Integrating the AR-QR Code Approach with Positioning and Orientation Sensors to Facilitate Deploying Drawings Information on Job Sites

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Abstract –

While general contractors often use tablets to review design and construction information, subcontractors typically rely on paper-based methods. Each of these methods has its own set of advantages and challenges. The AR-QR code approach aims to bridge the gap between paper-based and digital methods, leveraging the power of Augmented Reality (AR) to maintain the benefits of the paper-based approach while circumventing its drawbacks. This approach grants crews direct access to design and construction information by centralizing data and eliminating the need to refer to other drawings and documents. This research study addresses an issue inherent in traditional methods that the AR-QR code approach did not consider. In conventional practices, deploying drawings on-site necessitates that the crews mentally synchronize the drawing's coordination system with the actual job site. Additionally, they must mentally position and orient items to match their actual on-site locations. This process ultimately entails a mental visualization of the items on the job site to ascertain how the designed features correspond with the actual work. Such mentally demanding steps can exacerbate mental strain and increase the risk of errors. This study aims to propose a solution to alleviate this issue by enhancing the capabilities of the AR-QR code approach to facilitate visualization of the drawing's details on the jobsites. The research methodology includes process mapping and workflow development. The outcome is a workflow that offers insights into how the AR-QR code approach could be integrated with a positioning and orientation system to achieve the goal of this study.

Keywords –

AR-QR Code; Sensor; Positioning and Orientation; Augmented Reality; Construction Site; Indoor Positioning

1 Introduction

In this paper, first, we present a condensed overview of a research study on the AR-QR code approach presented in [1] and then focus on a new adaption to enhance the functions of this approach in construction sites. Construction workers use large shop drawings to access design information. Floor plan drawings using symbols and codes refer crews to notes, sections, details, elevations, schedules, and other supplemental information on other sheets or documents [1]. Sometimes, following various symbols and codes for accessing additional information could be complex, leading to potential confusion and errors. Another issue is that these drawings do not include critical construction details like work procedures, materials quantity, equipment and tools, safety, and so on [1]. Specification manuals [2], serving as additional documents to drawings, generally lack detailed instructions for individual building components. These manuals broadly outline the quality requirements for products, materials, and workmanship. When documentation is insufficient, workers rely on verbal instructions, which increases the risk of ambiguity, errors, and the need for costly rework [3]. Avoiding mistakes in interpreting structural drawings is crucial because errors in construction can have severe safety consequences, such as building failures [4,5]. According to statistics [6–9], 70 to 90 percent of construction failures are due to human errors during execution rather than design, with most structural failures arising from construction errors rather than incorrect design [10]. These human errors, which occur during component fabrication or installation, are a significant source of uncertainty and can lead to structural instability during and after construction [11–13]. Poor design and poor design communication are two main factors that lead to errors [14]. Poor design refers to errors originating from the design itself, which are the designer's responsibility [14]. Poor design communication involves the receiver's improper interpretation and decoding of the design message [15]. Poor design communication can happen due to a lack of supplementary content, inappropriate format, or choosing the wrong channels for conveying design and construction information. Poor design communication can lengthen the process of accessing design and construction information, thereby increasing construction crews' physical and mental workload and raising the risk of human errors [16–21]. Errors can cause safety issues, rework, productivity problems, environmental concerns, and the risk of disputes [3,22–24]. To enhance the accessibility of design and construction information, using Building Information Modeling (BIM) models with a high level of detail (LOD) could be a solution [1]. These models can combine all necessary details, potentially streamlining the information retrieval process [1]. However, significant barriers could be involved such as high cost of developing comprehensive BIM models, screen size limitations of mobile devices (i.e., the complex details of BIM models are intricate to review on the small screens of tablets and smartphones), and construction site workstation challenges (e.g., the use of digital 2D drawings typically requires PCs or workstations, which are cumbersome to move, especially in the early stages of construction where issues such as lack of electrical power, the absence of a sheltered location, and interference with material handling paths can arise) [1,25]. Despite these issues, there are practical reasons for the continued use of 2D paper-based drawings on construction sites: legal approval (e.g., they are often the only legal documents for building construction) [26], large size (i.e., a broader 2D view at once, no need for scrolling up and down on plan views), convenience and resilience (i.e., paper drawings are easier to carry around the typically harsh conditions of a construction site and do not depend on electricity), and they are simple to use, maintain, and can be easily replaced if damaged.

