Low Cost Augmented Reality Framework for Construction Applications

Sai Meghasyam Kodeboyina[a] and Koshy Varghese[b]

[a] Graduate Student, Department of Civil Engineering, Indian Institute of Technology Madras, India
[b] Professor, Department of Civil Engineering, Indian Institute of Technology Madras, India

E-mail: ce11b092@smail.iitm.ac.in, koshy@iitm.ac.in

Abstract –

Augmented Reality can be of immense benefit to the construction industry. The oft-cited benefits of AR in construction industry include real time visualization of projects, project monitoring by overlaying virtual models on actual built structures and onsite information retrieval. But this technology is restricted by the high cost and limited portability of the devices. Further, problems with real time and accurate tracking in a construction environment hinder its broader application. To enable utilization of augmented reality on a construction site, a low cost augmented reality framework based on the Google Cardboard visor is proposed. The current applications available for Google cardboard has several limitations in delivering an AR experience relevant to construction requirements. To overcome these limitations Unity game engine, with the help of Vuforia & Cardboard SDK, is used to develop an application environment which can be used for location and orientation specific visualization and planning of work at construction workface. The real world image is captured through the smart-phone camera input and blended with the stereo input of the 3D models to enable a full immersion experience. The application is currently limited to marker based tracking where the 3D models are triggered onto the user's view upon scanning an image which is registered with a corresponding 3D model preloaded into the application. A gaze input user interface is proposed which enables the user to interact with the augmented models. Finally usage of AR app while traversing the construction site is illustrated.

Keywords –

Construction, Augmented Reality, Marker-based Tracking, Information Retrieval, Google Cardboard.

1 Introduction

Augmented Reality (AR) is the enhanced version of reality created by the use of technology to overlay computer generated graphics, sounds and other data on user's view of the real world. It is different from the virtual reality where the user is immersed completely in a virtual environment. Augmented reality has a wide range of applications in various sectors like commerce, military, architecture and construction, medicine, gaming etc. In commerce, it can been used to enable a user to view the contents of a packaged product without actually tearing it open. In military operations AR can aid in projecting critical information on soldiers' goggles. Print and media industries develop apps to display digital content like videos & images that pop up on scanning printed magazines. Travellers can find information about places by pointing their cameras to subjects. Surgeons can image the 3D model of brain on top of the patient's anatomy without actually cutting it open. The simple augmented reality user case is: a person scans an image with camera on his smartphone or tablet and underlying platform identifies a marker in the image, triggering the invocation of a virtual model on that real-world image and is displayed on the camera screen.

The construction industry particularly can realise great benefits with the development of AR technology. AR makes visualization easy. In fact it reduces the effort of architects and designers by a great deal. Real time visualization of projects, upon pointing user's smartphone camera at a specific location or scanning a specific image, will benefit the architect in giving greater insights into details of the project to owners and contractors. Real time monitoring of the project can be done by superimposing the as-built 3D model of the project upon the actual built up structure without having to look at the construction schedules. But bigger challenges are faced in implementing technology at site due to lack of awareness, sophisticated nature of the current AR/VR systems, cost of AR/VR gear and cost of implementation. Also the inherent problems of augmented reality question its implementation to the fullest. The critical problem with any augmented reality systems is the difficulties in real-time and accurate tracking. The major requirement for any augmented information is it has to synchronise with the real world. Slightest of the errors in model synchronization with the real world can be easily caught by the human eye. Any mismatch between augmented objects and real objects can be discomforting and also result in incorrect information being given to the user.

There can be endless discussion on applications of augmented reality but for the purpose of this paper the notable benefits and of this technology are discussed and a specific solution for obtaining a cost effective AR framework is proposed. The solution proposed states the use of Virtual Reality (VR) device Google Cardboard and smartphone for providing AR experience. In Virtual Reality, the user gets immersed into another virtual world and cannot see the real world he actually lives in. So to provide AR experience, it is proposed we capture the real world from the smartphone camera and view the same from Cardboard to provide that immersive experience. Virtual models are now augmented onto the real world input from the camera and also a menu-based user interface has been created to interact with the augmentations

2 Survey on Applications of Augmented Reality in Construction Industry

The technical definition of augmented reality [1] is a system that combines real and virtual world, which is interactive in real time and is registered in three dimensions. Ivan Sutherland is credited largely for the concept of augmented reality as early as 1960s. One of the earliest works of augmented reality in architecture and construction industry is the work done at the Computer Graphics and User Interfaces Lab at Columbia University on so called “Architectural Anatomy” which is overlaying the graphical illustration of the structural systems of a building over the user’s view of the room which he currently is in [2]. The other work done at the same labs involves space frame construction. It is a step by step space frame construction process where the AR system directs the user to pick up elements though audio clippings, confirms whether the correct piece has been picked by scanning the barcode and virtual image is displayed next to it showing where and how to install the picked strut.

