first CAD programs could display patterns of the lines initially in 2D in 1962 (Aouad et al., 2013). However, the general method of design remained largely unchanged much until the mid-1990s; engineering had described their works by simple tools such as pen, paper, and ruler (Yan & Damian, 2008). In 1991, stereolithography was used as a feasible method for digital fabrication (Naboni & Paoletti, 2015). 1992 marked the point at which digital model was applied in a large project, fish-shaper pavilion (Naboni & Paoletti, 2015). The structural analysis was performed by the digital surface model (Naboni & Paoletti, 2015). It directed the production and assemblage of the full-scale structural components (Naboni & Paoletti, 2015). The first complete book, "Computer-Aided Architectural Model Building", which describes the digital fabrication in the architectural design process was published in 1996 (Streich & Weisgerber, 1996).

Fig. 1: Milestones in CAD (Adapted from Aouad et al. (2013))

These developments established the foundations for CAD interface used currently, which has expanded drawing possibilities and simply transfer the information among construction stages, leading to the rapidly process



(Stephenson, 1996).

2.2 2D and 3D modelling

CAD is useful in the construction industry, which is related to a high degree of repetition as well as the wide variety of different work disciplines that need to be completed quickly and accurately (Aouad et al., 2013). Saving time could bring a significant benefit in terms of profits to construction projects (Phiri, 1999). With the popularisation of computer and the characters of the industry, CAD drawings have been used frequently (Phiri, 1999). The design of projects could be assessed for cost, buildability or compliance with Building Regulations by the integration of

CAD and analytical applications (Aouad et al., 2013).

2.2.1 2D

2D has been the principal means of communicating design information in the construction industry since round the beginning of the 20th century (Schantz, 1989). It is undeniable that it has generated a number of advantages with few of disadvantages (Cory, 2001).

Figure 2 shows nine advantages and three disadvantages of adopting 2D CAD. Adopting 2D CAD provides facilities for the input and manipulation of basic graphics (Watson & Anumba, 1991). Different facilities with the abilities to erase, copy, move, alter (extend/trim, rotate, mirror, etc.) could be exploited for a series of stacked plans (Phiri, 1999). In addition, symbol libraries in which frequently occurring standard components or symbols are stored could enhance the efficiencies of drafting (Aouad et al., 2013; Watson & Anumba, 1991). Moreover, 2D CAD drafting can be altered quickly and is secured by saving in uneditable formats (Aouad et al., 2013).

In terms of the disadvantages, it only provides individual views which sometimes require interpretation (Cory, 2001). Regarding to the interoperatbility, 2D CAD will most likely enhance collaboration and information among stakeholders (Aouad et al., 2013). However, adopting different softwares could reduce the interoperability due to the different digital formats of 2D files which are uneditable (Aouad et al., 2013).