Due to these advantages, 2D drawings remain prevalent, especially among subcontractors' crews, despite the potential efficiencies offered by high-LOD BIM models and digital alternatives. According to site visits [27], general contractor teams, including project engineers, construction managers, and superintendents, typically use tablets for reviewing 2D shop drawings, whereas subcontractor teams, such as foremen and workers, often utilize paper-based shop drawings for their work. To leverage the benefits of both paper-based and digital methods while minimizing their drawbacks, [1] proposed a hybrid approach known as the AR-QR code approach. “The AR-QR code is an approach that uses the advantages of both paper-based and digital-based delivery methods (i.e., a combination approach) but avoids their disadvantages” [1]. “In this way, the advantages of paper-based 2D plan views (e.g., large size, simply carried, less care needed, etc.) are retained, while the disadvantages (e.g., difficulty in accessing different pieces of information that are not centralized, reliant on information in other sheets and documents, dependency on verbal instructions to transfer design intent and related construction requirements to crews, divided attention between different sheets and documents, facing unrelated information) are avoided” [1].

1.1 Issues Regarding Paper-based Procedures to Access Design and Construction Information

In the traditional approach, drawings frequently require cross-referencing with additional sheets and documents [15,27,28]. For example, if a crew needs to access information regarding a symbol on a plan drawing, they need to read the general notes on the footprint. Sometimes, these notes refer to another sheet, which may reference a detail on a subsequent detail sheet (Figure 1-A, Issue 1). This detail may reference sub-details on other sheets (Figure 1-B, Issue 2). At times, this process can be frustrating. Ultimately, the crew must mentally synthesize all these pieces to understand the complete geometry of the component (Figure 1-C, Issue 3). Concurrently, they must determine the orientation of the final item in relation to the plan drawing (Figure 1-D, Issue 4). Furthermore, construction information is not included on the drawing sheets in the paper-based approach (Figure 1-E, Issue 5). To obtain this information, crews must consult written instructions such as specifications, submittals, and other documents [1]. However, specifications often contain general information not tailored to each building element [1]. Moreover, information is not centralized in these documents and often refers to other documents [1]. Crews must cross through a substantial amount of documentation to find the relevant details, which can lead to scattered attention and a heightened risk of errors [1]. Verbal instructions in construction, usually provided by foremen or superintendents, can result in misunderstandings and inefficiencies (Figure 1-F, Issue 6). Crew members are expected to remember and act on these instructions while working, but this approach can be ineffective, posing potential safety risks, necessitating rework, and ultimately reducing productivity due to ambiguities [3]. To solve these issues, [1] prototyped a new approach (i.e., AR-QR code), and evaluated. The evaluation results showed that the AR-QR Code approach has the potential to improve crew access to design and construction information. The AR-QR code approach allows crews direct access to design and construction information by centralizing information and eliminating the need to refer to other drawings and documents [1].

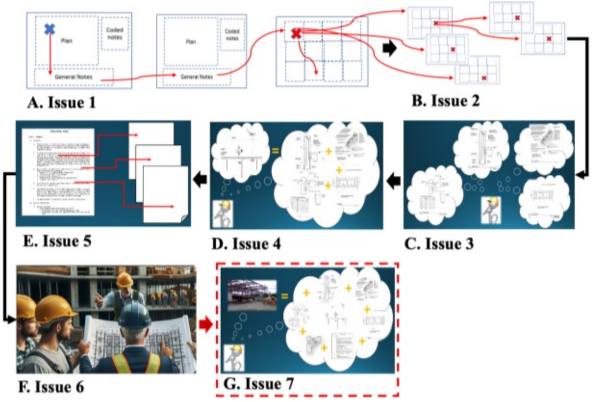

Figure 1. Paper-based procedure to access design and construction information (Adapted from [1])

1.2 Problem Statement

This study addresses another problem associated with the traditional method (Figure 1-G, Issue 7) and suggests that enhancing the AR-QR code approach could offer a potential solution. The problem is that in conventional practices, the deployment of drawings on-site requires the crew to mentally synchronize the drawing's coordination system with the job site. Furthermore, they need to mentally position and orient items to correspond with their actual locations on-site. Ultimately, this procedure involves a mental visualization of the items on the job site to compare the features with the actual work. These mentally intensive steps could increase mental strain and the likelihood of errors. Such challenges might occur prior to the fabrication of components when workers attempt to envision the final work in the field, or after completion when they need to evaluate how the actual work aligns with the design. For both scenarios, merely looking at paper-based drawings to visualize the final work on the job site can be challenging. Even if a 3D model of the element is available, there would still be a kind of non-connectivity between this element on the screen and the actual field environment.