From this stage the augmented reality application has shifted from indoors to outdoors enabling the user to move around with the heavy equipment. A prototype system developed by the Computer Graphics and User Interfaces Lab, Columbia University acts as an information system in the campus, assisting a person in finding places and allowing to request information about items of interest, like buildings, statues, etc. [3]. The user wears a head-mounted display that gets the inputs over a wireless network from a computer carried in the backpack. GPS is used to track the position of the user while the head mounted display gives the orientation information as the user looks around the campus, the head worn display superimposes textual labels on campus buildings. Also the user can interact with the system and obtain any information about the building on his screen.

The increase in need for information technologies in architecture, engineering, construction and facility management industries is owed to their complex nature that increased demand of information access for evaluation, communication and collaboration [4]. Thus the application of AR technologies are varied and across multiple verticals. AR technologies can benefit the AEC industry through: 1) Visualization of 3D models super imposed on the real world 2) Information Retrieval involving BIM models & drawings for on-site communication and 3) Interaction of virtual models in response to changes in the real world [5]. Some of the specific applications of AR in training, information retrieval and planning are described below.

Virtual Training System for Construction Excavator Operations: A virtual training system (VTS) is developed for construction excavator operators based on a game engine tool [8]. Their study reflects the experience of using a game engine to develop a VTS for an earthmoving excavator in a construction site. They selected Unity3D as a simulator construction tool because of its easy programming and versatility. Unity3D has an advantageous world building tool, user-friendly interface, and lots of target platforms -mobiles, web, PC/MacOS, etc. are supported [6]. Also they employed 3DS Max as modelling software for modelling the excavator and imported into a simulation environment created in Unity 3D. Various scripts are written which enable interaction of various 3D objects say bucket, boom and swing. Similarly soil is also modelled as grey boxes due to limitations in the older version of Unity. Based on this approach the whole training system is developed and used for training where the inputs to the model are given from the joystick connected to the display. This attempt in using game engine to create simulation environment for construction is considered to be an important step in adopting training programs with least cost burdens.

On-site Information Retrieval: A wearable device had been developed that projects the drawings and related information on user need basis [7]. This device is developed to help engineers avoid carrying bulky construction drawings to the site, and to pin point the exact drawing needed instead of going through the pile of drawings. Four modules enable the information from the BIM to the projection.1) Information integration module for transfer of information from BIM to image format to enable on site retrieval 2) Position module to enable users load images based on their location 3) Manipulation module to understand the gestures of the user like touch and turn and then perform changes to images accordingly 4) Display module that links to the projector, scales the images properly and ensure projection to the scale based on the information from other three modules. A test was done at site by enabling engineers to use these helmets and access particular information. Those with the helmets showed increased accuracy in acquiring the information quickly than manual searching through the 2D drawings.

Plan virtual construction site: AR Planner is an AR system that enables the construction worksite planner to position construction materials and machines/equipment, handling devices and the corresponding outing lines in the planned worksite using representative 3D-model model objects in the virtual world [8]. Fiducial markers are used to trigger the 3D objects onto the virtual worksite where they can be moved by the user. There is also a data base that stores all the virtual element set that is modelled and can be used in planning.

Apart from the above mentioned applications there are generalized frameworks which enable integrating AR with Building Information Models for various uses. A conceptual framework that integrates AR with building information modelling (BIM) to detect construction defects has also been presented [9]. In order to visualize the dynamic site operations during construction phase a mobile 3-dimensional AR system has been investigated [10].

Not only in the domain of engineering has AR found its utility, also in teaching especially classroom education. Enhancing a text book with 3D and multimedia virtual information by designing a collaborative Context Aware Mobile Augmented Reality Tool (CAM-ART) in construction and civil engineering curriculum [11]. A group of students were tested on using this CAM-ART by loading an AR application in their smartphones and tablet computers. Performance data was analysed which showed CAM-ART actually had a positive impact on students' learning in both short term and long term.

