The Use of Cloud-Based BIM and Augmented Reality for Mobile Construction Site Visualization

xxxxxxxxxxxxxxx
California Polytechnic State University
San Luis Obispo, California

This paper gives a presentation of the development of Cloud-based BIM platforms currently in use in the building sector and explores the different technologies that have been and are currently being developed in the attempt to deliver that information to field personnel in a more efficient manor. It explores the use of mobile apps that are downloadable onto smartphones and tablets, which are starting to become the primary information-sharing medium between stakeholders and the project team. It covers the benefits and increased use of on-site computer kiosks that give workers full access to the BIM model, which are significantly reducing confusion and the need for RFI's and thus reducing costs and time while improving quality. And the bulk of this paper is devoted to the development of different Augmented Reality technologies that give users a superimposed BIM model over the real-life project site visualization. All forms of Augmented Reality are explored, from head-mounted displays, to tablet and smartphone visualizations, even the software architecture behind the technology is explained. This paper is an attempt at showing the future of on-site construction techniques using the benefits of Augmented Reality technology.

Keywords: Building Information Modeling (BIM), Augmented Reality (AR), Cloud-based BIM, AR4BC, jobsite kiosks.

Introduction

History Leading to the Development of BIM

The common practices of the building industry have never evolved quicker than they have in the past few decades. For centuries, the development of a building was overseen entirely by one person, the "master builder." From inception to fruition it was solely their responsibility. The availability of paper in the 1500's created a huge leap forward for the design industry because finally building plans could be saved for future reference. The 1600's and the Enlightenment brought about pencils, the concept of linear perspective drawing, and the ability to scientifically describe a building by accurately projecting a 3-dimensional building into 2-dimensional plans. The next three hundred years had great improvements in the construction industry with the constant evolution of new machinery and construction technology, however, very little technological improvements took place in the design industry. It wasn't until the invention of the home computer in the 1980's that hand-drawn plans began to be replaced by the ever more efficient computer aided drafting (CAD) plots. Exponential improvements in computer technology over the last three decades are what lead to the current trend in building design, building information modeling (BIM), a term made popular by the Autodesk publication "White Paper" in 2002. In that paper, Autodesk described the benefits of BIM as follows; claiming that "building information modeling solutions create and operate on digital databases for collaboration, manage change throughout those databases so that a change to any part of the database is coordinated in all other parts, and capture and preserve information for reuse by additional industry-specific applications…they enable higher quality work, greater speed, and improved cost effectiveness for the design, construction and operation of buildings" (Autodesk, 2002).

Adoption of BIM in the Industry

Over the past decade or so, building information modeling has gained widespread, nearing universal acceptance in both the design and construction sectors. According to an analysis from McGraw-Hill Construction entitled "The Business Value of BIM in North America," it showed that BIM adoption rates in America rose from 17% of the industry in the design and construction sectors in 2007, to 70% in the design industry and 74% in the construction industry in 2012 (Sullivan, 2013). The growth is due primarily to the fact that BIM data is immensely useful in all stages of a buildings development, from design and the development of the construction documents, through the construction phase, for planning and coordination of the project team, and even into facilities maintenance and all end-user requirements. In recent years, the use of BIM and integrated design practices have evolved beyond simply creating data-rich 3D models, to the point where the 4th, 5th, and 6th dimensions are included in the models in the attempt to make the BIM data useful throughout the lifecycle of the building. Integrating time into the model in the form of the construction schedule (4D), including the costs associated with each phase of construction (5D), and finally going as far as to include the pertinent operations and maintenance information (6D) has enabled the digital BIM data to be invaluable to all members of the project team, as well as to all end-users throughout the building's lifecycle.