1.3 Aim and Objectives

This study aims to propose a solution to alleviate the cognitive-spatial synchronization issue by enhancing the capabilities of the AR-QR code approach to facilitate visualization of the drawing's details on the job sites. To accomplish this aim, the following objectives were defined: 1) Identify the traditional process for deploying drawing information on the job site; 2) Propose an approach based on tracking systems to enable crews to navigate to the precise position and orientation of the drawing's details on the jobsites at the construction site.

2 Background Information for Method Development

2.1 Communication Elements in Construction

To enhance the AR-QR code approach, it is necessary to identify and incorporate new communication elements into this method. This section reviews the characteristics of various communication elements. The communication elements in construction include messages or information content, senders who encode messages, receivers who decode messages, media or formats of information, channels to transmit messages [29–31] and channel links if more than one channel type is used. Sender and Recipient [28]: In construction, senders may include architects or designers, while recipients could be contractors or craftsmen. Senders encode and transmit messages, and recipients decode them. Media [28]: Media refers to the format of information, which can be verbal or non-verbal, including speech, drawings, and written documents. The choice of media depends on the context and the parties involved. Channels [32,33]: Channels are conduits like air, paper, or electronic devices that transmit content. Both physical and electronic channels are used, with electronic channels being devices like smartphones, tablets, VR/AR headsets, and physical channels being air or paper. Channel Link [1]: A channel link or tracker can be used to bridge a physical channel with a digital one. These links are classified into two types: those that are marker-based and those that are marker-less. Marker-based links can be printed and attached to surfaces [34]. Some examples of marker-based links are dot-based markers [35], QR code markers [36,37], circular markers [38], square markers [39], and alphabetic combination markers [39]. A fiducial marker like a QR code could effectively connect the information available in the electronic channel to the physical channel. Computer vision techniques can easily identify QR codes' distinguishable textures through scanning. A QR code can be created and attached next to the related element for each section, code, or notice related to each element in the plan drawings. This technique can give direct access to the required information in proper formats (e.g., image, 3D model, audio, video, text) for each section, code, or notice related to each element. The marker-less options are further divided into visible and non-visible categories. Visible links are environmental features like edges, corners, and specific points [40], which can be recognized and utilized by algorithms such as SIFT as substitutes for physical markers. In contrast, non-visible links are invisible signals, like sound waves, infrared light, or vibrations, which certain sensors can detect and employ in place of traditional markers. Some features of these sensors and related signals are listed as follows [41]:

GPS sensors are capable of detecting satellite signals to pinpoint a location in three dimensions. However, their functionality is restricted to outdoor settings, and their location accuracy is relatively imprecise [42,43]; Inertial sensors respond to motion and vibrations but suffer from cumulative errors over time, necessitating frequent recalibration [43]. Examples include gyroscopes, which measure orientation angles, and accelerometers, which measure both velocity and changes in motion direction [42]; Compasses consistently indicate the direction of magnetic north [42]; Wi-Fi technology communicates data using radio waves between a device and a network router, offering extensive indoor coverage and location accuracy within a range of 15 to 20 meters indoors [44]; Bluetooth sensors can accurately determine location within a space, achieving 75% accuracy for partial coverage and up to 98% with full coverage, provided the target devices remain stationary [45]; Ultrasonic sensors are affected by temperature variations, obstructions, ambient noise, and require significant infrastructure, offering limited update frequency [46]; Infrared sensors operate over short distances and are constrained by the necessity for a clear line of sight, as utilized in systems like Active Badge [47]; Radio Frequency sensors, operating on standards like IEEE 802.11 or WLAN, have a median location accuracy of 2 to 3 meters but suffer from scalability issues [48,49]; and Ultra-Wideband (UWB) Radio Frequency sensors utilize UWB signals that can penetrate through walls and offer high accuracy, albeit at a higher cost due to the required infrastructure [50,51]. A hybrid channel link combines both marker-based and marker-less systems to compensate for the limitations inherent in each method [52].