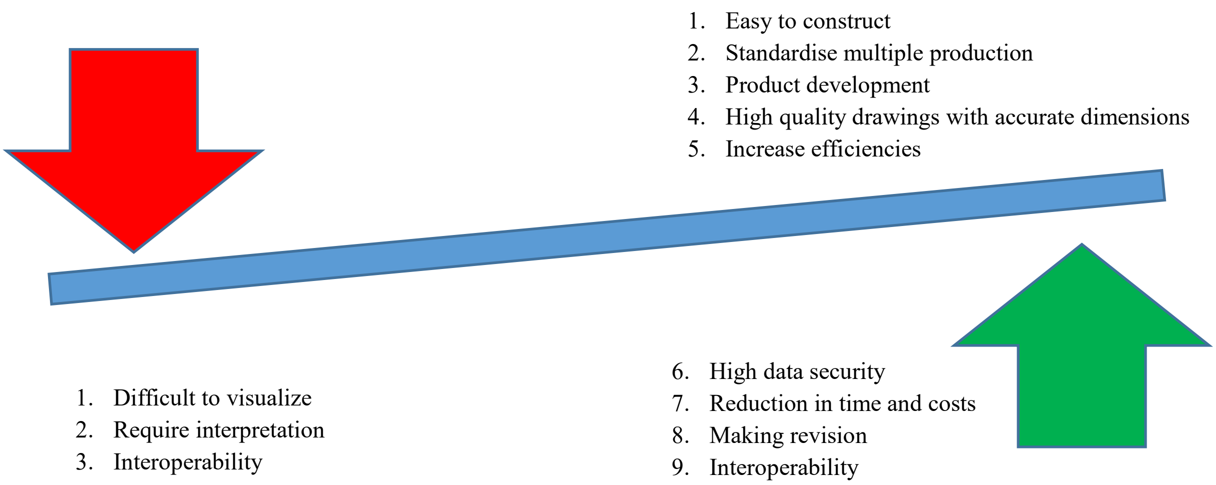


Fig. 2: Advantages and disadvantages of 2D CAD

2.2.2 3D

3D modelling, which provides multi-view drawings, represents the real world in a more complete way rather than 2D (Watson & Anumba, 1991). Therefore, AEC industry has been focusing on utilizing 3D models to generate all construction working documentation for projects (Cory, 2001).

Compared to 2D, 3D offers numerous benefits, indicated in Figure 3. It increases the productivity by the flexible modification of the designs at different levels (Watson & Anumba, 1991). Changes that are made will be immediately reflected in all the available views of those models (Phiri, 1999). It generates a computer copy of the proposed real-life projects which can be analysed automatically to generate plans and elevations; extract volumetric information, and predict its response to different environmental conditions (Aouad et al., 2013). It also enhances competitiveness in bidding for different forms of contracts due to the 3D visualization, ranging from simple block modelling at the early design stage to full rendered images for final stage, which is persuasive in communication ideas (Phiri, 1999). The exploded views could also reduce the potential design errors and checking time (Cory, 2001). Moreover, architects, engineers, and clients could earn benefits with facilities for 3D modelling and easily understood printouts as they clearly transfer the information exchanges among stakeholders, leading to the minimization in costs of site alterations and other expenditures (Aouad et al., 2013; Cory, 2001; Phiri, 1999).

Although many benefits can be achieved with 3D model use, it has a number of disadvantages including. 3D modelling requires an extremely high learning curve which requires substantial time and cost for training (Aouad et al., 2013; Cory, 2001). Besides, completing models with full properties declarations for entire structures and materials involves the cooperation among stakeholders (Cory, 2001). However, the level of interoperability among 3D packages is limited which considerably reduces the success of projects (Aouad et al., 2013).

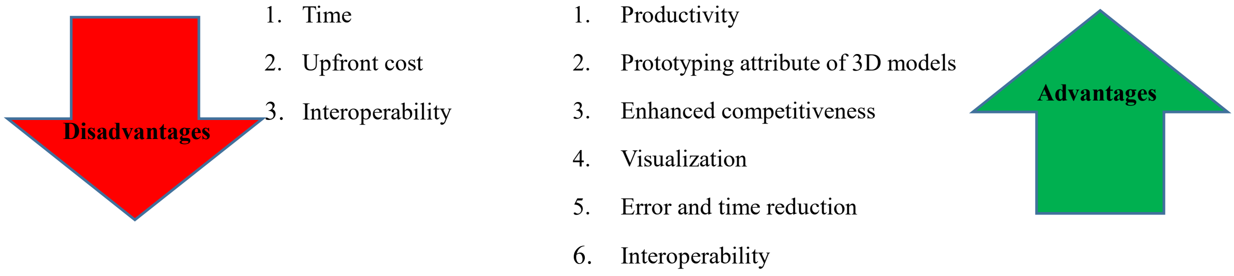


Fig. 3: Advantages and disadvantages of 3D CAD

2.2.2 2D and 3D overview

Both 2D and 3D bring considerable benefits to the construction industry. Depending on the characteristics of the project and the capability of organizations, the decision to choose either 2D or 3D will be made. Although 3D is encouraged and has become popular in construction projects, the final design output required on the site is a set of 2D drawings (Paterson et al., 2015). This is because 2D drawings are still the conventional means of communication among engineering staff (Cheng, 2013).

3D modelling is known as a compliance of drawings which improves the coordination between stakeholders which could reduce project conflicts. While 2D drafting still plays an important role at the final output of the design process, integration between 2D and 3D is necessary to maximum their potential benefits.