The benefits of augmented reality to construction industry can be extended from individual construction activities or structural systems invocation to the scale of projects as a whole. Deployment of drones with powerful cameras makes this possible. Once a drone flies over the project area, its cameras scan the whole area and pick up markers that are positioned in the site. When these markers are tracked all the augmentations like as-built 3D site map or project monitoring information can be passed as live feed to the top managers at site or can be recorded into a memory device. This saves a lot of time and gives the whole summary of the project at one go. Also the use of Simultaneous Localization and Mapping (SLAM) helps in generating a site map in real time at different stages of the project which can be compared with the planned site map. When the user walks the site with SLAM app scanning the path along, the determination of the position of the user on the site on a virtual map and 3D mapping of his surrounding environment is done simultaneously. Both the above mentioned benefits of AR are costly investments but when compared to its costs to benefits which are at the scale of project, it is a profitable investment.

3 Cost Effective AR Technology – Hardware and Software

The basic hardware requirements for AR are: input devices, sensors, processor and display. Modern computing devices like smartphones and tablet computers contain these elements which usually include a camera and Micro-Electro-Mechanical-Systems (MEMS) sensors such as accelerometer, GPS, and solid state compass, making them appropriate AR platforms. Head Mounted Displays (HMD) are trending in the current AR and VR display systems. Oculus Rift, Razer's "OSVR", HTC and Valve's "Vive", Samsung Gear VR are considered to be the leading head mounted displays in the virtual reality domain. Google glass, an optical head mounted see through display, uses ubiquitous computing technique that aims at giving people the best AR experience. To assist swift development of Augmented Reality Application, some software development kits (SDK) have emerged. Some of the well-known AR SDKs are offered by Vuforia, ARToolKit, Mobinett AR, Wikitude, Blippar and Layar [12].

Cost of AR application has two main components. The cost of application building and the cost of hardware. The cost of application depends entirely on the creative content added in it and is almost same irrespective of the hardware used. The difference can be made by choosing low cost hardware as the application building cost is almost same across different platforms.

Currently a very ambitious AR device which is dedicated to give high end AR experience to users is the Microsoft HoloLens. It's a mixed technology headset using both augmented and virtual reality where it merges real-world

components with virtual images called holograms. The headset is not connected to any PC as it is run on battery with a Windows 10 system built in it. It has a Kinect-style receiving of voice commands and gestures. There is no other device in the making which is as close to HoloLens in giving that high end AR experience. In the VR devices category Oculus Rift is one of the first consumer-targeted device. HTC Vive offers 360 degree tracking and also a "context aware controller" which enables interaction with the virtual world elements. FOVE VR differs from the likes of Rift and PlayStation VR because it enables interactive eye-tracking using an IR sensor inside the headset that monitor's wearer's eyes and controls the rendering on the screen based on where we look. The Gear VR is an Oculus Rift-powered device which has a Samsung Galaxy smartphone as its processor and display. The Galaxy handset simply slots in front of the lenses, into a Micro USB dock. The smartphone's super AMOLED display serves as the screen for the user. It comes in handy for AR experiences if one can enable the phone's camera to capture the real world. Table 1 lists the popular devices various devices currently in the market or in the development stagealong with the market price. It can be seen from the table that the Google Cardboard device is the most economical option. As a smartphone has become ubiquitous, this work focused on exploring the current and extensible capabilities of this platform in providing AR experience for construction applications.
Google Cardboard is a virtual reality (VR) and augmented reality (AR) platform developed by Google for use with a head mount for a mobile phone. This is intended to be the low-cost system to boost interest and development in AR and VR applications. Users can build their own cardboard viewer by using low cost materials or purchase from third party with specifications issued by Google.

While choosing the cheapest hardware enables widespread application, the challenges lie in developing a suitable application that can provide a seamless AR experience. Open Source Software Development Kits (SDK) are available to extend and customize the capabilities of the platform. A popular Augmented Reality Software Development Kit (SDK) which enables the creation of AR applications for mobile devices is Vuforia. In Vuforia, Computer Vision technology is used to recognize and help in real time tracking of planar images (Image Targets) and simple3D objects, such as boxes [13]. It is this capability that enables developers to extend capabilities to enable positioning and changing the orientation of virtual objects, such as 3D models and other media, in relation to real world images when these are viewed through the camera of a mobile device.

