Improving Access to Paper-Based Construction Documents and Information via Augmented Reality Facilitators/Connectors

Mohsen Foroughi Sabzevar, M.Sc.
L. James Lo, Ph.D.
Drexel University
Philadelphia, Pennsylvania

Masoud Gheisari, Ph.D.
University of Florida
Gainesville, Florida

While the technology and tools used to design and present structural elements in building construction have advanced, construction drawings are still mainly two-dimensional (2D). Paper-based floor plans often reference other drawings to deliver design intent to construction site crews. This process sometimes results in poor design communication, since deciphering the intent from many 2D drawings, which can be out of exact context, is time consuming, confusing, and prone to human error. Poor design communication can cause quality, safety, and productivity issues in construction sites and even disastrous scenarios like building collapse. This study proposes an improvement to the process of using paper-based 2D drawings by providing simpler access to detail drawing information associated to a specific floor plan in order to decrease potential errors. To achieve this goal, the current process of viewing, accessing, and interpreting drawings in construction sites was investigated. Then, a workflow was proposed to facilitate accessing detailed drawing information by overlaying 3D models of detail elements on paper-based floor plans using augmented reality (AR). Finally, to test this workflow, a case study was conducted to compare the AR based process against the traditional paper-based drawings. The results of case study showed that AR based process has the potential to decrease time and errors when accessing detail drawing information. The result also indicated that participants preferred the AR-based method over the traditional paper-based one.

Keywords: Augmented Reality (AR), 2D drawing, 3D model, augmented drawing, case study, access, design communication, paper-based drawings

Introduction

Humans have used drawings to communicate design ideas for thousands of years (Barr R.E. and Juricic, D. 1994). The primary types of architectural drawings, which lacked dimension and depth, were used by early Greeks (1100 BC to 100 BC), while the earliest technical drawings were created during the Renaissance period (1400-1600) (URL1). In the United States, a new era of engineering drawings, based on orthographic projection theory and drafting standards, began two hundred years ago, when "engineering design representation […] relied on engineering drawings" (Barr, R. E. and Juricic, D. 1994). Advancements in computer technology in the 19080s led to the development of the 2D CAD systems (Varma, 2008). In 1985, 3D modeling solutions opened the door for Building Information Modeling (BIM) in the following decades (URL3). Despite these advancements in technology and tools as well as huge investments in 3D design technology, the format of engineering deliverables to construction has remained unaffected (Goodrum et al. 2015). As a result, 2D-based documentation is still the main source of information on construction sites (Su et al. 2013) (Gould and Joyce 2013) (Sweany et. al. 2016). A set of 2D drawings includes different views such as plan views, elevations, detailed sections, and isometrics (Dadi et al. 2014b). These different views usually reference each other in different drawing sheets to deliver the user an image of the final design intent from all viewpoints, which is a complex process, especially if there are numerous drawings (Dadi et al. 2014b). As the only deliverable medium on construction sites, 2D drawings must be both spatial and technical communication tools to transfer the design intent from designer to different participants (Gould and Joyce 2013). However, research studies have proved that the quality of design communication in 2D drawings is poor. For instance, "the contractor must reference several different drawings to understand the design intent for a particular building element" (Dadi et al. 2014b). Poor design communication can occur due to variation in the symbols and terminologies used by different

designers (Emmitt and Gorse 2003). The geometric descriptive method created in the 18th century (Barr, R. E. and Juricic, D. 1994), which is the basis for displaying a 3D object in multiple 2D views (Sweany et. al. 2016) in 2D drawings, can be confusing. According to Varma (2008), due to complexity, variation, or vagueness in 2D shop drawing details, "sometimes attention to details is missing, and some vital checks are not made." 2D drawings are not ideal for visualizing complex objects because of possible errors and misinterpretations that might lead to costly and time consuming issues for construction companies (URL2) (Zaki, 2015). According to Eckert and Boujut (2003), poor design and poor design communication are two different issues as well as the main reasons for errors in construction documents. While errors related to poor design are based on designer faults, poor design communication is a result of insufficient interpretation of the design message (Dadi et al. 2014b). Poor design communication can cause confusion and error in task execution, and quality, safety, and productivity issues in construction projects (Mourgues and Fischer 2008).
An alternative to 2D engineering deliverables is 3D engineering deliverables. Dadi et al. (2014a, 2014b, 2014c) verified that the cognitive demand for 3D engineering deliverables is lower than 2D. At the same time, Sweany et. al. (2016) proved that the task performance of construction crafts at jobsites can be improved using 3D rather than 2D information.

This study proposes an approach to improve the poor design communication of paper-based 2D drawings by providing in-context access to detail drawing information associated to specific floor plans in order to decrease the cognitive demand placed on crews. This simpler approach is possible by overlaying 3D models of detail elements onto paper-based floor plan drawings. The paper-based plan is then viewed through a camera phone or tablet using augmented reality (AR) technology. To achieve this goal, the following objectives were defined: (1) Understand how crews in construction sites view, access, and interpret the information they need to perform tasks. (2) Propose a workflow to facilitate accessing detail drawing information and superimpose a 3D model of details on paper-based floor plans at construction sites. (3) Define a case study and evaluate the proposed method (workflow) using this case study in contrast with the traditional method of design communication. In order to limit the scope of this work, and due to the importance of construction structural elements, this research tested this AR approach on structural steel fabrication drawings only. The evaluation method focused on time spent on task, error rates, and preference of the proposed method versus the traditional method of communication with drawings.

