Integration of Augmented Reality, Building Information Modeling, and Image Processing in Construction Management: A Content Analysis

Ali Karji[1]; Asregedew Woldesenbet[2]; and Saeed Rokooei[3]

[1] Ph.D. Student, Durham School of Architectural Engineering and Construction, Univ. of Nebraska-Lincoln, The Peter Kiewit Institute 117A, 1110 S 67th St., Omaha, NE 68182-0816. Email: akarji@unomaha.edu

[2]Assistant Professor, Durham School of Architectural Engineering and Construction, Univ. of Nebraska-Lincoln, The Peter Kiewit Institute 105C, 1110 S 67th St., Omaha, NE 68182-0816. Email: awoldesenbet2@unl.edu

[3] Post-Doctoral, Durham School of Architectural Engineering and Construction, Univ. of Nebraska-Lincoln, The Peter Kiewit Institute 117A, 1110 S 67th St., Omaha, NE 68182-0816. Email: srokooei@unomaha.edu

Abstract

Today, the advancement in digital infrastructure such as augmented reality (AR), building information modeling (BIM) and image processing (IP) are flourishing the construction industry. AR provides virtual information on physical surfaces which helps to interact with the real world through a combination of virtual information and real information. Advertisement, assembly of equipment, safety tips and facility management are good examples of current application of AR, while BIM has wider implementation in planning, visualization, and demolishing of construction waste. Image processing (IP) is the practice of analyzing an image or video in order to obtain information and set of different characteristics. While some studies have put an effort to take advantage of these advancements separately or in combination, the integration of AR, BIM and image processing can offer a huge advantage to the construction industry in such a way that BIM contains a huge amount of detailed information about building elements which can be imported along with data that can be captured by image processing into an AR application. This study presents a preliminary review of prior studies and current practices that has been conducted in these three areas and integration efforts.

INTRODUCTION

Nowadays, our world is going toward a digitalized era. According to Viveca's (2016) prediction, 20% of all business sectors' content will be authored by machines in 2018. The construction industry is one of the sectors that is adopting digital technology and information systems in its daily business practice. However, the industry is relatively behind other industry sectors in taking advantage of digitalization to generate reliable information and support decision-making processes (Woldesenbet et al. 2015). Figure 1 illustrates this fact whereby the construction industry ranks the lowest with an industry digitalization index of 34.9 out of 60 compared to thirteen industry sectors in terms of implementing technologies (Roman et al., 2013). Although this is the case, it is an undeniable fact that the development of innovative approaches and technological advancement such as Building Information Modeling (BIM), Artificial Intelligence

Downloaded from ascelibrary.org by Pennsylvania State University on 09/12/19. Copyright ASCE. For personal use only; all rights reserved.

(AR), and Image Processing (IP) is empowering the construction industry in recent years. Each of these technologies have their own usage and potential application from various perspectives of the construction industry. The following sections will describe each of these technological advancement and their applications in the construction industry.