2.2 Benefits of the AR-QR Code Approach

In the AR-QR Code approach, crews access information by scanning QR codes associated with each element on the plan sheet. As depicted in Figure 2, this allows the crew to view design details, such as geometries, in augmented reality (AR), virtual reality (VR), and 2D views. AR and VR enable the manipulation of a 3D model from various angles, improving their understanding of the details. AR, in particular, merges the plan view with the 3D model, facilitating a combined review. Construction information is available through a custom user interface, allowing access to specific construction information such as work procedures, safety, material quantities, FAQs, verbal instructions (audio), equipment, tools, and sustainability considerations [1]. This method can significantly streamline the process of accessing design and construction information, thereby reducing time, errors, and complexity [1]. According to a survey conducted by [1], construction professionals believed that adopting the AR-QR code system could greatly mitigate issues arising from the use of paper-based drawings, especially in terms of reducing queries from the workforce, improving productivity and safety, and addressing sustainability. They found the system to be broadly applicable, user-friendly to a degree, and quite beneficial. They also noted advantages such as better coordination and teamwork across different trades, decreased need for redoing work, more efficient handling of requests for information, less time spent on document review, and improved ease and clarity of information access. These points affirm the perceived merits of the AR-QR code system by those on the construction site.

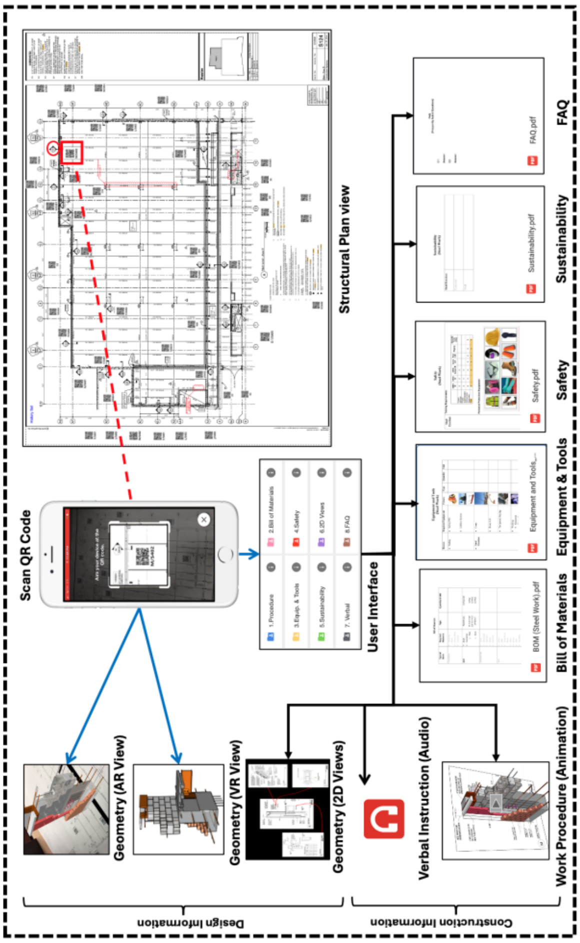

Figure 2. AR-QR Code approach [1]

3 Research Methodology

To fulfill the first objective, a process map was developed through observations and unstructured interviews conducted at five different construction sites in the USA. To meet the second objective, a thorough analysis of positioning and orientation systems was carried out to establish the necessary features. Subsequently, a workflow was developed to demonstrate how these systems could be integrated with AR-QR codes, serving the specific goals of this study.

4 Adapting the Traditional Procedure of Deploying Drawings Information on Jobsites Using the AR-QR Code Approach with Positioning and Orientation Sensors

Figure 3 illustrates the traditional process for decoding design meaning in contribution with the construction field. In this procedure, the crew needs to match the drawing coordination system with the jobsite coordination system. Then, the crew needs to match the detail's position and orientation with the actual spot on the jobsite. In the end, the crew mentally visualizes the item on the jobsite to be able to compare the features of the designed work with the actual work. Since these steps should be conducted mentally, mental workload and error rates could increase. The suggested adaptation could be eliminating and replacing these steps with a straightforward method.

Suggested Adaptation: An adaptation could be using the AR-QR code approach, scanning the related QR code on the plan drawing, navigating the user to the correct spot on the jobsite, and superimposing the detail element information (e.g., 3D model) with the correct orientation for an accurate position. Figure 3 illustrates the steps that can be replaced with new ones.