Method

Site visits: To understand how crews on construction sites view, access, and interpret information, the first author visited five construction projects sites at Penn State University main campus in 2016. During the site visits, the first author observed that, on the construction sites, crews widely used 2D drawings. The following behaviors were documented: the general contractor crews (project engineers, construction manager, and superintendent) opened a *.pdf version of 2D shop drawings on their tablets for inspection purposes, while subcontractor crews (foremen and craftsmen) always used paper-based shop drawings to execute their tasks. These visits confirmed firsthand beyond paper citations that construction crews still rely on 2D drawings as their main information source. Beyond generic look-ups, it was also observed that craftsmen had to follow different symbols and instructions on different sheets to access associated information, as discussed previously (Dadi et al. 2014b) (Emmitt and Gorse 2003). To evaluate the accessing process, the first author reviewed shop drawings related to structural steel fabrication at one of the visited construction sites. Structural drawings were selected due to the significance of steel connections. Poor design communication could prompt human error in the construction of the detail elements and subsequently cause the disastrous fatal collapse of a building structure (Frühwald et al. 2007). Through the reviewing the accessing process, it was noted that, on steel floor plans, different types of symbols, such as ♦, ▲, ●, etc., were used to reference information related to the type of joints on other sheets. In other words, a crew needed to follow these symbols to find the related instructions, and, based on these instructions, find the related information about the 2D shape of the joint, type of steel section, dimensions, and so on. For example, the required steps that a crew had to follow to access detail information related to joint (♦) are illustrated in Figure 1. These steps are as follows:

1. The crew should open the structural shop drawing (S134) related to the mezzanine floor of the building. As is labeled (See Figure 1, label 1), there is a symbol (♦) that represents a type of steel connection.
2. To understand the meaning of the symbol (♦), the crew must read the notice on the bottom center of the sheet (See Figure 1, label 2). The notice about (♦) says: *"See sheet S124 for the reminder of framing notes"* (as highlighted in Figure 1, label 2). Therefore, the crew should open S124, which is another shop drawing.

3. On drawing S124, there is a notice on the bottom of the drawing that includes an explanation for (♦) symbol, which says: *"♦ Moment connection to wide flange column. See E/S 402."* (as highlighted in Figure 1, label 3). Thus, the crew should open S402, which is another shop drawing.

On drawing S402, the crew should look for section (E). Section E is the detail related to symbol (♦) (See Figure 1, label 4).