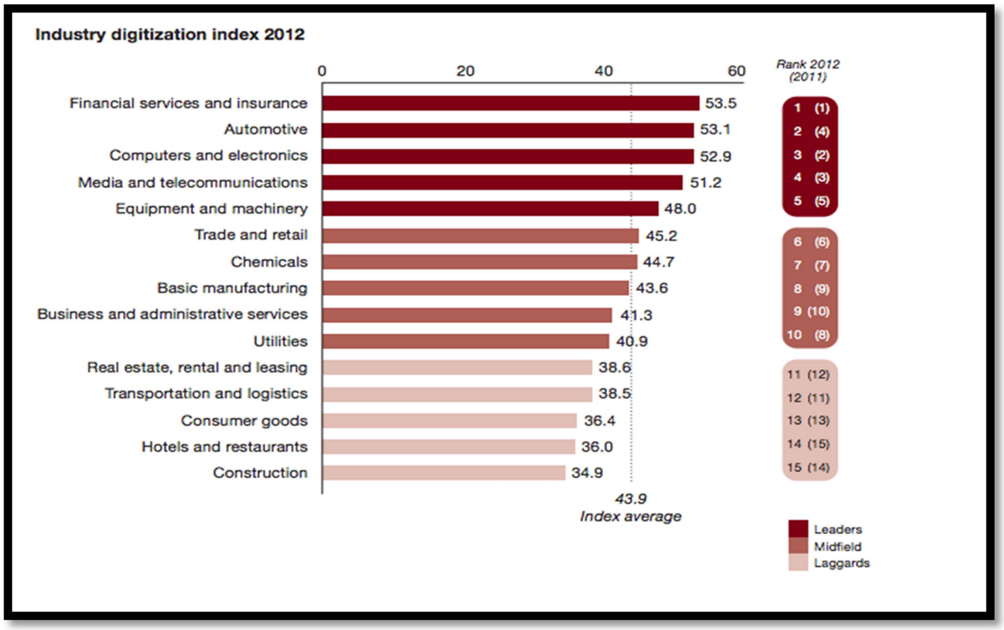

Figure1- Industry Digitization Index (Roman et al., 2013)

CONTENT ANALYSIS

Augmented Reality

Augmented reality is a technique of combining digital and real information on a virtual device screen, such as cellphone or tablet to provide a user real-virtual view. This real-virtual view helps one to get access to valuable augmented information that makes decision making process easier. By using augmented reality, the virtual world is shown next to the real world object. Azuma et al. (2001) defines AR as "a system that supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world". So far, various industries have used AR in multiple applications including: navigation (Narzt et al., 2005); medical (Azuma, 1997); smart shopping (Madushanka et al., 2014); entertainment (Azuma, 1997; Tang et al., 2003); education (Kesim and Ozarslan, 2012) and training (Tang et al., 2003); assembly (Tang et al., 2003) and manufacturing (Azuma, 1997); museum and libraries (Pence, 2010); travel guide apps such as Wikitude (Winnie, 2011); safety (Furht, 2011); interior design (Tang et al., 2003); and smart glasses such as google glass (Hwang and Peli, 2014).

In the construction industry, this technology is used pretty much in a similar fashion with a subtle difference. For instance, AR has shown to be a potential tool in the education sector since it can change the traditional way of theoretical teaching to a novel approach. This approach is based on a real-virtual touching of an object at a jobsite which motivates students to interact about the materials that is being taught by the instructor. Behzadan and Kamat (2013) developed a real time interactive visual information framework to augment the jobsite visual information

© ASCE

Downloaded from ascelibrary.org by Pennsylvania State University on 09/12/19. Copyright ASCE. For personal use only; all rights reserved.

Downloaded from ascelibrary.org by Pennsylvania State University on 09/12/19. Copyright ASCE. For personal use only; all rights reserved.

for students using head-mounted display (HDM) and an AR Book. Since AR can provide virtual dimension on real surfaces, a person can easily monitor the geometrical properties of a building without using any pre-installed target panels. This application of AR was investigated by Dong et al. (2013) to measure the inter-story drift ratio (IDR) for measuring the damage made to a building as a result of catastrophic events. This method is really promising in the construction industry since it is non-destructive.

One of the most popular use of AR in the construction industry is advertisement. The idea is that a contractor can show a completed version of a building to the owner using AR. Shin et al. (2013) compared 3-D and AR representation of an object to find the appropriate scene imagination in non-existing buildings and found out that AR to be more favorable. Assembly of an equipment in a construction site is another practical usage of AR that attracted a lot of companies to provide AR software. Typically, AR is used to put the designed object into their real position through a virtual-real view of the object and its surroundings. The object could be a wall, window or pipes (Hou et al., 2015). Tang et al. (2003) also investigated the effectiveness of AR for an assembly task with a printed manual and computer assisted instruction. The study concluded that AR helps a user to reduce error by 82% . In the area of facility management, Irizarry et al. (2013) developed a new mobile AR to improve the situation awareness of facility managers in finding the nearby facilities that they were looking for.