Table 1. Cost comparison of AR/VR devices

Device	Price
Microsoft HoloLens 	$3,000.00
HTC Vive 	$799.00
Oculus Rift 	$599.00
FOVE VR 	$349.00
Zeiss VR 	$120.00
Samsung Gear VR 	$99.00
Google Cardboard 	$20.00

The Vuforia platform supports both Android and iOS smartphones and tablets as well as digital eyewear. Developers can build Vuforia apps in Eclipse, Xcode and Unity cross-platform game engine. Unity 3D is one of the best professional multiplatform development engine. It is used to develop video games for PC, consoles, mobile devices and websites. There is also a SDK for Cardboard which helps in creation of VR application from scratch or conversion of existing application to VR or enabling switching of application in and out of VR. Therefore, importing Vuforia and Cardboard SDKs (software development kit) on Unity can help in the creation of augmented reality system compatible with Google Cardboard. Taking advantage of this feature a low cost augmented reality solution is presented in this paper.

4 AR Mechanisms

Over the years the AR technologies have evolved rapidly and today we are in the age of smart glasses. The likes of Google Glass and Microsoft HoloLens have emerged which are ubiquitous computing devices that project digital information directly onto the human eye. Figure 1 shows how AR technologies have evolved throughout the years in various levels.

Figure 1. Road Map of AR Technologies

With reference to Figure 1, Level 0 of AR is the simple hyperlinking where we are directed to a particular website upon scanning a barcode tagged with an URL. Level 1 comprises of the major area where our proposed solution lies in. A large number of applications both for Hand-held and Head-mounted devices have been developed for marker based tracking which then evolved into Level 2- as tracking based on the natural features in the environment and geo location. The final level or Level 3 is the currently most concentrated area for development where even contact lenses with AR capability are aimed to be achieved. For the purpose of this discussion we stick to the 2D image target capability on a smartphone with a Cardboard mount.

The simple AR case is the user scans a target in the real world and the virtual model is invoked and aligned itself accordingly to give the augmented experience. There is a triggering event which occurs every time a target is scanned. This target can be an image or an object.

Image targets represent those images which the SDK detects and tracks. The Vuforia SDK usually detects and tracks the features that are found in the image itself by comparing these natural features against a known target resource database. Once the Image Target is recognized from the database which contains correspondence information i.e. the corresponding 3D model to a particular image target, the SDK will track the image as long as the image lies in the camera's field of view.

Object Targets are generated by creating a digital representation of the features and geometry of a real physical object. They are different from image based targets that require the use of a planar source image. Vuforia Object scanner generates object targets by scanning physical 3D objects. Object targets are ideal in cases of building rich interactive experiences with rigid 3D objects. They can be augmentations on toys, manuals overlaid on consumer products or triggering of new events on scanning a consumer product.

For the application in construction site where one would like to augment building models or information onto their displays we have chosen image targets because of its ease of implementation and a variety of images can be created by the user to serve various purposes. One can use QR codes or floor or elevation plans or any other specific purpose images as targets. Figure 2 below shows the buildings being augmented onto the real world once the image (a cover page lying on the desk) is scanned with the AR app.

Figure 2. Difference between normal view and augmented view

4.1 Extended Tracking

Extended tracking is another powerful feature which can be used efficiently to position various models in the real world. It uses the features of the real world environment to improve tracking performance and continue tracking even when the target is no longer in view. When the target goes out of view, other information from the surrounding environment is used by Vuforia to obtain the target position by visually tracking the environment [13]. A map is built around the target for this purpose and therefore assumes that the target and environment are static. Once a model is enabled for extended tracking even if it is not in the view of the camera not only the model still stays but the coordinate system still remains intact with respect to the target.

Figure 3. Models in place even after respective image targets have been removed. This is made possible by enabling extended tracking feature.

If extended tracking is enabled the AR application remembers the reference frame of the first target for an extended time even when the camera encounters a problem. Also the subsequent images that are tracked after the first target maintain their positions with respect to the first target as well as with respect to the surrounding environment. From Figure 3, it can be seen that the models stay in their positions with respect to each other as well as the environment even after there are no image targets. Also for extended tracking to work better the environment should be feature rich and static. This is one of its limitations. The more moving parts or features in an environment the lesser efficient is the positioning of the model with respect to the environment.