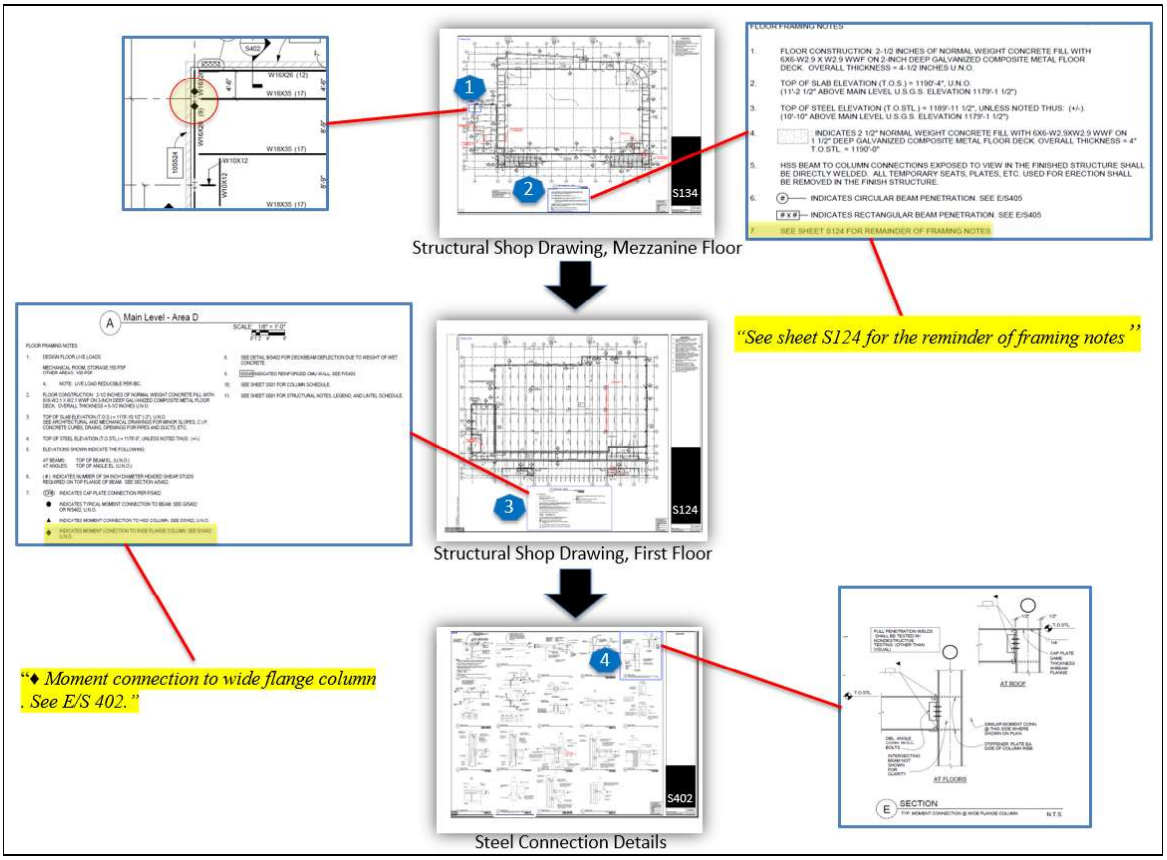


Figure 1. An example of the current 2D engineering deliverable method on construction sites; details and instructions are referenced in several sheets, which make access to information difficult and prone to error.

The crew had to review signs and notices in three different sheets to identify what type of connection should be used. This multi-step identification process is long and prone to human error due to the attention required to conduct the process accurately, especially in the messy, noisy, and unstable outdoor circumstances of a construction site with other safety concerns that can distract workers. The second problem was that, after successfully accessing the detail information of (♦) in the detail sheet, to be able to construct it on jobsite, a crew member must use his/her mental capability to interpret the 2D view of an element that is representative of a 3D element. The third problem is that, after interpreting the shape of a detail and its related features (on the detail sheet), the crew member needs to use his/her mental faculties again to interpret the relationship of this 2D element to the surrounding elements on the floor plan (in-context). This process (interpreting of 2D drawings) carries a high mental workload and cognitive demand (Dadi et al. 2014b; Sweany et. al. 2016), which increases the chance of misunderstanding during the execution of tasks at construction sites.

By contrast, if a crew member can access the detail information from the floor plans without the need to review several drawing sheets and view the 3D model of a detail element in addition to the 2D view, and this 3D model is overlaid on its position on the floor plan, the required mental capacity may be reduced. Errors related to miscommunication can be eliminated. Considering these ideas as a solution to cover the weaknesses of 2D drawings led the first author to propose a different workflow that improves design communication beyond 2D drawings. This workflow eliminates the need for reviewing several sheets to access a detail element and allows crews to access a 3D model of the details in addition to 2D drawings.

The required technology to overlay data (e.g., a 3D model) on a real environment (in this case, a 2D drawing) is called Augmented Reality (AR). According to Azuma (1997), AR "allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it." In other words, AR is a combination of real-world with digital information through a single interface (Gheisari et al. 2016). Thus, AR is an appropriate technology that can be used to improve design communication regarding the access and interpretation of 2D drawings. As shown in Figure 2, the combination of a real environment (paper-based drawing) and a 3D model creates the AR experience, which can be presented through a handheld device such as a smartphone or tablet.

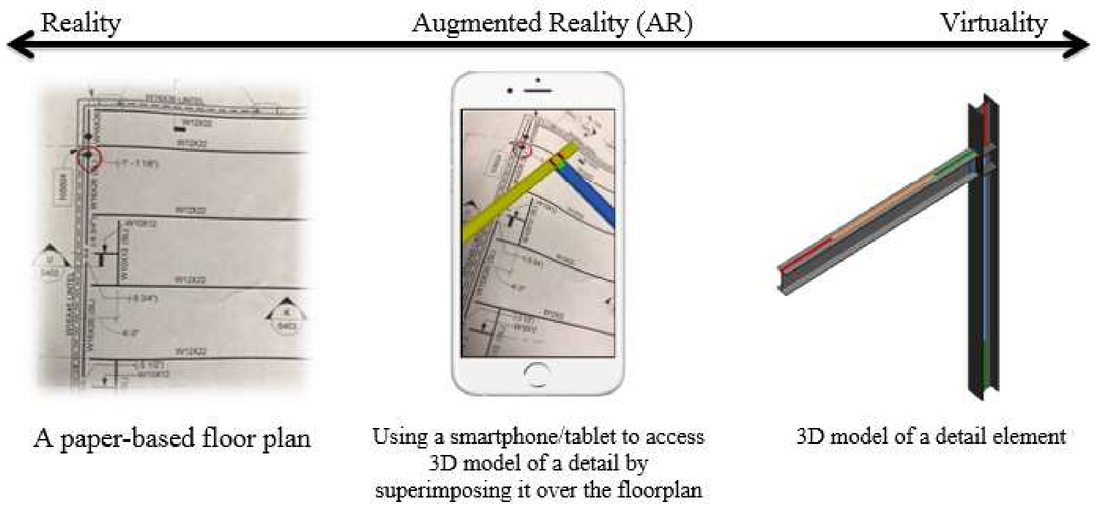


Figure 2. 2D, AR experience, 3D

Proposing an AR-based workflow to review paper-based 2D drawings: Different researchers and commercial companies have proposed many different applications to create an AR experience. In this section, a process architecture and workflow are presented to show how a commercial mobile augmented reality application called 'Augment' (URL8) can facilitate accessing detail drawing information and superimpose a 3D model of details on paper-based floor plans at a construction site. To augment 2D drawings, it is required to have a 3D model of the detail and its associated information (in this case, only digital images of a 2D detail was used as information, but this can be in other formats such as a text file, voice, video, etc.) and a set of paper-based (in this case a set of structural steel drawings were used) floor plans and detail drawings. This process consists of four phases: data, conversion, integration, and presentation.