In addition, AR provides benefits in reducing risk and maximizing safety of a jobsite as shown in Chen et al. (2016). The study used AR to reduce accidents during a crane operation. AR can also be used in energy optimization. Yabuki et al. (2015) used AR technology along with wireless sensor network to monitor the temperature distribution in an air conditioned room. In navigation, Koch et al. (2014) developed an AR framework that navigates managers to the items they are looking for in a building. The study used natural markers such as exit signs, as AR markers to assist navigation in the framework. Shin and Dunston, (2009) developed an AR system called ARCam to inspect a steel column. The study concluded that AR provides faster inspection for a steel column inspection than the traditional usage of total station. Lastly, positioning construction objects has been an interesting technique for companies and experts. Kuo et al. (2013) developed a mobile augmented reality indoor positioning system to put construction objects into their desired location. The marker for their research was infrared invisible marker. These aforementioned studies can be considered as some of the key usage of the AR in construction industry. However, the potential of AR has not been used to the fullest compared to other industries. AR is a promising technology that is still is in its early age and as all other technologies, it will continuously be embraced by experts in construction industry over time.

Image Processing

Image processing is the practice of analyzing an image or video in order to output some information such as an image or set of characteristics. Similar to AR, image processing has wide usage in the construction industry including the detection of construction components for tracking or for progress monitoring such as steel and concrete work; productivity analysis which could be the result of the detection of components; tracking of construction resources and activities; quality assurance (inspection and maintenance) as an inspection of the cracks in a cured concrete beam Table 1 summarizes a detail breakdown of the different aspects image processing usage in the construction industry.

© ASCE

Table1- Application of Image Processing in Construction Industry

Authors	Application	Methodology
Abeid Neto et al. (2002)	Detection of structural components in a picture that is taken at construction site	Detection based on the RGB range of construction materials such as steel and concrete and also using an algorithm called Edge-Detector to find the boundary of the intended object
Zhu and Brilakis (2010)	Concrete Column Detection in construction images and videos	Identifying the long vertical lines on the edges of an object in an image using Edge detection technique and Hough transform, then using the visual features (e.g., RGB code) of the region between long lines to find its material signature and finally matching it with the material signature database
Wu et al. (2010)	Detection of the intended objects in a construction image to monitor construction progress	First, preprocessing the image to enhance its quality. Then, developing an image mask filter using 3D CAD to help to remove the unnecessary information in the initial stage of using the two integrated techniques, Canny edge detection and watershed transformation, on the preprocessed image.
Chi and Caldas (2011)	Construction Object detection using video cameras	Detecting a moving object in a construction video using background subtraction and region segmentation and then identifying the correspondence detected object in two consecutive images based on region centroid position, size of the area occupied by pixels and height/width ratio. Finally the identified objects were classified using their shape and position and their color.
Son et al. (2012)	Concrete Detection	Detection based on the combination of color-based methodology (HIS) and machine learning algorithm (vector machine model)
Gong and Caldas (2010)	Productivity measurement using the videos recorded at the construction operations	Developing the video interpretation model, based on computer vision techniques and model based computer reasoning, to measure productivity. In this model the extraction of the information from the video frames was conducted with the integration of video computing algorithms with the prior knowledge of the construction task.
Junhao and Hyoungkwan (2005)	Measuring the construction equipment idle time	Using HSV for image segmentation, the concept of the object with close centroid for tracking, and the changes of centroid as a sign of moving
Quiñones-Rozo et al. (2008)	Monitoring excavated soil surface	Using Close-Range photogrammetry and Image Reasoning to quantify excavated soil surface changes
Lange et al. (2007)	Detection of the crack in concrete	Using Photogrammetric measurement
Kim et al. (2013)	Updating 4D CAD model using image processing	Taking pictures of the construction site, removing the unnecessary information in the pictures using HSV, improving the picture using morphological image processing, comparing the resulted image with the 3D CAD-based image mask filters to calculate the construction progress of each component and as a result to get the schedule information of each component and finally integrating the existing 3D CAD model with the schedule information to have update 4D CAD model

Downloaded from ascelibrary.org by Pennsylvania State University on 09/12/19. Copyright ASCE. For personal use only; all rights reserved.