4.2 Gaze input user interface

Once the user places a smartphone in the Cardboard slot and mounts it for use, he/she cannot interact with the mobile with touchscreen. So one has to depend on other methods of input. Gaze input user interface is a way of interacting by looking at a certain point. An onscreen cursor appears in the user’s view which moves with the head motions of the user.

Wherever the user points his head the onscreen cursor also points in the same direction. So once this onscreen cursor is placed on the User Interface (UI) buttons, a particular function, which is preassigned to the UI buttons is performed.

Figure 4 illustrated how the user points his/her smartphone at the image target (QR code) a menu pops up onto his/her view. In the menu shown there are three UI buttons each associated with a specific function. In order to select the menu options the user has to tilt and orient his/her head such a way that the cursor lies on the UI buttons. Ray casting technique is used to determine when the cursor overlaps with UI objects and the resulting action is triggered. Specific functions for each UI buttons are attached using code scripts.

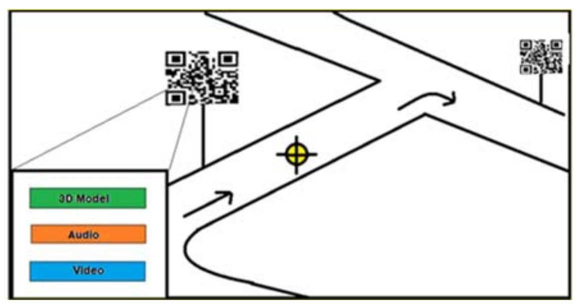

Figure 4. UI buttons and on-screen cursor on user's view

4.3 Integration with Cardboard

Cardboard SDK enables conversion of any application to VR mode. Integrating both Vuforia and Cardboard SDK on Unity game engine can result in the following output shown in the Figure 5 below. It shows a stereo output of the augmentations. The image target in the figure is “TRACKER” which when scanned gives a 3d model augmentation. But since the app had been integrated with Cardboard, for the viewer to get the immersive experience, the stereo output of the augmentation is intended. This integration is done on Unity 3D, where the AR camera from Vuforia SDK is bound to the Left and Right Cardboard Main cameras imported from Cardboard SDK.

Figure 5. Stereo output of AR app

5 Construction Application- Case Illustrations

When the user mounts the cardboard and starts traversing along the site he/she usually picks up the real world camera input until he encounters the image targets. Here the image targets are the QR codes which are specifically positioned at places to ensure the right superimpositions.

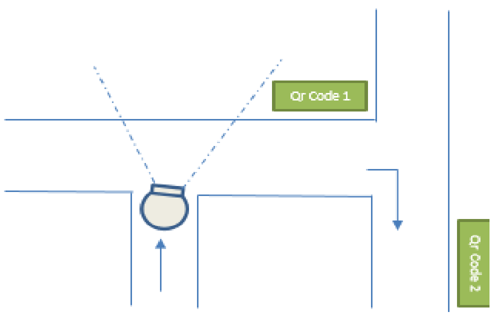

Figure 6. Plan view showing the user's head mounted with Cardboard while traversing the site.

From the Figure 6, 7 and 8 it can be seen that the user traverses the path initially with no augmentations till he encounters QR code 1, then he visualizes a building which is scaled and located at a particular orientation and position with respect to the image target. Also the dotted face in the Figure 7 shows that even when the image target is out of view the model is seen. Hence the first model tracked here is extended tracked as discussed in section 4.1. In an extended tracing system the subsequent models can be as shown in Figure 8, where model 1 stays referenced even though the user is viewing another image target. In this way the entire site can be traversed while positioning the models with respect to the initial image tracked.

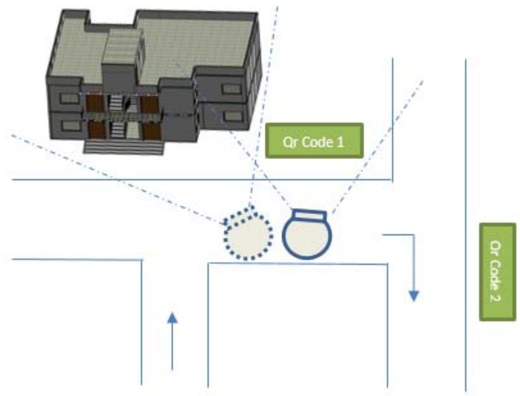

Figure 7. Building model augmented once the user views the QR code.