In the data phase, a 3D model, and a snapshot from each detail element needs to be created. To create a 3D model, Autodesk Revit (URL4), a commercial software, can be used. To create a snapshot from a detail, a camera phone/tablet can be used to capture a picture from a detail.

In the conversion phase, a commercial software like SketchUp (URL5) converts the 3D model (first data) file's format from (*.rvt) to (*.dae). This phase was needed, since the format of the file produced by Revit (*.rvt) was not usable for the subsequent steps. In this phase, the detail image (the second data) needs to be converted to (http://...) format. Alternatively, other information formats (e.g. pdf, voice, video, etc.) can be used but need to be converted to (http://...) as well.

In the integration phase, the outputs from the previous phase (*.dae and http://...) should be imbedded into a tracker (QR code). The required tool for this task is Augment Manager (URL7), a web-based software.

In the presentation phase, a handheld device, such as an iPad or iPhone, with Augment (URL8) (a commercial augmented reality browser) and the tracker (QR code that was previously generated) are required to enable the users to interact with paper-based 2D drawings. The QR code needs to be shown on the paper-based drawing as a tracker. An example of the location of the tracker on paper-based drawings will be explained later in the case study.

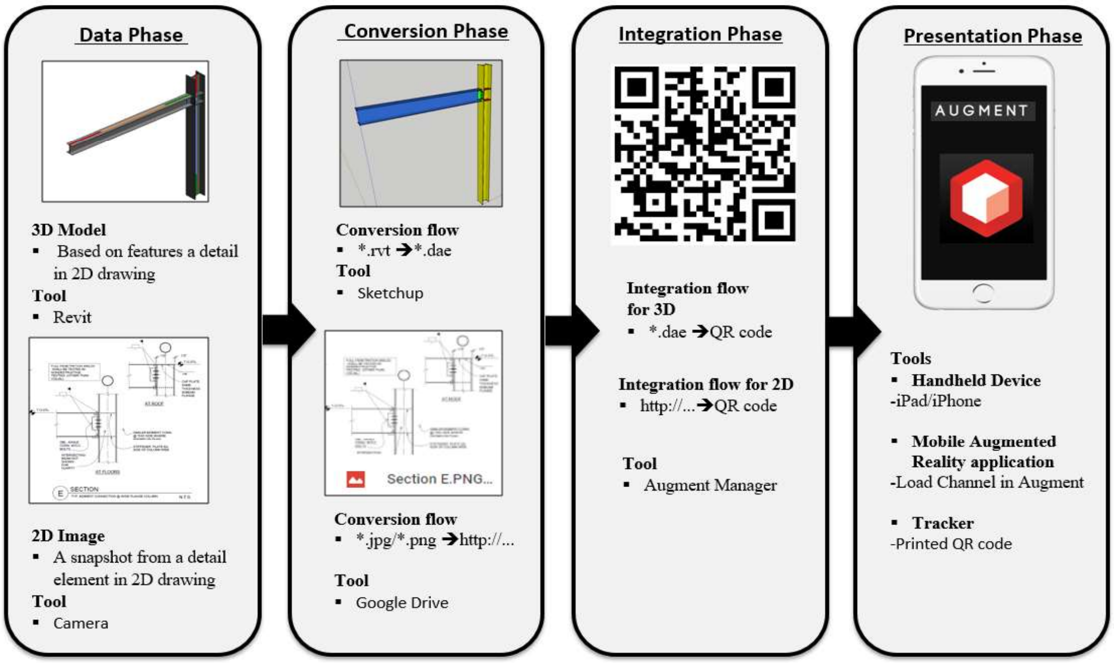


Figure 3. Process architecture

With the process architecture defined, the workflow, which brings the layers of data (3D model and 2D image) for a detail on a paper-based floor plan drawing is illustrated in Figure 4. The workflow is divided into two sub-processes. The first sub-process starts with creating a 3D model from a 2D detail in Autodesk Revit. Then, the model is exported in (.dwg) format and saved. Next, the (.dwg) file is imported into SketchUp, exported in (.dae) format, and saved. After this, the (.dae) file is uploaded into Augment Manager. The second sub-process begins with taking a snapshot from the paper-based detail element. Then, this file (*.png/*.jpg) is saved in Google Drive (URL6) and its sharable-link copied. Next, the sharable-link (http://...) is pasted into the same folder of the 3D model in Augment Manager. Running Augment Manager automatically imbeds the inputs from the first and second sub-processes (*.dae and http://...) into a tracker (QR code). The next step is printing the tracker and attaching it to the paper-based floor plan drawing. Finally, a user can interact with a paper-based floor plan through Augment, a mobile augmented reality browser. The result is a paper-based floor plan that is enabled to be augmented and gives users access to the 3D models and 2D information of detail elements.