2.3 AR

Using the AR technique integration between 2D and 3D could be achieved. With the 2D drawing outputs, virtual objects could be created from 3D BIM model using the mobile-device AR.AR is referred as an integrated technique of image processing and display system of complex information which generates virtual objects over real objects to produce a mixed world (Irizarry et al., 2013; Jiao et al., 2013; Yang et al., 2013). According to Azuma et al. (2001), it could combine real and virtual objects in a real environment, run interactively in real time, and align with each other. AR has been developed since the 1960s with the introduction of the ultimate display to present 3D graphics (Azuma et al., 2001; Yang et al., 2013). In 1968, simple wireframe drawings could be displayed in real time with the use of an optical see-through head-mounted display and one of two different 6 Degrees of Freedom trackers (Yang et al., 2013).

In the late 1990s, several conferences on AR were organized such as the International Workshop and Symposium on Augmented Reality, the International Symposium on Mixed Reality, and the Designing Augmented Reality Environments workshop (Azuma et al., 2001). During this time, ARalso received more attention from well-funded orgranizations, including Mixed Reality Systems Lab in Japan and the Arvika consortium in Germany (Azuma et al., 2001). In 1997, a survey to guide and encourage further research in this area was published (Azuma et al., 2001; Azuma, 1997). In 2000s, new possibilities in the field of 3D data visualization, navigation and interaction far beyond the traditional static navigation and interaction were created by the synergy of AR (Portalés et al., 2010; Yang et al., 2013).

AR has been adopted in many fields of science and engineering. Thomas et al. (2000) carried out research on outdoor/indoor AR first person application ARQuake, an extension of the desktop game Quake. Regenbrecht and Specht (2000) investigated an approach to solve the problem of providing sufficient computational and graphics power on conventional wearable computers by AR implementation. Livingston et al. (2002) developed the Battlefield Augmented Reality System (BARS) for military operations. Birkfellner et al. (2002) presented a simple design of the modified head-mounted display for AR visualization in medicine.

AR is also considered as one of the advanced computer technologies which has potential to provide significant advantages through visualization to the AEC industry (Dunston, 2008). There are some issues in the AEC industry including a lack of information for field operators (Chi et al., 2012; Schall et al., 2009; Woodward et al., 2010), gaps between planned solutions and practical implementations (Dunston, 2008), and poor communications between related project participants (Chen & Schnabel, 2009; Hammad et al., 2009; Kim et al., 2011). AR has shown the potential to solve these issues (Chi et al., 2013). Kuo et al. (2013) stated that AR has been gaining extensive applications in the construction field, such as real-time 3D display of on-site construction progress (Woodward et al., 2010), introduction of objects assembling procedures (Behzadan et al., 2006), design and revitalization in existing built environments (Donath et al., 2001), and others. Dunston (2008) described a vision for Mixed Reality implementation, especially AR systems, for AEC industry. Golparvar-Fard et al. (2009) proposed the visualization of performance metrics to represent progress deviations through superimposition of 4D as-planned model over time-lapsed photographs in single and comprehensive visual imagery. Dunston (2009) evaluated the benefits of inspection with the ARCam versus a conventional method in AEC industry. Roberts et al. (2002) used AR to overlay locations of subsurface utility lines onto real world views to assist maintenance workers to avoide buried infrastructure and structure elements (Behzadan & Kamat, 2013).

Mobile-device AR has been researched to optimize workflows for various purposes including quality control, safety management, scheduling, mocking up spaces for clients, training workers, construction education (Irizarry et al., 2013), and in this research for construction site coordination.

3. TECHNOLOGY

The traditional method for construction coordination includes 2D-based method and BIM-based method 2D-based method holds its advantages in stakeholders' comprehension in its dimensions, while BIM-based method take advantages of its visualization for the spatial relationship of each component. However, onsite stakeholders do not fully understand the 2D drawings in some complex cases. Furthermore, not all of them are always well-skilled with BIM technology, it is suggested that this can cause the low utilization for BIM model. Therefore, a match of 2D drawings and BIM model could be of significant value. Moreover, the introduction of AR will be useful to achieve it. The process of AR-based method for construction site coordination includes steps shown in Figure 4.

Firstly, the engineers should integrate their design data in BIM model and out put the 3D model. Secondly, They should optimize their output 3D model so that different materials can be distinguished. If the 2D blueprints are not complex enough for identification and recognition, they should also be optimized in PhotoShop. Thirdly, a AR environment is needed to correlate the 3D models to the 2D drawings. Finally, the UI designers should make a friendly interface so that the workers onsite can install and use it easily.