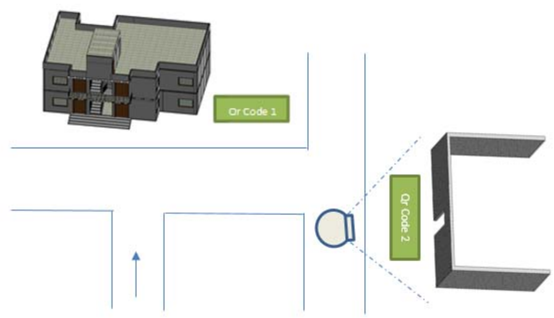

Figure 8. Extended Tracking shows the first image still in position while tracking the next one.

In the modes discussed the models have been invoked as soon as the image target is tracked. But if a menu is invoked instead of the model directly, the user can decide what he wants to view. As shown in Figure 9, a user can use the menu to select whether to view just the 3D model or the reinforcement being superimposed or MEP lines superimposed on the walls.

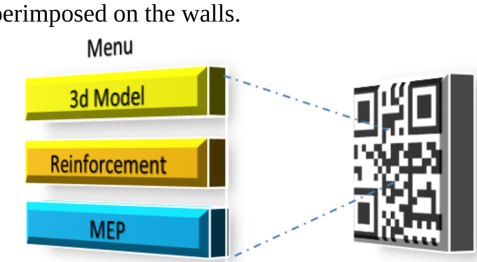

Figure 9. Menu options invoked from QR Code.

Consider the case where the user encounters a QR code as shown in the Figure 10. Once the user mounts the cardboard and views the same image it appears that the menu pops up first onto his view as shown in the Figure 9. And then using the head movements the user has to point the cursor on the desired menu option. In the case below first the user points the cursor onto the “3d Model” option to view the wall with two windows and an entrance. For example, if the QR code to be printed and erected on site is having a width of 30cm, while modelling itself the wall is scaled 10 times to the size of QR code image, so that once 30cm QR code is scanned a 3 meter model wall gets augmented. Also the positioning with respect to the image is done accurately otherwise the slightest of the errors can be picked up by the eye if the model doesn’t overlap with the real world as expected.

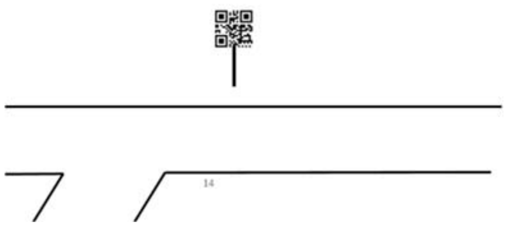

Figure 10. Naked eye view of QR code

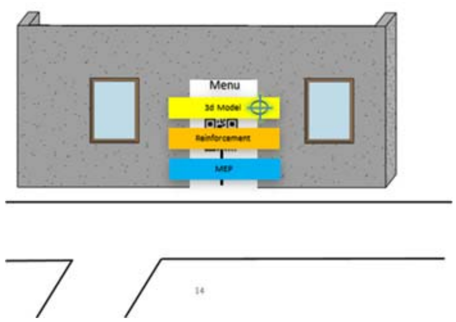

Figure 11. Cursor Invoked 3D model

Similarly the other options are selected by the user by gazing the cursor on the corresponding menu options. Figures 12 and 13 show the super-imposition of the reinforcement and Electrical Lines onto the augmented wall. Also if there is an existing real wall, one can invoke a reinforcement or other attribute display onto it. The visualization of such details of elements helps in understanding where the embedded lines run so that one can exactly pin point a location for maintenance or other activities without actually cutting it open and without going through a large number of drawings.