Case study to test the proposed workflow: To test whether the AR method workflow would be superior than the paper-based traditional method, a construction-related case study was defined. The case study was conducted in different locations but within similar indoor environment conditions and laboratory settings. For this construction-related case study, two tasks (tests) were conducted by 10 participants. The first task was accessing a detail element and its associated information traditionally. The second task was accessing a detail element and its associated information using the AR method. Both methods were tested by professionals at construction sites. The goal of this case study was to investigate how these two methods perform in accessing detail elements as well as how time and error rate factors in accessing detail information from paper-based floor plans can be improved through the AR method. Also, the opinion of the users regarding their experience under both test conditions were evaluated. An observer collected data related to time and errors while participants conducted these tasks. In addition, a pre-study questionnaire (to collect participant demographic information) was conducted before starting the tasks, and a post-study questionnaire (to collect opinions from participants regarding these two methods) after completing the tasks was completed by the participants. For the first task (traditional method), the drawings were pure. For the second task (AR

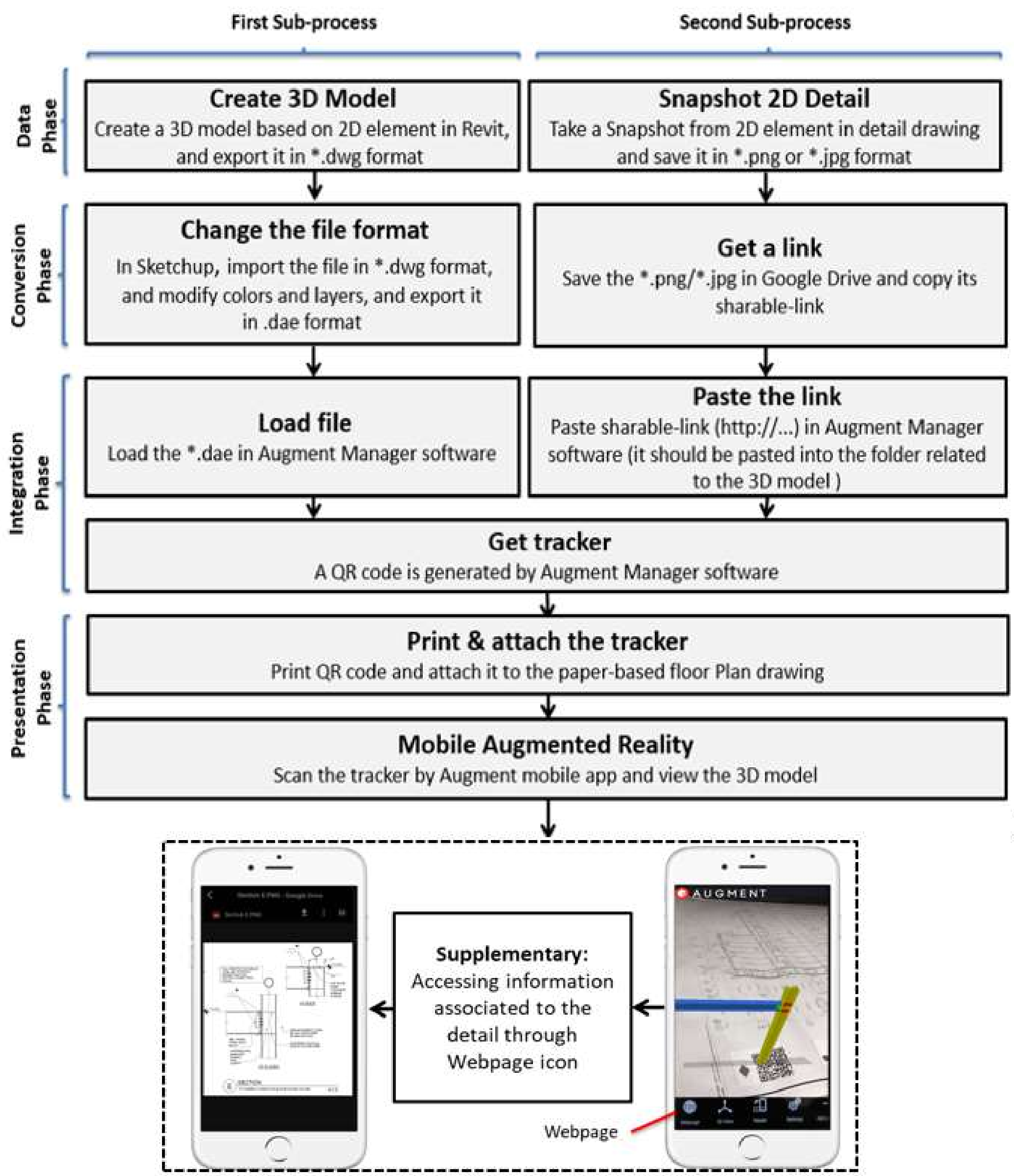


Figure 4. Workflow to augment 2D drawings

method), the floor plan could be augmented. For the first task (traditional method), drawings S134 (mezzanine floor plan), S124 (first floor plan), and S402 (details) were used (See Figure 1). For the second task (AR method), drawing S144 (roof plan) was used (See Figure 5). The paper-based drawings, study a set of steel fabrication drawings, were chosen for two reasons. First, structural drawings are representative of load resisting elements. Second, these drawings were a sample of drawings used during a real construction project. Crews who worked on this construction project were not invited to participate in this case study to avoid a learning curve, as they had already used the drawings. Some examples of this set of drawings are illustrated in earlier parts of this research paper in Figure 1.