The Evolution of BIM

Creating Industry Standards for BIM Data

The overwhelming benefits and efficiencies of using BIM models for designing and constructing buildings are well understood, and not the emphasis of this paper, more so the purpose of this paper is to describe the possibilities BIM software has created and discuss where the industry is heading. As discussed in the previous section, the BIM data files are beneficial to far more than just the project team. BIM data is useful to all end-users and facility management (FM) personnel and is why the industry is currently transitioning to a "Cloud-based" universe. Formats such as COBie, Construction-Operations Building Information Exchange, are creating new ways for designers and contractors to directly provide owners and facility management personnel electronic files of operations, maintenance, and asset management information as that information is created (East, 2014). More importantly than creating real-time accessible information for FM teams, Cloud-based design enables designers to improve efficiency by working in real-time with all members of the project team. As Phil Bernstein, architect and technologist with Autodesk, said in describing a Cloud-based BIM universe, "Imagine an energy analysis routine running virtually in a parallel with a designer's copy of Revit, giving her real-time feedback on her scheme as it unfolds?" (Sullivan, 2013). This type of a real-time modeling universe has amazing benefits as it links multiple parties together in real-time regardless of where they are based. In addition, it creates a permanently stored, commonly readable medium for others to utilize the model even after the project is complete.

This new industry trend to store all the information of a building in the "Cloud" so it is readily available to any person necessary in real time, created a new need, a need for an industry standard so that modeling data can be read across all platforms (Revit, Tekla, Bentley, etc.). In an effort to create this industry standard and infrastructure for this new Cloud-based BIM trend in the building industry, the Facility Information Council (FIC) was re-chartered in 2008 as the National BIM Standard-United States™ Project Committee (NBIMS-US). They are a part of the BuildingSMART Alliance and it is their mission to "improve the performance of facilities over their full life-cycle by fostering common and open standards and an integrated life-cycle information model for the A/E/C & FM industry" (nationalBIMstandard.org, 2014). The NBIMS-US Project Committee consists of the broadest and deepest constituency ever assembled for the purpose of establishing and managing through an industry consensus process a series of open source national standards and guidance for all aspects of building information modeling (nationalBIMstandard.org, 2014). If this industry standard is successfully implemented, nearly every piece of information an owner may need to know about a building throughout its life, would be available electronically through the "Cloud." It is currently the goal of the National Institute of Building Sciences "to establish, through the NBIMS-US™ Project, the standards needed to foster innovation in processes and infrastructure so that end-users throughout all facets of the industry can efficiently access the information needed to create and operate optimized facilities" (nibs.org, 2014).

Getting BIM Information to the Jobsite

The current issue that the building industry has failed to capitalize on is getting the BIM information to the actual project site. BIM is effectively used throughout the pre-construction phase, however, it fails to be utilized effectively during the actual construction. Most contracting firm's use of BIM stops at the project office door, generally adjacent to the actual site where the building is physically being assembled. Field personnel, whom could potentially benefit the most by using BIM in regards to reducing both costs and time while improving quality, are still using 2D hardcopy drawings to perform their tasks. In a report written in July of 2013 entitled “BIM Giants 300,” dozens of top A/E/C firms were asked to share where they think the BIM industry is heading, and what is currently missing in the industry (Barista, ‘BIM 2.0’), and the overwhelming response was centered on getting BIM into the field. Some of the responses include: (1) Steve Wilkerson, the Associate Vice President of Haynes Whaley Associates, commented on the need for improving precise field placement methods by incorporating geospatial data in the BIM model with robotic total stations. (2) Don Ghent, the Principal and Global Technical Leader of Gensler, had a response that was perfectly in line with the current trend of our culture as a whole with his suggestion on improving the ability of using BIM on the go. Allowing design teams to instantly communicate with the construction and fabrication crews in the field through use of viewing the cloud-based BIM models on their phones or tablets. (3) Andre Zoldan, Chief Information Officer of Albert Kahn Associates, had the most cutting-edge and all-encompassing response with his suggestion of integrating BIM information with virtual reality technologies (Barista, ‘BIM 2.0’). The concept of overlaying graphical and contextual information onto real world images is described as an “Augmented Reality,” and is the future of BIM field use. The final section of the paper goes into detail about the different Augmented Reality (AR) technologies currently in existence as well as what is still in the design phase.