© ASCE

Downloaded from ascelibrary.org by Pennsylvania State University on 09/12/19. Copyright ASCE. For personal use only; all rights reserved.

Based on Table 1, most studies utilized image processing in the detection of construction components such as columns. Digitalized detection of construction components is essential for the purpose of monitoring the progress of the construction process and quality control. The main techniques for detection of these components rely on the color and the shape of the objects. Every material has its own specific RGB color which makes it different from the others. For the shape of an object, there are techniques that usually deal with finding the edge of an object such as Edge detector as it is used by Abeid Neto et al. (2002) and also Zhu and Brilakis (2010). Sometimes the height/width ratio is useful for comparing two images when the intended object comes toward the camera in one image and as a result it seems to be bigger in the other picture (Chi and Caldas, 2011). Along with color and shape based methods, there is a preprocessing technique to enhance the quality of an image before going through the detection functions as it was used by Wu et al., (2010).

Some researchers like Son et al. (2012) utilized machine learning algorithms to detect concrete components. This method was effective as it received tan overall accuracy of 93.06% at detection of the concrete. Measuring productivity is another usage of image processing. Gong and Caldas (2010) used video computing algorithms to compute the productivity of a concrete column pour operation. Junhao and Hyoungkwan (2005) also found that HSV is more favorable than RGB for image segmentation. The study used the concept of an object with close centroid for tracking. This concept argues that objects with close centroid in two consecutive frames are said to be same and it is a means to track an object in different frames when it moves. Other applications of the image processing consist of monitoring excavated soil surface (Quiñones-Rozo et al., 2008), concrete crack detection (Lange et al., 2007) and updating 4D CAD model (Kim et al., 2013). As mentioned in the AR section, these applications are not all the usage of image processing and we cannot limit its practicality to just this table. For instance, image processing has lots of usage in the transportation in the detection of the passing cars in streets or highway. One thing that is probable is that it is an emerging technology that will have huge impact on construction industry since it is aligned with the digitalization of the world.

Building Information Modelling

Building Information Modeling (BIM) is the process of visualizing the construction industry. The first word “Building” refers to any kind of building like commercial, residential or infrastructure. The second word “Information” refers to a vast variety of information like equipment, material properties, worker, the schedule, the component of a structure such as wall or room and the cost of the construction. Finally, the term “Modeling” refers to the visualization softwares and frames that are associated to the information. National BIM Standard-United States (NBIMS-US) defines BIM as “a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward.” (Deke, 2012). According to Autodesk, “Building Information Modeling (BIM) is an intelligent 3D model-based process that equips architecture, engineering, and construction professionals with the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure”. However, BIM is more of a process and rather than application.

Recently, BIM’s usage has gained wide recognition among the newest advancements in the construction industry. Hardin and McCool (2015) argued the value of the BIM in the construction industry as equivalent to the value of the technology in people’s daily life.

© ASCE

Although this value varies in the industry, almost every aspect of the construction has benefited from this advancement. In 2015, according to Dodge Data & Analytics, 48% of survey participants saw a 5% decrease or more in construction cost by using BIM and 31% reported a 25% improvement in labor productivity. BIM also has a lot of application in waste management, safety management and facility management. Thus, it is a fact that BIM is growing rapidly around the world that many countries are trying to incorporate and mandate BIM as integral part of the construction industry.

Downloaded from ascelibrary.org by Pennsylvania State University on 09/12/19. Copyright ASCE. For personal use only; all rights reserved.