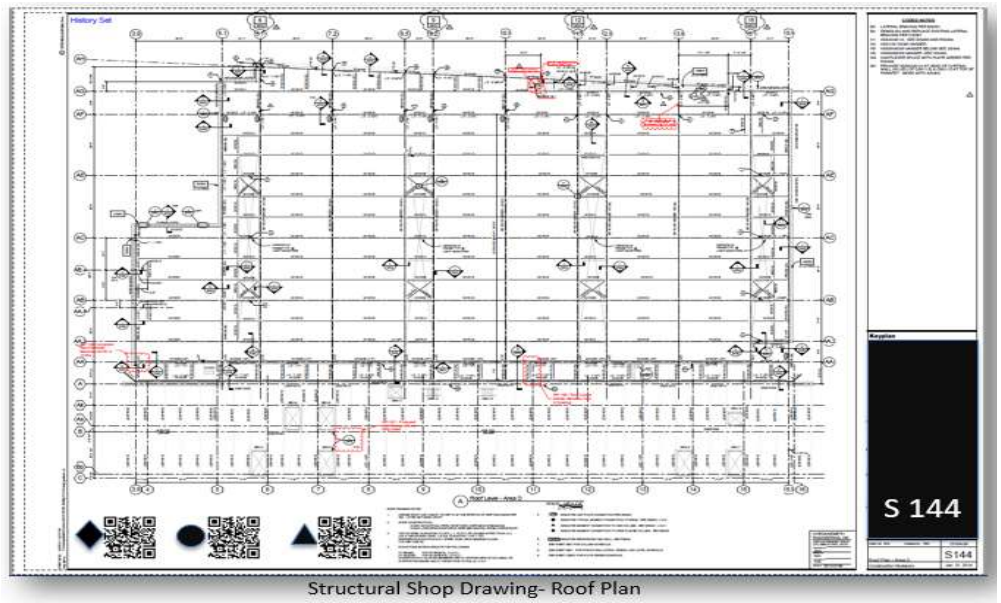


Figure 5. Paper-based roof plan drawing enabled to be augmented used for the second task

To complete the first task (traditional method), a user only needed to have a set of pure paper-based drawings. In contrast, to run the second task (AR method) a user needed to have drawings that were enabled to be augmented and a handheld device to scan a QR code. Before the tests, to enable the pure drawing of S144 to be augmented, the workflow explained in previous sections was used. First, the detail elements associated with symbols (♦, ▲ and ●) were found on the detail drawing of S402. Then, 3D models and 2D image of the details were created by Autodesk Revit and a camera phone respectively (Shown in Figure 6). Then, the format features of the files were modified according to workflow instructions in the previous section (Figure 4). Afterward, the data was imbedded into QR codes. Next, the QR codes were printed, attached to the bottom of the roof plan (S144), and labeled with symbols (♦, ▲ and ●), as was shown in Figure 5.

3D model data 2D image data

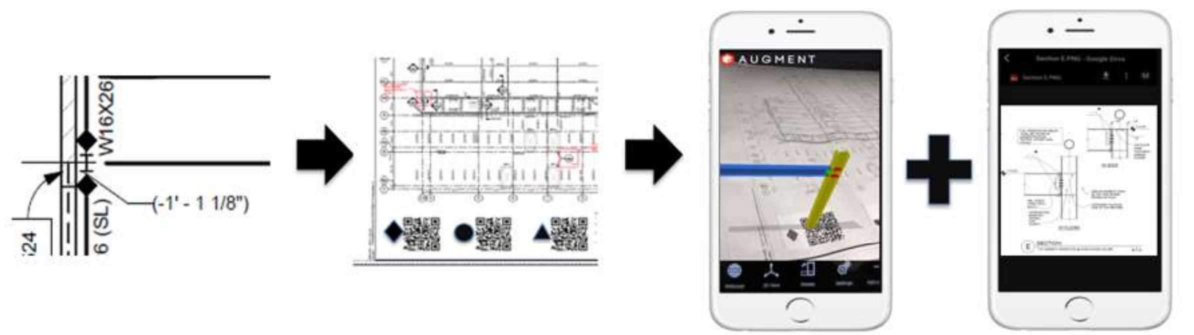
Figure 6. Creating data, based on a detail element (detail drawing S402).

The AR method was defined as the second task to be tested. This could reduce the learning effect in finding the correct detail element.

This within-subjects case study included using a smartphone (an Apple iPhone, IOS operating system) as a mobile tool to conduct the second task only. Other operating systems, such as Windows or Android, were not tested in this case study. Before starting, the observer asked the participant to complete a pre-study questionnaire to collect demographic information. Then, for the first task (traditional method), the observer assigned the first set of drawings (S134 mezzanine floor plan, S124 first floor plan, and S402 details) to the participant. Symbol (♦) was circled in red on the floor plan. The participant was supposed to find the related detail and inform the observer aloud when he/she thought he/she found it. This would be the end of the first task. The duration of conducting the task was recorded by the observer, who checked the accuracy of the detail element found by the participant.