JE Dunn Case Study: Current In-The-Field BIM Use

A perfect case study to explain the current cutting-edge BIM technologies in practice today was the development of the National Renewable Energy Laboratory in Golden, Colorado, constructed in 2012. Construction giant JE Dunn collaborated with SmithGroupJJR to create the 181,621sf Energy System Integration Facility that is used to study clean energy technologies on a megawatt scale. The lab’s advanced computer modeling and simulation abilities are powered by a petaflop-scale computing system and data center that is rated as one of the most energy efficient in the world (jedunn.com, 2013). Every aspect of the project was designed in close collaboration with the facility’s eventual occupants and O&M team and their incredibly high standards. To meet this demand, JE Dunn created their own custom, Cloud-based BIM/VDC collaboration platform with the use of third party tools like Microsoft SharePoint and Autodesk BIM 360. The platform, called the “Dunn Dashboard,” enables all building team members in different locations to view and collaborate on the model in real time, with electronic submittals and invoicing, customizable security options enabling different persons to only view their respective portions of the model, real-time updates, and mobile jobsite kiosks allowing field workers to view and manipulate the model (Barista, ‘BIM for all’).

The Cloud-based BIM platform not only allows all users to visualize and manipulate the model, including clients with little or no BIM knowledge, but it creates the opportunity to save potentially hundreds of thousands of dollars in cost avoidances by reducing change orders, compressing preconstruction and design development schedules, and allowing owners to better visualize the project and reduce the tendency to change the design mid-construction. Arguably the most important feature and innovation that JE Dunn is implementing is the use of portable, weatherproof, Wi-Fi computer kiosks on the jobsite with the Dunn Dashboard installed, enabling all field personnel to view and manipulate the model with real-time updates. John Jacobs, LEED AP, JE Dunn’s Chief Information Officer, states that they “regularly see lines forming at these kiosks. People walk up and quickly access what they need, whether it be a cut sheet or a detail view. They can move the model around and view an intersection of materials, like a window jamb or flashing detail, so they are sure to build it right the first time” (Barista, ‘BIM for all’).

The Dunn Dashboard is a perfect real-life example of a company utilizing the benefits of a Cloud-based BIM universe and bringing that information to the jobsite in the form of on-site computer kiosks. The Dunn Dashboard, which is a Cloud-based operating platform that was created for the use on one specific job, was so successful that it has now spread nearly throughout the company and is in use on over 425 of the firm’s project teams. Other large construction firms, including McCarthy Building Companies and Mortenson Construction are also investing in their own custom, cloud-based BIM operating platforms to utilize on projects because they greatly increase the value of the BIM models and increase the accessibility of the information to a large number of stakeholders (Barista, ‘BIM for all’). The only downside to these systems are that they are completely custom and specific to each individual company, which is why the NBIMS-US Project Committee is trying to establish an industry standard so that these independent operating platforms can be universal for improved future uses.

Additional Current In-The-Field BIM Uses:

Currently, many of the primary BIM software producers have mobile app extensions of their software that can be downloaded on smartphones and tablets for use in the field. Companies such as Tekla and Autodesk offer free downloads of their field apps so all stakeholders in the project can get real-time updates of the project on the go. Tekla's BimSight, Autodesk's BIM 360 Field Mobile, and about a dozen other apps enable users to reference project documents, and run QA/QC, safety, and commissioning checklists on the go. The mobile apps are not generally used to actually manipulate the BIM models due to the ineffectiveness of viewing the immensely data-rich BIM files on a cell phone, instead, they are primarily used for communication with the project team and simply staying up-to-date on issues and changes in the project. To actually view the BIM models, contractors are using local Wi-Fi on field tablets such as one of the four rugged tablets produced by Motion Computing, or simply an iPad or android tablet. BIM also finds its way into the field with the use of automated total stations that survey the ground and pinpoint markers based on BIM geospatial data. This connection between the digital BIM world and the physical assembly site is now seeing amazing improvements thanks to advances in Augmented Reality technology. Which is what the remainder of this paper will focus on.