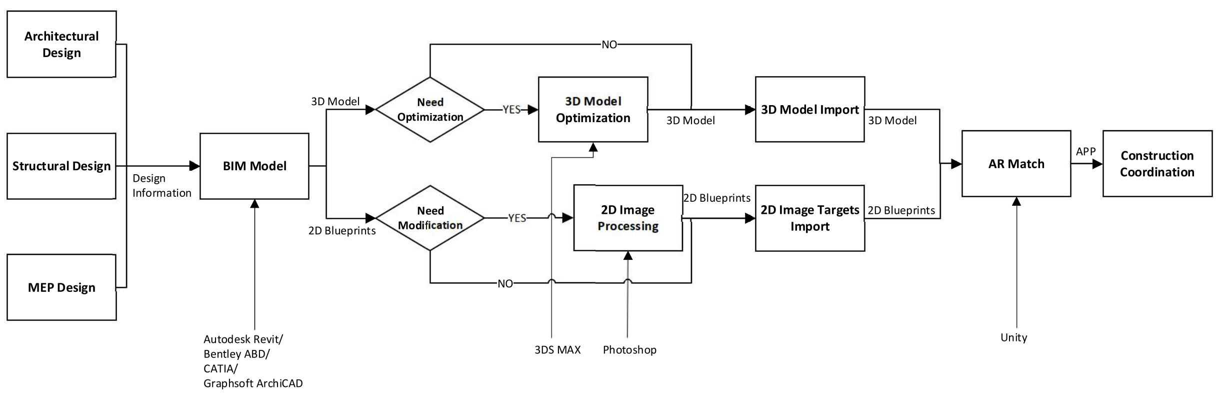


Fig. 4: The process of AR-based construction site coordination

4. CASE STUDY

To validate the effectiveness and efficiency of the technological roadmap, this study select BMW Brilliance Automotive Ltd. Dadong Plant New 5 Series Construction Project Assembly Shop as the case study. This project involves complex pipes covering multiple disciplines and the construction quality requirement is very high.

4.1 General description

BMW Brilliance Automotive Ltd. Dadong Plant New 5 Series Construction Project Assembly Shop is located at Dadong District, Shenyang, Liaoning Province of China. The project commenced 1st, May, 2014 and expected to be completed on 31th, March, 2017. With a total area of 165,000 m^2, the client requires a high standard of quality for the Mechanical, Electrical & Plumbing (MEP) installation.

4.2 Issues to be faced

This project faces three main issues:

a) Due to the complex MEP installation processes required for project, more visual methods are needed to coordinate onsite for sustainable construction management. The use of a Conventional 2D method will not successfully show the construction workers how to work successfully onsite. Furthermore, onsite workers may not have enough 3D software skills. Thus, the first issue is how to show the 3D relationship for each pipeline of this project.

b) The project would also benefit from the use of BIM to coordinate onsite. BIM can provide an nD model that provides rich information including 3D relationship data, however the conventional popular mobile BIM platforms such as BIM 360 GLUE, BIMx present the roaming of a building in shade mode, which are not easy for onsite workers to adapt. Moreover, there are not enough mobile devices onsite for mobile BIM applications. Thus, the adoption of mobile BIM applications onsite is the second issue.

c) The adoptive design document form for delivery is 2D drawings, this may not present information comprehensively, especially MEP pipelines. Meanwhile, 3D digital drawings are not currently allowed for design review. Thus the project team should provide 2D drawings which satisfy the requirements of 3D design.

4.3 Application of AR-based Onsite Coordination

a) Create the BIM models for each discipline and export the 3D models. Designers have the choice from a range ofplatforms including Autodesk Revit, Bentley AECOSim Building Designer, Graphsoft ArchiCAD, Dassault CATIA etc. to create the BIM model. Meanwhile, the design works always include architectural design, structural design, MEP design, all the designers in different disciplines will work based on the same central documents to fasten the model creation works. After all the works are finished, the designers should agree on which disciplines should be shown in the AR-based construction drawings and single discipline or the integrated one. Then, the 3D models should be exported. Figure 5 shows the BIM model of this project created in Revit 2016.

b) Generate 2D construction drawings and export them as images. Within a BIM framework, 2D construction drawings can be done by sectioning from 3D BIM models. The designers should then dimension each component and 2D generate the construction drawings.