The observer then checked the detail element that the participant believed was in correspondence to symbol (♦) to determine the accuracy of the response. For the second task, the second set of drawings (S144 roof plan) was assigned to the participant. Like the previous test, symbol (♦) was circled in red but was located on the roof steel fabrication floor plan. The participant was supposed to find the associated detail related to this symbol. However, this time the participant knew that he/she should use the mobile augmented reality application through their iPhone to scan the QR code associated to (♦) to find the related detail. Again, the participant was supposed to inform the observer aloud when he/she believed that he/she could find the detail and related information. This would be the end of the second task. The duration of conducting the task was recorded by the observer, and the participant was rated as successful or unsuccessful based on his/her results. Figure 7 shows the steps that the participants took to conduct the second task during the case study. First, the participant looked for details related to the diamond on sheet S144 (Figure 7.a). Then, he/she scanned the related tracker (Figure 7.b). Next the participant informed the observer when the 3D model appeared on the 2D drawing (Figure 7.c). Finally, the participant needed to click on the Webpage icon to see the 2D detail and again inform the observer (Figure 7.d). After conducting the second task, the participant was asked to complete a post-study questionnaire. This questionnaire measured participants' preferences regarding the methods for accessing detail elements (traditional versus AR).The participants were asked to score their level of agreement about the statements expressed on the questionnaire using a 7-point Likert Scale. The list of statements and answers are presented in Table 2. To create this questionnaire, some sections of Tseng's (2010) preference questionnaire were used.

This was a simple case study to observe how a user would interact with paper-based drawings in both traditional and AR methods.



a. Look for the diamond symbol on the sheet S144

b. Scan the related tracker (QR code) on the bottom of the sheet

c. Inform the observer when 3D model of detail was observed

d. Inform the observer when 2D detail was observed

Figure 7. The flow of the second task (AR method) that participants completed.

Results

According to the pre-questionnaire response, ten participants contributed to this case study. In this population, four participants were working for general contractor companies, one was working for facility management owner, and five were working for a designer. Six participants had a bachelor's degree, two had a master's degree, and the remainder had diploma and associate degrees. The education of the participants is important, since the ability to conduct the tasks needs to be normalized. Between the participants, there were four project engineers and one superintendent who were all working in the construction sector, three designers and one intern who were working in the MEP sector of facility management, and one assistant director who was working for a facility management owner. The personal identification data of the participants were not collected.

The criteria to measure performance was time, errors and success rate (Nielson 1994). The recorded times and the measured success and error rates from the first and second tasks were used to measure the performance of the traditional method versus the AR method, as shown in Table 1. While the average time for completing the first task (traditional method) was 127 seconds, the second task (AR method) only took 7 seconds to complete. Moreover, the rate of success in finding the correct associated detail to the symbol (♦) was 40% (4 out of 10 participants) for the first task (traditional), while this number increased to 100% (10 out of 10 participants) for the second task (AR method).

Table 1
Rate of success and average time spent on tasks to complete task 1 (traditional method) and task 2 (AR method)

Metric	Task 1 (Traditional Method)	Task 2 (AR Method)
Average time spent on each task (Seconds)	127	7
Rate of success in conducting each task	40% (4 out of 10 participants)	100% (10 out of 10 participants)

According to the post-study questionnaire, participants believed that using the new method (AR), in contrast with the traditional method (paper-based), was easier (AR method: 5.0 vs. paper-based: 3.8). In addition, they indicated that they preferred to look for details through the AR method (AR: 4.5 VS. paper-based: 4.1). Furthermore, the participants indicated that the AR method was quicker in relation to the traditional one (AR: 4.9 VS. paper-based: 3.3). Additionally, they agreed that the new method reduced the risk of selecting an unrelated detail item (AR: 4.8 VS. paper-based: 3.8). Results showed that participants disagreed about the statement, "to me, there is no difference between using paper-based or AR method" (average agreement: 2.9). The results are presented in Table 2.

Table 2
Evaluation results Scale: (1 = strongly disagree) to (7 = strongly agree) Number of subjects=10

Question	Statements	Average
1	It is *easier* to look for a detail through paper-based method.	3.8
2	It is *easier* to look for a detail through AR method.	5.0
3	If I have a choice, I would *prefer* to look for details through AR method.	4.5
4	If I have a choice, I would *prefer* to look for details through paper-based method.	4.1
5	To me, there is *no difference* between using paper-based or AR method.	2.9
6	It is a *quicker* way to look for a detail through paper-based method.	3.3
7	It is *quicker* way to look for a detail through AR method.	4.9
8	AR method can reduce the *risk* of selecting a wrong detail.	4.8
9	Paper-based method can reduce the *risk* of selecting a wrong detail.	3.8

Discussion

Improvement in access to detail elements and related information on floor plans, the improvement in accuracy of finding such information, along with user satisfaction with the AR method demonstrated the significance of including augmented drawings in the construction process. This improvement was achieved by eliminating the need to review several sheets to access a detail element by allowing the crews to access a 3D model of the details in addition to the 2D plans. In contrast with the traditional paper-based method, using augmented drawings to streamline access to detail elements and eliminate the need for referencing different drawing sheets reduced the time spent on the accessing process and decreased human error. Such improvement shows the augmented drawings are a viable and perhaps a better alternative to the traditional paper-based drawings, which were demonstrated with severe design communication problems. While the paper based 2D plans are still the main source of information in construction sites, the proposed workflow and the case study, along with the performance, preference evaluations, provided a base for understanding the weaknesses associated with paper-based drawings and possible improvements in the process of design communication using augmented reality in the field of construction. Although some improvements were demonstrated, this study did not evaluate how the AR method can directly improve user interpretation when viewing the 3D model over 2D drawings. Another study must be conducted to measure the cognition demand from both the traditional and AR method. In addition, a separate study is required to improve the human-computer interaction (HCI) aspects of the new method to increase the satisfaction level for end users.