Augmented Reality on the Construction Site

The Development of Augmented Reality

Augmented Reality (AR) is a technology where virtual objects are superimposed over real world images. As opposed to virtual reality that replaces the real world with a simulated version, Augmented Reality takes a real world image and adds virtual objects that can be interacted with by the user. The technology works by calculating the position and angle of the camera device with real-time positioning and image processing, then instantly and automatically superimposes all the virtual information uploaded to the software with that specific location and presents virtual objects in the real-world scene that the user can interact with (Chen & Chang, 2014). A common example of AR in practice today is the yellow first down line that you see on your television when you are watching a football game. The video feed of the game is a real-world image, and the yellow line is a virtual object that is superimposed over the image to give us, the users, additional information. AR is also the same technology that is currently being explored by the Google X developers with their Google Glass project. Google Glass is intended to be a head-mounted display (glasses) that delivers AR information in real-time with voice commands.
Google Glass is trying to expand on currently available AR technology that is available for download on most smartphones. A pioneer of this technology is Mani Golparvar-Fard and his app called the Mobile Augmented Reality System (MARS) that makes use of his core technology called HD4AR. Golparvar-Fard developed this software when he was a Ph.D. student at Illinois along with his advisors, Feniosky Pena-Mora and Silvio Savarese, engineering professors at Columbia University and the University of Michigan, respectively. Due to its high amount of potential, the National Science Foundation is currently supporting their software company. This specific mobile app is currently used primarily for the real-estate industry and for step-by-step instructions of car related issues, but has endless potential. The app has an ever-expanding and constantly updated database of homes for sale and countless different car features and instructions on things like how to jump-start your car. With this software, the user can simply take a photo of a house for sale, or your cars dashboard or engine, and the software will automatically correlate the image with the data stored in its database, and provide precisely located virtual objects over the photo that can be interacted with for more information (cee.illinois.edu, 2011). MARS is just one of many currently available downloadable apps that utilize this same AR technology. AR technology probably has the greatest potential for impacting the construction sector, and it is just starting to find its way into the field with multiple different companies currently working on the technology and producing prototypes.

The Potential Benefits of Using Augmented Reality on the Jobsite

The potential benefits of bringing AR in full 4D to the jobsite are truly limitless. The AR technology currently being designed today implements the time schedule into the software, enabling the user to "scroll" through the construction process and see every phase of the construction process unfold in front of them. In the design phase of a buildings development, architects commonly use photo matching with tools like Photoshop to see how their design will look in the real world and especially for showing clients their designs. AR enables real-time photo matching at full scale from any angle. Designers will be able to take clients on a "walking tour" of their proposed designs while physically on the site. Or show them possible options and let them make decisions based on real world visualizations. In the engineering and analysis phase, engineers already run wind and seismic tests in the BIM environment on their computers, but AR will enable engineers to do seismic analysis, structural modeling, acoustic performance, and other analysis' at full scale while walking around the physical site. In the surveying and layout phase, AR could essentially eliminate the need for tape measures and marking excavation locations. The virtual projections enable all users to see the precise location of building elements, intuitively and in real time, as well as potentially provide any necessary assembly instructions or specifications (Barista, '12 applications').

The potential benefits of AR all break down to the general concept of finally getting all the necessary people the required information they need to do their job appropriately in the quickest and most efficient way, thus saving valuable time and money. Management can use the 4D visualization to study and plan sequencing and logistics. Craftsman will be able to view the proposed work in context, at full-scale, and intuitively understand the project at hand. Laborers will no longer need to consult superintendents for clarifications, nor wait for timely RFI or Change Order paperwork to be processed. They will be able to instantly immerse themselves into a detail by simply walking around a space and not need to sit at a desk and use a mouse and keyboard to find the right portion of the model. Quality control by both contractor management as well as third-party inspectors will be significantly improved by simply overlaying the BIM model over the actual in-progress work to ensure it is up to quality. Utilizing the 4D scheduling aspect of the software and comparing it to the on-site developments, the schedule can be closely monitored to ensure timely completion. Programing OSHA standards into the model and continuously ensuring that hazardous work conditions and emergency information is highlighted in the AR view will ensure that workers are aware of the hazards when relevant and superintendents can constantly monitor safety concerns. Finally, one of the better conveniences of AR technology, especially for pre-existing buildings, is the ability to see the entire building system for maintenance and repair purposes. AR provides users with "X-ray" vision of walls, to avoid costly and timely unnecessary destructive demolition when performing routine maintenance or renovations. The ability to precisely locate studs or pipes within a wall simply by looking at it is invaluable (Barista, '12 applications').