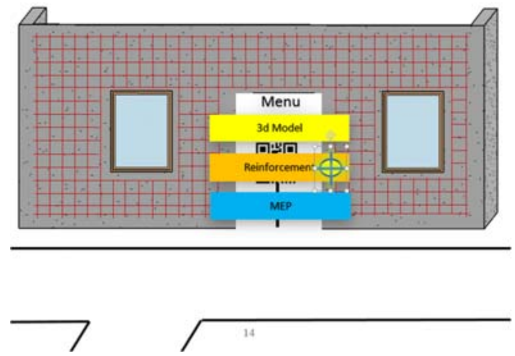

Figure 12. Superimposed Reinforcement

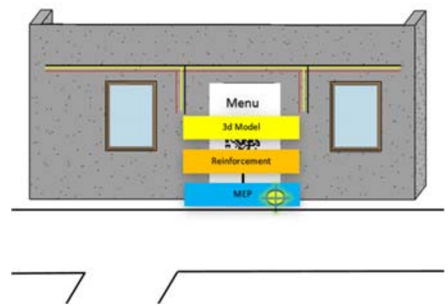

Figure 13. Superimposed Electrical Lines

6 Discussion & Conclusion

Investment in any kind of technology needs a detailed assessment of the value and the potential return on investment. One might deem that implementing advanced technology at construction site would simply increase the cost of construction and early adopters of new technology take a large risk. . Although AR is a technology in its infant stage, the projected utility is enormous that no one can ignore it and preparing for its adoption is a must.

Low investment efforts such as this enables decision makers to experience and evaluate the benefits of AR with minimal financial risk. As full scale deployments of AR technologies in construction becomes feasible the impact on the productivity should be significant.

The cost effective AR platforms is also expected to contribute to the widespread adoption of the technology. While there is need for expensive and sophisticated technologies such as the Microsoft HoloLens, it is the availability for inexpensive and familiar platforms which will propel the widespread usage. Though there are certain limitations to this technology, as a starter these technologies can be used for training workers on site, visualization purposes that gives a clear understanding of the product they are working on. From preliminary initiatives like these the technology can be taken to a full-fledged adoption once it is observed that the results are fruitful.

References

[1] Azuma R. A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments*, 6(4), pages 355-385, 1997.

[2] Webster A., Feiner, S., MacIntyre B., Massie W. and Krueger T. Augmented reality in architectural construction, inspection and renovation. In *Proceedings of ASCE Third Congress on Computing in Civil Engineering*, pages 913-919, 1996.

[3] Feiner S., MacIntyre B., Hollerer T. and Webster, A. A touring machine: Prototyping 3d mobile augmented reality systems for exploring the urban environment. ISWC'97: *Proceedings of the 1st IEEE International Symposium on Wearable Computers, strona 74, Washington, DC, USA. IEEE Computer Society*, 1997.

[4] Rankohi S. and Waugh L. Review and analysis of augmented reality literature for construction industry. *Vis Eng*, 1(1), page 9. 2013.

[5] Dong S. and Kamat V. SMART: scalable and modular augmented reality template for rapid development of engineering visualization applications. *Vis Eng*, 1(1), page 1, 2013.

[6] Wang X., Dunston P.S., Proctor R., Hou L. and So J. Reflections on using a game engine to develop a virtual training system for construction excavator operators. In *Proceedings of the 28th International Symposium on Automation and Robotics in Construction (ISARC 2011): Seoul, Korea.* 2012

[7] Yeh K., Tsai M. and Kang S. On-Site Building Information Retrieval by Using Projection-Based Augmented Reality. *Journal of Computing in Civil Engineering*, 26(3), pages 342-355, 2012

[8] Wang X. Using Augmented Reality to Plan Virtual Construction Worksite. *Int J Adv Robotic Sy*, page1. 2007

[9] Park C., Lee D., Kwon O. and Wang X. A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template. *Automation in Construction*, 33, pages 61-71.2013.

[10] Behzadan AH., & Kamat VR. Integrated information modelling and visual simulation of engineering operations using dynamic augmented reality scene graphs. *Journal of Information Technology in Construction*, ITcon: 16, pages 259–278, 2011.

[11] Shirazi A. and Behzadan A. Design and Assessment of a Mobile Augmented Reality-Based Information Delivery Tool for Construction and Civil Engineering Curriculum. *J. Prof. Issues Eng. Educ. Pract.*, 141(3), page 04014012. 2015

[12] Augmented Reality. Online. https://en.wikipedia.org/wiki/Augmented_reality, Accessed: 01/03/2016.

[13] Developer.vuforia.com. *Vuforia Developer Portal*. Online. http://developer.vuforia.com, Accessed: 01/03/2016.