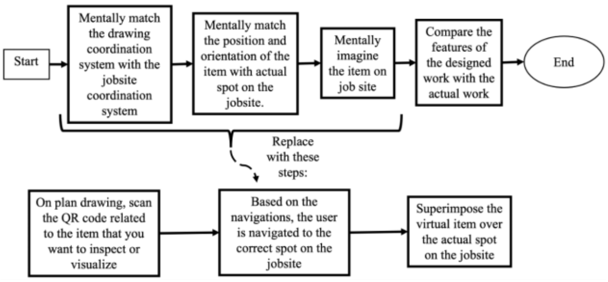

Figure 3. Traditional procedure for deploying drawing information on the job site

To implement this suggestion, the content will be the component geometry properties. The medium will be a 3D model of the items that the crews need to visualize on a jobsite. The physical channel will be a surface or spot on the jobsite where the information needs to be superimposed, the electronic channel's hardware will be a smartphone, and the electronic channel's software will be an AR browser. Among various tracking technologies, ultra-wideband (UWB) systems are considered the most precise for positioning, boasting accuracies up to ±10 cm [50]. This level of precision significantly surpasses that of conventional systems utilizing Wi-Fi, Bluetooth, RFID, or GPS. According to Pozyx [50], a tag, and multiple anchors (minimum of four anchors) are needed for the UWB system to function effectively. The tag interacts with the anchors via UWB radio signals capable of penetrating indoor barriers. These anchors serve as reference points, and the system calculates the tag's position by measuring the time-of-flight (TOF) of signals from the tag to each anchor, using the equation: Distance = time of flight × speed of light, where the speed of light is 299,792,458 meters per second. Positioning is then determined through multilateration [51]. To ascertain three-dimensional orientation, the Pozyx tag is equipped with sensors to measure acceleration, magnetic fields, and angular velocity. Although each sensor has its own limitations, by integrating data from all sensors, the system can accurately determine 3D orientation [50]. Thus, the channel link will be built based on positioning sensors (Ultra-Wide Band wave generators and detectors) in integration with orientation sensors (accelerator, magnetometers, and gyroscope).

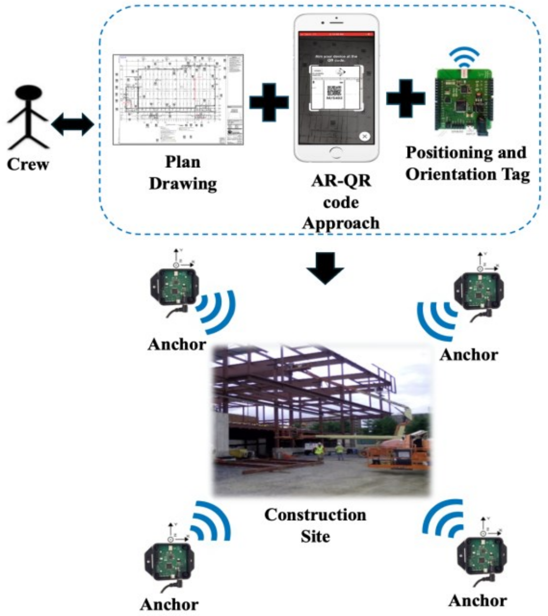

Figure 4. Integrating AR-QR code approach with positioning and orientation sensors

These sensors can help the user adjust the position and orientation of the smartphone where the 3D model and other related information need to be superimposed. To better understand how these 3D positioning and orientation systems can be integrated and implemented for the purpose of this study, a system architecture is shown in Figure 4. As shown, a crew needs to use the AR-QR code approach, scan a QR code related to a section cut on the plan drawing, access the related design and construction information, follow the tag (the tag needs to be attached to the smartphone or tablet by a USB cable to display the navigation signs) navigation signs to navigate to the correct position and orientation on jobsite, and use the power of the AR to superimpose and review the information on the jobsite. For the positioning estimations, the tag communicates with a minimum of four anchors (i.e., reference points) through ultra-wideband RF signals. These anchors need to be installed on construction sites. For orientation estimations, three sensors are embedded in the tag: accelerator, magnetometers, and gyroscope, which work together to detect acceleration, magnetic field, and angular velocity to estimate the tag orientation. In future studies, this workflow will be prototyped and tested to evaluate the precision and accuracy of this enhanced AR-QR code approach.

5 Conclusions

This research study focuses on enhancing the capabilities of the AR-QR code approach to facilitate deploying the drawing's information on the job sites. For this purpose, the traditional procedure for deploying drawing information on the job site was depicted, and an adaptation of the channel link of the AR-QR code method was suggested to modify the procedure. The outcome is a development workflow that shows how AR-QR code can be integrated with positioning and orientation sensors to enable crews to navigate to the precise position and orientation of the drawing's details on a jobsite and deploy and visualize drawing information. In future studies, this workflow will be prototyped and tested to evaluate the precision and accuracy of the enhanced AR-QR code system and if this method can reduce the mental workload and errors for workers on construction sites.

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