Pioneering AR Technology for the Building Construction Sector

Charles Woodward and his team at the VTT Technical Research Centre of Finland and other industrial partners from the Finnish B&C sector have been pioneers in bringing AR to the construction sector. Entitled AR4BC, Augmented Reality for Building and Construction, the Finnish team "aims to provide the mobile user at the construction site with direct two-way access to 3D CAD and 4D BIM information" (Hakkarainen et al., 2009). Their early work involved using Google SketchUp and Google Earth to use building markers and geo-coordinates to superimpose the 3D model into its correct real-world location. The AR4BC project expands on their previous work, incorporating the 4th dimension (time) into the software, as well as implements a feedback system from the construction site to the studio software. The software required sophisticated tracking and positioning systems like inertia sensors, gyroscopes, and electronic compasses, as well visual based methods for model and feature based tracking (Hakkarainen et al., 2009). All of these features made the actual development of this application not cost effective for the jobsite, until the release of the iPad in 2010 which made it economically feasible to use this software on site. The software architecture of the AR4BC system is shown in Figure 1, and has three main components: the 4DStudio, MapStudio, and OnSitePlayer.

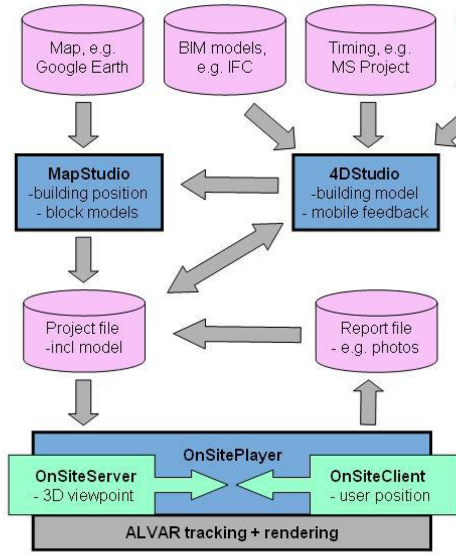

Figure 1 - AR4BC system architecture (image courtesy of Woodward et al., 2010)

The 4DStudio portion of the software handles the 4th dimension of the project, all the timing and scheduling information. It not only accepts the user defined initial schedule as an input, but also constantly updates the real-time development of the project as the OnSitePlayer portion of the software oversees the development. The MapStudio portion of the software uses Google Earth and geospatial coordinates to accurately position the BIM in the appropriate location. Finally, the OnSitePlayer portion of the software is the user interface for the AR visualization. The OnSitePlayer takes the camera's feedback, the MapStudio input, and the 4DStudio input to accurately augment the model in the real world view and adjust it according to the user's geospatial position (Woodward et al., 2010). Accurate camera tracking and real-time rendering has been the biggest obstacle for the different AR design teams to overcome.

Early Field-Use Prototypes Utilizing AR Technology

The development of the iPod, iPhone, and especially the high-computing power of the iPad created an opportunity in the market to capitalize on existing AR technology to fulfill a need in the construction industry. The high-quality camera, on board gyroscope sensor, accelerometer, GPS, and Bluetooth abilities on the Apple products presented themselves as the perfect machines to operate the AR software at affordable prices. Stemming from the innovative AR software developments of AR4BC, HD4AR and others, a number of companies have produced their own versions of AR software programs for the building construction sector. A company called JBknowledge for example released a program called SmartReality that is currently available for free as a beta test prototype. It uses Revit as the BIM input, and accurately superimposes the model in context over any image of the building. It is used primarily to superimpose the 3D model in a full 360-degrees when viewed over 2D plans. For example, when you pan the camera of the iPad over a section drawing of a wall, it will recognize the building element and superimpose the 3D extrapolation of that detail in context over the drawing. You can then rotate the camera around the paper drawing, or simply spin the paper drawing around the table relative to the camera and get a full 3D immersive view of the 2D drawing. Another AR software example came in 2012 when the University of Canterbury released a program called CityViewAR in response to the 2011 Christchurch earthquake in New Zealand that allowed city planners and engineers to visualize the buildings that were destroyed in the earthquake to better assess the damage (Yoders, 2014). Both of these examples, and numerous other versions in beta-test stages at the moment, are only used for external views of buildings, and haven't grasped the ability to do "walk-through's" and see interior components of the building.