Potential Usage of BIM, AR and IP

There have been numerous studies in the area of BIM, AR and Image Processing as discussed in the introduction part. The primary reason as to why these areas are critical in the industry is the fact that they are aligned with the digital era. BIM provides a huge information about the construction site; AR provides virtual information on the real physical environment; and IP analyzes a picture and provides some information related to it. However, despite some difficulties there has been some research trying to connect or integrate these advancements. Kwon et al. (2014) used Image processing, AR and BIM to detect the defects in a concrete. By defect, the study referred to the dimensional error of the built concrete. However, the study did not utilize image processing and AR and BIM at the same time, but rather did two experiments: i) the first one with image-matching and BIM and ii) the second one with BIM and AR. The study concluded that their system will reduce the cost and time of a project (Kwon et al., 2014). Another study was done by Park and Kim (2013) about using of BIM and AR. The study integrated AR, BIM, location tracking and game technologies to develop a framework for improvement of safety in the construction site. Wang integrated BIM with AR to create real-time visualization of construction task. This integration provided as-built information for BIM (Wang et al., 2013). The integration of BIM and image processing also could lead to the as-built models as Yang et al. (2016) reconstructed a building façade using images. Apparently there are not a lot of studies integrating BIM and image-processing. These prior studies focused more integrating BIM with AR, however there are limited studies that combine image processing with either BIM or AR or all three.

Barriers to Integrate AR, BIM and IP

One of the potential reasons for integrating these advancements could be attributed to the fact that each are relatively new to the construction industry in comparison to other industries and as a result researchers are more prone to explore each separately. In other words, each of this technology has its own level of complexity to work with. For using AR technology, a construction researcher needs to know programming skills such as ARToolkit which is a cross-platform that is programmed in C+ for modification and be built on another application such as Microsoft Visual Studio in Windows and Xcode in Mac. This holds the same for image processing which requires programming skills such as MATLAB and C++. However, the difficulty level for BIM is less than the other two since most of the BIM applications are more well-known and practiced.

For Image Processing, another barrier is noise in the images taken before the detection process. Typically, after an object is detected, there is a need to improve the quality of the detected object. Morphological image processing is one of the methods used to improve the quality of the detected object as Wu et al. (2010) and Chi and Caldas (2011) used in their image and video detection process, respectively. This technique uses the spatial image analysis to join smaller

© ASCE

Downloaded from ascelibrary.org by Pennsylvania State University on 09/12/19. Copyright ASCE. For personal use only; all rights reserved.

detected parts to bigger parts or to remove them (Chi and Caldas, 2011). However, there is still a need to improve the quality of detection to get better result and information. The other problem that may arise when using image processing technique is when two objects are close to each other. This may get worse when one obstructs the view of another object. In the absence of a picture of an object, how can an algorithm can detect the object? One solution could be putting the camera on a higher elevation. However, this solution has its own problems. Letting alone the practicality of this solution, when a picture is taken from a far distance, the quality of the image will decrease and as a result the detection accuracy will decrease. Another solution could be the installation of more than one camera which makes tracking more complicated.

Talking about integration of these advancements, the big challenge that hampers the integration of is the specific area of application. On one hand, BIM works with information and modeling which can provide information for the life cycle of a building. On the other hand, image processing works with images and videos to produce valuable data, while AR works with augmentation of the information. So there are not a lot of opportunity for these advancements to overlap and work on the same subject. In addition, each has its own specific input and output data which are not aligned with each other all the time. The input for a typical BIM could be geometrical data of a site plan and scheduling information with the output of a 3-D virtual model connected with the time and resources of each construction operation. Augmented reality combine live view with virtual information/view to provide a user real-virtual view. Image processing takes an image or video and outputs data such as detection and tracking of an intended component. Instances of incompatible input/output could be utilized using the output of AR as an input for image processing or as an input to develop BIM or using the output of BIM for image processing or the output of image processing for AR.

CONCLUSION

Today, the advancement of digitalization such as Augmented Reality (AR), Building Information Modeling (BIM) and Image Processing (IP) are enhancing the construction industry. In this paper, prior studies and current practices in each of these advancements have been summarized. In the construction industry, AR has been practiced in education, measuring building damage, advertisement, assembly, facility management, risk management, energy optimization, inspection and indoor positioning system. Detection of construction component, monitoring productivity, tracking construction resources and activities, inspection and maintenance, and progress monitoring are some of the areas in the construction industry that image processing is utilized. The usage of BIM is more than AR and image processing. This process can be used for scheduling and visualizing of the construction, facility management, cost management, productivity, waste management and safety management. The integration of BIM, AR and image processing and the efforts made and barriers to integration have also been discussed. Although there are a lot of studies in each of these areas, there are limited studies that tries to tie all three. This can be attributed to the following reasons. First, each of this advancement has its own level of complexity, such as programming in AR and image processing which makes it difficult to integrate. Second, there are limited areas of common applications where these three advancements can suit. Third, the input/output of these three advancements may not be aligned in some cases. Thus, there is a gap to integrate these three advancements in moving the construction industry one step forward.