References

Azuma, R. T. (1997), "A survey of augmented reality", Presence-Teleop. Virt. Environ., 6(4), 355–385.

Barr, R. E. and Juricic, D. (1994), From Drafting to Modern Design Representation: The Evolution of Engineering Design Graphics. Journal of Engineering Education, 83: 263–270. doi:10.1002/j.2168-9830.1994.tb01114.x

Dadi G.B., Goodrum P.M., Taylor T.R., Carswell C.M. (2014a), Cognitive workload demands using 2D and 3D spatial engineering information formats, J. Constr. Eng. Manag. 140 (5) (2014) (1943-7862.0000827, 04014001).

Dadi G.B., Goodrum P.M., T.R. Taylor (2014b) , W.F. Maloney, Effectiveness of communication of spatial engineering information through 3D CAD and 3D printedmodels, Vis. Eng.2 (1) (2014) 1–12

Dadi G.B., Taylor T.R., P.M. Goodrum (2014c), W.F. Maloney, Performance of 3D computers and 3D printed models as a fundamental means for spatial engineering information visualization, Can. J. Civ. Eng. 41 (10) (2014) 869–877.

Eckert, C, & Boujut, JF. (2003). The role of objects in design co-operation: communication through physical or virtual objects. Computer Supported Cooperative Work, 12, 145–151.

Emmitt, S, & Gorse, C. (2003). Construction Communication. Oxford: Blackwell Publishing.

Frühwald, E., Serrano, E., Toratti, T., Emilsson, A., & Thelandersson, S. (2007). Design of Safe Timber Structures - How Can we Learn from Structural Failures in Concrete, Steel and Timber? Division of Structural Engineering, Lund University.

Gheisari, M., Foroughi Sabzevar, M., Chen, P., Irizzary, J., (2016). Integrating BIM and panorama to create a semi-augmented-reality experience of a construction site. Int. J. Constr. Educ. Res. 12, 303–316

Goodrum. P. Miller. J. (2015). Innovative Delivery Methods of Information to the Crafts, RS 327-1 Construction Industry Institue, The University of Texas at Austin

Gould, F, & Joyce, N (2013). Construction project management (4th ed.). New Jersey: Prentice hall Factors in Computing Systems, ACM, Portland, OR, USA, 1941-1944.

Jakob Nielsen and Jonathan Levy. 1994. Measuring usability: preference vs. performance. Commun. ACM 37, 4 (April 1994), 66-75. DOI=http://dx.doi.org/10.1145/175276.175282

Mourgues, C, & Fischer, M. (2008). A Work Instruction Template for Cast-in-Place Concrete Construction Laborers: Center for Integrated Facility Engineering.Stanford University. Working Paper #109.

Su Yu-Chih et.al. (2013), "Developing BIM-based shop drawing automated system integrated with 2d barcode in construction, Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction ", (EASEC-13), Sapporo, Japan.

Sweany J.Goodruma P., Miller J. (2016), "Analysis of empirical data on the effects of the format of engineering deliverables on craft performance" Automation in Construction, Volume 69, September 2016, Pages 59-67

Tseng, Min-chen (2010), "Factors That Influence Online Reading: An Investigation into EFL Students' Perceptions." Reading Matrix: An International Online Journal, Reading Matrix, Inc. University of South Florida Polytechnic, College of Human and Social Sciences, Division of Education, 3433 Winter Lake Road LMD 8038, Lakeland, FL 33805. Tel: 863-667-7712; Fax: 863-667-7098; e-Mail: Editors@Readingmatrix.com; Web Site: Http://www.readingmatrix.com/Journal.html, eric.ed.gov/?id=EJ908513.

URL1, http://www.automotiveillustrations.com/tutorials/history.html (Retrieved Sep 12, 2017)

URL2, http://designrfix.com/3d/solidworks-advantages-3d-cad-2d-cad (Retrieved Sep 1, 2017)

URL3, https://www.autodesk.com/campaigns/inspired-by-autocad/cad-innovation (Retrieved Sep 13, 2017)

URL4, https://www.autodesk.com/education/free-software/revit (Retrieved Sep 12, 2017)

URL5, www.sketchup.com (Retrieved Sep 12, 2017)

URL6, https://www.google.com/drive/ (Retrieved Sep 12, 2017)

URL7, https://manager.augment.com/ (Retrieved Sep 12, 2017)

URL8, www.augment.com (Retrieved Sep 12, 2017)

Varma Virendra (2008), "Advances in the production of shop drawings and their impact on constructability", Annual Conference, American Society Engineering Education; Pittsburgh, PA.

Zaki T. and Khalil C. (2015), "QR-coded clash-free drawings: an integrated system of BIM and Augmented reality to improve construction project visualization", 5th International/11th Construction Specialty Conference, 5e International/11e Conférence spécialisée sur la construction, Vancouver, British Columbia.