In an effort to achieve this missing element, in 2012 a wearable device, called the iHelmet, was developed in an effort to produce construction drawing information on-site on the basis of the needs of the user. The iHelmet is composed of a standard issue construction helmet, with an Optoma LED projector and an iPod Touch. The program that runs the device consists of four modules; the information-integration module, the display module, the positioning module, and the manipulation module. The information-integration module, powered by the iPod Touch, transfers the BIM information into images that can be projected. The position module uses the GPS on the iPod Touch, as well as manual input of position, to allow the system to automatically search for the images that the user might need relative to their geospatial positioning in the building. The manipulation module analyzes the motion of the user using both manual manipulations of the Touch screen as well as the iPod's on-board accelerometer to crop the images in an effort to display the appropriate content. Finally, the display module analyzes the information from the other three modules and scales the image appropriately to create a good projection. Trial runs of this device were implemented with 34 users, and the results showed that information retrieval time using the iHelmet had a mean of 44 seconds, whereas traditional paper drawings had a mean retrieval time of 99 seconds (Yeh et al., 2012).

Current Cutting-Edge Indoor AR Technology

At the 31st International Symposium on Automation and Robotics in Construction and Mining (ISARC) in 2014, engineers from the National Taiwan University of Science and Technology proposed their current studies in developing integrated indoor positioning for AR technologies. Their system uses a Cloud-based BIM database and the WorldViz Vizard operating program to run the technology. The system requires that the building has an indoor wireless network established because it uses wireless access points (WAP's) and markers to identify the building elements within the rooms. Their system requires you to initially input all the building markers that you want the AR program to identify, but once set up, the system is completely automatic. They developed a head-mounted display (HMD) that accurately superimposes the virtual BIM on the real on-site scenes as you walk from room to room without the need to manually navigate the system (Chen & Chang, 2014).

One of the largest and most cutting edge examples of AR technology in the U.S. construction industry is currently being implemented by McCarthy Building Companies on their Kaiser Permanente Oakland Medical Center Replacement project. McCarthy is currently implementing their own Cloud-based BIM platform and further integrating that information into the physical building space through the use of QR codes and AR technology. In the doorjamb of nearly every door in the building, as well as on most of the buildings equipment and major elements you will find a QR code sticker. "At any given time, a project superintendent, subcontractor, architect, facilities team member, or other field personnel can scan one of the QR codes throughout the campus with a smartphone or tablet computer and instantly immerse themselves in the up-to-date, as-built 3D BIM model or 3D laser scan of that space" (Barista, 'AR goes mainstream'). A user simply needs to open the AR program on their phone or tablet, scan the QR code in the doorjamb, and simply point the camera on the device toward the building element they are interested in and you have a real-time AR BIM overlay of the entire room. In describing the custom McCarthy BIM and AR platform, Chris Pechacek, McCarthy's Virtual Design and Construction Director, said that it was designed so "the user doesn't have to be a software guru and know how to navigate through the model, or start their AR session on the outside of the building and have to make their way into the building. It enables all users to instantly access the information they need, saving precious time and avoiding frustrations with traditional systems" (Barista, 'AR goes mainstream'). The QR codes also provide the project team with real-time updates and access to important project documentation, including change orders, RFI's, warranties, submittals, operating manuals, 2D plans, and markups. The key to their AR implementation has been due to them using 3D laser scanning to capture the as-built environment at several stages during construction. They also conducted comprehensive scanning sessions during the final-inspection stage, when all of the infrastructure and building systems were installed and before the walls and ceilings were closed off. As Pechacek said, "most AEC firms will laser scan existing conditions for use for design development on a renovation project, we're doing it during the course of construction, creating the as-builts as we go, and using that as a component within our change-management process" (Barista, 'AR goes mainstream'). These methods have significantly helped them mitigate the impacts of changes, as well as help to keep them on schedule and within budget.