© ASCE

Downloaded from ascelibrary.org by Pennsylvania State University on 09/12/19. Copyright ASCE. For personal use only; all rights reserved.

REFERENCES

Abeid Neto, J., Arditi, D., and Evens, M.W. (2002). Using Colors to Detect Structural Components in Digital Pictures. Comput.-Aided Civ. Infrastruct. Eng. *17*, 61–67.

Azuma, R.T. (1997). A Survey of Augmented Reality. Presence Teleoperators Virtual Environ. *6*, 355–385.

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., and MacIntyre, B. (2001). Recent Advances in Augmented Reality. IEEE Comput. Graph. Appl. *21*, 34–47.

Behzadan, A.H., and Kamat, V.R. (2013). Enabling Discovery-based Learning in Construction using Telepresent Augmented Reality. Autom. Constr. *33*, 3–10.

Chen, Y.-C., Chi, H.-L., Kang, S.-C., and Hsieh, S.-H. (2016). Attention-Based User Interface Design for a Tele-Operated Crane. J. Comput. Civ. Eng. *30*, 04015030.

Chi, S., and Caldas, C.H. (2011). Automated Object Identification Using Optical Video Cameras on Construction Sites. Comput.-Aided Civ. Infrastruct. Eng. *26*, 368–380.

Deke, S. (2012). National BIM Standard-United States version 2 (©2012 National Institute of Building Sciences buildingSMART alliance™).

Dong, S., Feng, C., and Kamat, V.R. (2013). Sensitivity analysis of augmented reality-assisted building damage reconnaissance using virtual prototyping. Autom. Constr. *33*, 24–36.

Furht, B. (2011). Handbook of Augmented Reality (Springer Science & Business Media).

Gong, J., and Caldas, C.H. (2010). Computer Vision-Based Video Interpretation Model for Automated Productivity Analysis of Construction Operations. J. Comput. Civ. Eng. *24*, 252–263.

Hardin, B., and McCool, D. (2015). BIM and Construction Management: Proven Tools, Methods, and Workflows (John Wiley & Sons).

Hou, L., Wang, X., and Truijens, M. (2015). Using Augmented Reality to Facilitate Piping Assembly: An Experiment-Based Evaluation. J. Comput. Civ. Eng. *29*, 05014007.

Hwang, A.D., and Peli, E. (2014). An Augmented-Reality Edge Enhancement Application for Google Glass: Optom. Vis. Sci. *91*, 1021–1030.

Irizarry, J., Gheisari, M., Williams, G., and Walker, B.N. (2013). InfoSPOT: A mobile Augmented Reality method for accessing building information through a situation awareness approach. Autom. Constr. *33*, 11–23.

Junhao, Z., and Hyoungkwan, K. (2005). IMAGE PROCESSING FOR CONSTRUCTION EQUIPMENT IDLE TIME ANALYSIS.

© ASCE

Kesim, M., and Ozarslan, Y. (2012). Augmented Reality in Education: Current Technologies and the Potential for Education. Procedia - Soc. Behav. Sci. *47*, 297–302.

Kim, C., Kim, B., and Kim, H. (2013). 4D CAD model updating using image processing-based construction progress monitoring. Autom. Constr. *35*, 44–52.

Koch, C., Neges, M., König, M., and Abramovici, M. (2014). Natural markers for augmented reality-based indoor navigation and facility maintenance. Autom. Constr. *48*, 18–30.

Kuo, C., Jeng, T., and Yang, I. (2013). An invisible head marker tracking system for indoor mobile augmented reality. Autom. Constr. *33*, 104–115.

Kwon, O.-S., Park, C.-S., and Lim, C.-R. (2014). A defect management system for reinforced concrete work utilizing BIM, image-matching and augmented reality. Autom. Constr. *46*, 74–81.