c) Collect all the contexts, figures and videos that need to be included. Some joints are complex and it is difficult for onsite workers to understand the construction method. Thus, construction knowledge is needed to be attached by AR in the form of context, figures and videos.

d) Optimize the 3D models and distinguish different systems with standard colors. Sometime, in MEP design, there are few systems to be distinguished such as different HVAC systems. Developers create the BIM models first, then export to 3DS MAX for optimization. In 3DS MAX, standard materials should be used to distinguish each system. If they are not optimized, it will be time-consuming to change materials or colors in AR development engines.

e) Optimize the 2D images to meet the recognition requirements. There is a recognition index in each AR development engine to show how the image can be recognized. If the image full of similar patterns, it would be difficult to be recognized. Therefore, when this happens, developers should use image processing software such as Photoshop to add recognition patterns on it. Then, it is exported to image format such as .jpg, etc.

f) Transform the 2D images to image targets. Images are with image format that would not adaptable to AR required format. Thus, the developers should upload the image to certain websites such as Vuforia, etc. to transform 2D images to image targets packages.

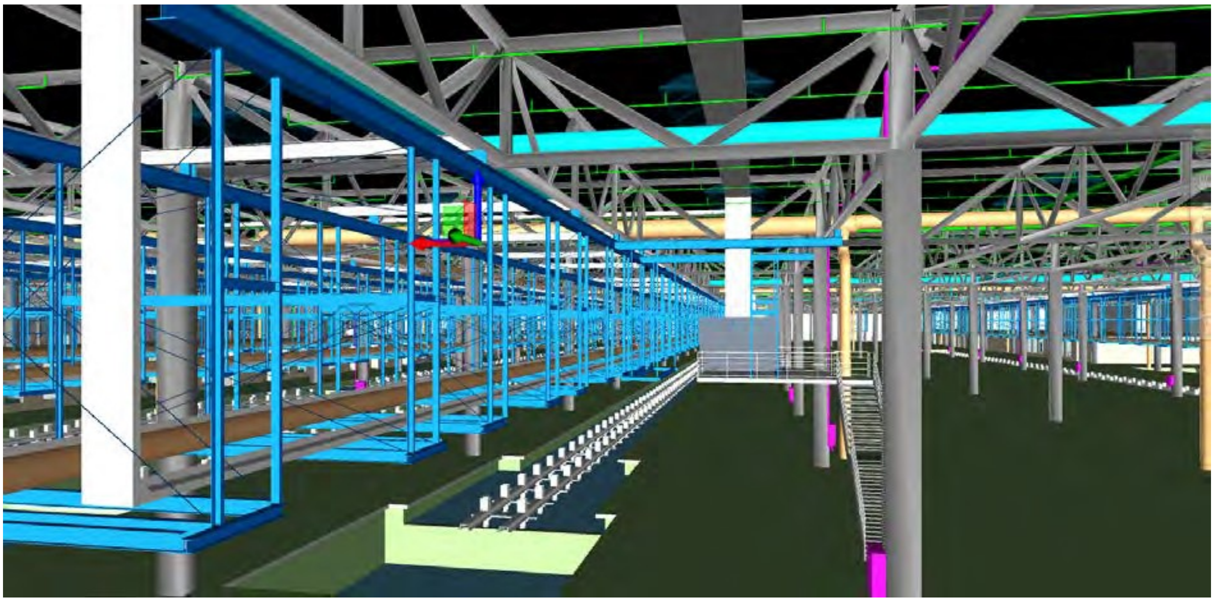


Fig. 5: The overview of BIM model for Assembly Shop.

g) Load all the require sources include optimized 3D models, image targets, contexts, images, videos in certain AR development engines. After all the sources are already collected, then the developers need to load them in AR development engines such as Unity before matching the sources in the right position with the image targets. Figure 6 has shown the relationship between image target and 3D model for a part of Assembly Shop.