Conclusion

This paper has been a presentation on the development of BIM and AR technology and its use in the construction field. The widely used BIM software programs and all of their informational benefits had failed to make their way into the actual construction field, and new technologies like Cloud-based BIM platforms and 4D Augmented Reality solutions are creating that opportunity. The Cloud-based BIM platforms are currently being developed independently by major contractors for the sole use on their own projects, but foundations like the National BIM

Standard-United States™ Project Committee are currently trying to standardize the industry for better use by all. Currently, major projects are utilizing on-site mobile computer kiosks so workers can utilize the model and gain additional information in a very time-effective manor. The Cloud-based BIM platforms also serve as the launch pad for the revolutionary AR technologies that take the BIM information and superimpose virtual objects over the real-life images to give the users on-site information in real-time. Some primitive AR devices such as the iHelmet have been produced in an attempt to bring the critical, detailed, indoor BIM information to the worker in a time-effective manor, but those devices were quickly replaced by more efficient technologies. The current best innovative use of AR technology in practice is McCarthy's use of QR codes on doorjamb's and comprehensive 3D laser scans of the as-built building, to allow users to instantly and automatically bring up the appropriate AR BIM information for their respective location in the building. Additional technologies that utilize WAP's are creating fully automatic AR solutions that will soon be a common reality and utilized throughout the building sector.

References

Autodesk, Inc. (2002). "White Paper," *Building Information Modeling*.

Barista, D. (2013). "BIM 2.0: AEC Firms Share Their Vision for the Great Leap Forward in BIM/VDC Implementation [2013 Giants 300 Report]." *BIM 2.0: AEC Firms Share Their Vision for the Great Leap Forward in BIM/VDC Implementation [2013 Giants 300 Report]*. Building Design + Construction, 19 July 2013. Web.

Barista, D. (2013). "'BIM for All' Platform Pays off for the Contractor." Building Design + Construction, 3 Dec. 2013. Web.

Barista, D. (2013). "Augmented Reality: 12 Applications for Design and Construction Professionals." *Building Design + Construction*, 4 Sept. 2013. Web.

Barista, D. (2013). "Augmented Reality Goes Mainstream: 12 Applications for Design and Construction Firms." *Building Design + Construction*, 4 Sept. 2013. Web.

Chen, Hung-Ming and Chang, Ting-Yu. (2014). Integration of Augmented Reality and indoor positioning technologies for on-site viewing of BIM information, in The 31st International Symposium on Automation and Robotics in Construction and Mining (ISARC 2014), Sydney, Australia, July 2014.

East, B. (2014). "Construction-Operations Building Information Exchange (COBie)." *WBDG*. National Institute of Building Sciences, 4 Aug. 2014. Web.

Hakkarainen M., Woodward C. and Rainio K. (2009). Software Architecture for Mobile Mixed Reality and 4D BIM Interaction, in Proc. 25th CIB W78 Conference, Istanbul, Turkey, Oct 2009.

Sullivan, C. C. (2013). "The Future of Construction: Meet BIM (or Else)." *SmartPlanet*. Architecture, 12 Feb. 2013. Web.

Woodward, C., Hakkarainen M., Korkalo O., Kantonen T., Aittala M., Raino K., and Kahkonen K. (2010). "Mixed Reality for Mobile Construction Site Visualization and Communication." *Proc. of 10th International Conference on Construction Applications of Virtual Reality*, Sendai, Miyagi, Japan. CONVR, 4 Nov. 2010. Web.

Yeh, Kai-Chen, Tsai, Meng-Han, and Kang, Shih-Chung. (2012). "On-Site Building Information Retrieval by Using Projection-Based Augmented Reality." *Journal of Computing in Civil Engineering* 26.3 (2012): 342-55. Web.

Yoders, J. (2014) "How Is Augmented Reality Being Used in Construction." *LINESHAPESPACE* Autodesk, 21 Mar. 2014. Web.

"About the National BIM Standard-United States™." *About the National BIM Standard-United States*. National Institute of Building Sciences BuildingSMART Alliance, 2014. Web. <http://www.nationalbimstandard.org/about.php>.

"Civil and Environmental Engineering at Illinois." *Augmented Reality System Useful for Construction and beyond*. The University of Illinois, 2011. Web. <http://cee.illinois.edu/mars_jan13>.

"National Renewable Energy Laboratory (NREL) Energy System Integration Facility Phase I | JE Dunn Construction." *National Renewable Energy Laboratory (NREL) Energy System Integration Facility Phase I | JE Dunn Construction*. JE Dunn, 2013. Web. <http://www.jedunn.com/projects/national-renewable-energy-laboratory-system-integration-facility-phase-i>.

"Standards - National Institute of Building Sciences." *Standards - National Institute of Building Sciences*. N.p., 2014. Web. <http://www.nibs.org/?page=standards>.