Lange, J., Benning, W., and Siering, K. CRACK DETECTION AT CONCRETE CONSTRUCTION UNITS FROM PHOTOGRAMMETRIC DATA USING IMAGE PROCESSING PROCEDURES.

Narzt, W., Pomberger, G., Ferscha, A., Kolb, D., Müller, R., Wieghardt, J., Hörtner, H., and Lindinger, C. (2005). Augmented reality navigation systems. Univers. Access Inf. Soc. *4*, 177–187.

Park, C.-S., and Kim, H.-J. (2013). A framework for construction safety management and visualization system. Autom. Constr. *33*, 95–103.

Pence, H.E. (2010). Smartphones, Smart Objects, and Augmented Reality. Ref. Libr. *52*, 136–145.

Quiñones-Rozo, C.A., Hashash, Y.M.A., and Liu, L.Y. (2008). Digital image reasoning for tracking excavation activities. Autom. Constr. *17*, 608–622.

Roman, F., Alex, K., Florian, G., and Birger, M. (2013). The 2012 industry digitization index (Booz & Company).

Shin, D.H., and Dunston, P.S. (2009). Evaluation of Augmented Reality in steel column inspection. Autom. Constr. *18*, 118–129.

Shin, D.H., Park, J., Woo, S., and Jang, W.-S. (2013). Representations for imagining the scene of non-existing buildings in an existing environment. Autom. Constr. *33*, 86–94.

Son, H., Kim, C., and Kim, C. (2012). Automated Color Model–Based Concrete Detection in Construction-Site Images by Using Machine Learning Algorithms. J. Comput. Civ. Eng. *26*, 421–433.

Susan, P. Study Finds BIM Offers Substantial Benefits for Construction Industry.

Downloaded from ascelibrary.org by Pennsylvania State University on 09/12/19. Copyright ASCE. For personal use only; all rights reserved.

© ASCE

Tang, A., Owen, C., Biocca, F., and Mou, W. (2003). Comparative Effectiveness of Augmented Reality in Object Assembly. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, (New York, NY, USA: ACM), pp. 73–80.

Viveca, W. Gartner Reveals Top Predictions for IT Organizations and Users for 2016 and Beyond.

W.A.L.Madushanka, Silva, P.H.A.M.D., and B.A.L.Madhushani (2014). Smart Shopping: Building a Tool Based on Augmented Reality. COMPUSOFT Int. J. Adv. Comput. Technol. *3*, 1186–1192.

Wang, X., Love, P.E.D., Kim, M.J., Park, C.-S., Sing, C.-P., and Hou, L. (2013). A conceptual framework for integrating building information modeling with augmented reality. Autom. Constr. *34*, 37–44.

Winnie, S. (2011). Top 10 augmented reality travel apps | CNN Travel.

Woldesenbet, A, Jeong, H., and Park, H. (2015). Framework for Integrating and Assessing Highway Infrastructure Data, J. Manage. Eng., ASCE, Vol. 32 Iss. 1

Wu, Y., Kim, H., Kim, C., and Han, S.H. (2010). Object Recognition in Construction-Site Images Using 3D CAD-Based Filtering. J. Comput. Civ. Eng. *24*, 56–64.

Yabuki, N., Hosokawa, M., Fukuda, T., and Michikawa, T. Visualization of Indoor Thermal Conditions Using Augmented Reality for Improving Thermal Environment. In Computing in Civil Engineering 2015, (American Society of Civil Engineers), pp. 339–346.

Yang, J., Shi, Z.-K., and Wu, Z.-Y. (2016). Towards automatic generation of as-built BIM: 3D building facade modeling and material recognition from images. Int. J. Autom. Comput. *13*, 338–349.

Zhu, Z., and Brilakis, I. (2010). Concrete Column Recognition in Images and Videos. J. Comput. Civ. Eng. *24*, 478–487.

Downloaded from ascelibrary.org by Pennsylvania State University on 09/12/19. Copyright ASCE. For personal use only; all rights reserved.

© ASCE