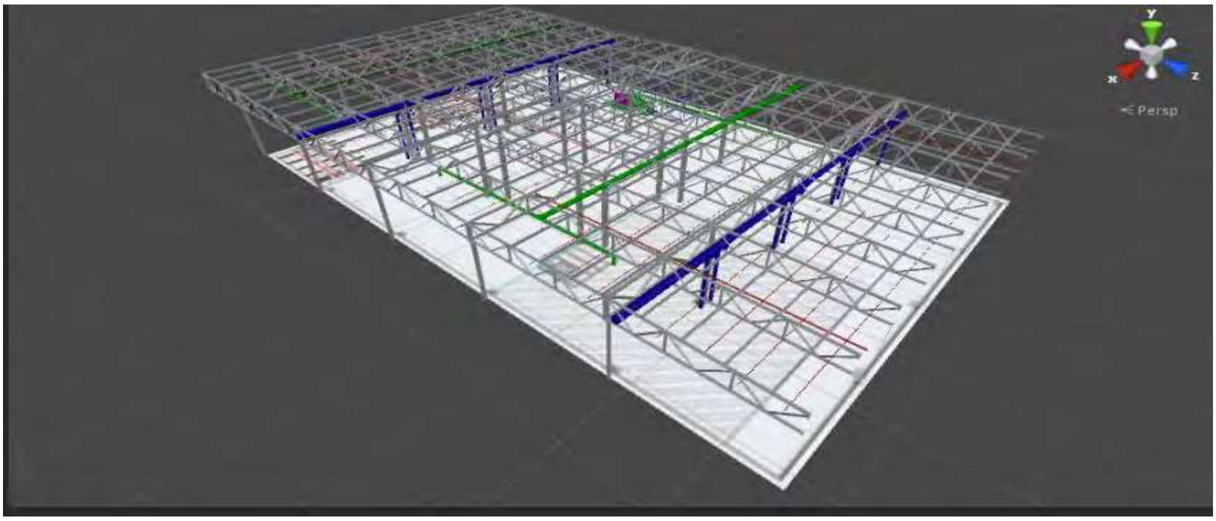


Fig. 6: The match of 3D model with 2D image target for a part of Assembly Shop.

h) Design the interfaces of the APP and the operation modes. The developers should design the interfaces of the APP and add several basic functions to it including the framework of operations, the operation modes, etc. After that, the APP for Android, ios, windows, Linus platform is published. Finally, the APP in devices and coordinate onsite will be installed. Figure 7 shows the onsite stakeholders use mobile phone to check the AR-based construction drawings. Figure 8 is the results of the APP onsite.

Above all, in this project, the onsite workers utilize the AR-based construction drawings to make 3D relationship of pipes clear. Whenever they get confused, they can refer to the AR-based 3D model to align their position. In this project, each dimension could be shown on 2D drawings and the AR-based 3D model only to show the relationship without dimensions. In case of in some complex positions where contains much more pipes it was difficult for 2D drawings to detail the dimensions, onsite workers also asked for help from BIM engineers.

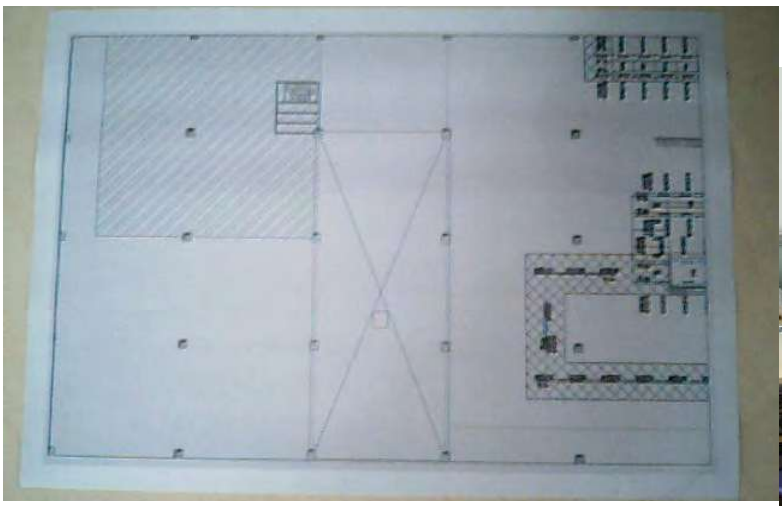


Fig 7: The application of AR-based construction drawing

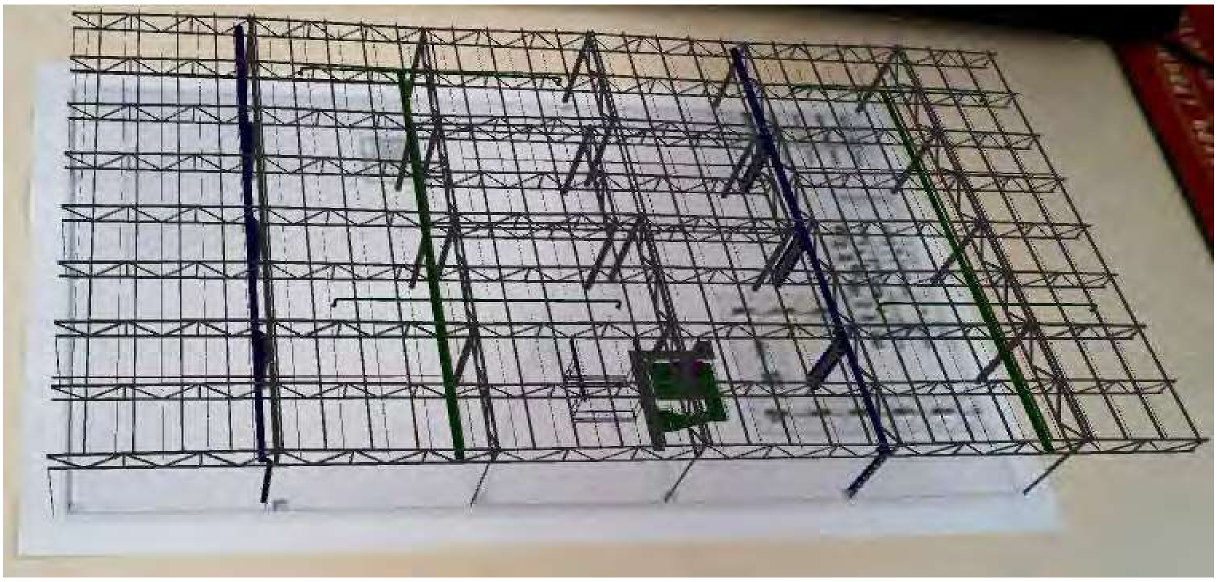


Fig 8: The result of AR-based construction drawing APP

5. DISCUSSION

This paper has presented the process of AR-based construction site coordination. The results demonstrate the applicability of the proposed technology to construction sites. It can successfully improve the performance of existing on-site management processes by providing the 3D virtually based on 2D images. The 2D outputs could be virtualized comprehensively with a mobile AR, thereby enhancing the interoperability. In addition, reducing time and errors in the projects is also achieved with this potential technology. Besides, onsite workers without knowledge concerning 3D software skills still have the ability to complete their works without attending training courses. While this paper presented the initial works toward AR-based construction drawings, several challenges remain. These challenges include that the AR-based drawings are currently set only with the presentation of the 3D models above the 2D drawings, however, the dimensions are missing, which is important onsite. In this project, the onsite workers only use 2D drawings for dimensions and 3D AR-based model for clearing the relationship between different components. Secondly, in this project, the proposed method is limited by the real-time adaptive capacity. Although the proposed method can review the 3D drawings in real time based on 2D drawings, the real-time communications among stakeholders have not been involved in this project. Finally the hardware of the mobile devices is becoming the limitation of the application of AR-based APP. The mobile phones of the onsite workers are usually with low configurations and normally can only integrate fewer 3D drawings in their mobile phones.

6. CONCLUSION

In this paper, an overview of CAD and AR, including historical developments, together with potential benefits and challenges, was presented. AR is a rapidly growing field in construction sector since late 1990s. The development of mobile computing solutions has provided a flexible and powerful environment for on-site construction management and it is expected to shift the conventional construction management practices. Mobile-device AR has been researched to optimize workflows for various purposes including quality control, safety management, scheduling, mocking up spaces for clients, training workers, construction education. This paper presented mobile AR as an advanced and innovative tool for construction site coordination, AR-based construction drawing APP. A case study involving construction of an assembly shop in China was conducted to validate the system. The case study showed that the proposed system has a high potential to achieve more sustainability, profitability, interoperability, and security in the construction sector.

This study contributed to the existing body of knowledge by demonstrating how AR mobile can improve the existing on-site construction management practices. Future studies, however, are required to encourage the involvement of mobile cloud streaming technology to solve the hardware obstacles. In addition, the development of functions such as dimension and communication related functions, etc. is also encouraged.

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