AUGMENTED REALITY (AR) IN POST-TENSIONED STRUCTURES

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Augmented reality (AR) is one of the biggest technology trends right now, and it will get bigger as AR devices become more accessible around the world. AR enables us to see the real-life environment right in front of us and adds digital elements to a live view—often by using the camera on a smartphone. Augmented reality is, in fact, readily available and being used in a myriad of ways, so a solution to be used in post-tensioned (PT) structures has been developed. The details of punching shear, top and bottom reinforcement, and two-dimensional (2-D) tendon profiles are important, not clearly defined, and can lead to incorrect field assembly. Using marker-based AR and a quick response (QR) code printed on the project drawings, it is possible to display the detail in three dimensions (3-D) with the possibilities of rotating, zooming, making the elements transparent, and also suppressing information that is not useful at the moment. The results showed with this technology may reduce mistakes in the field when assembling PT structures. This article shows the steps necessary to use AR on a project.

KEYWORDS

augmented reality (AR); building information modeling (BIM); E-drawings.

Augmented reality (AR) technology was invented in 1968 by Ivan Sutherland when the first head-mounted display (HUDSET) system was developed, making truly realistic pictures of solid three-dimensional (3-D) objects. In Sutherland,[1] numerous difficulties were reported, such as showing "opaque" objects with hidden lines removed, which was one of the goals, but the equipment showed the objects' transparent "wire frame" line drawings. However, we cannot forget that it

was a significant advance time, and that there has been a rapid evolution in HUDSET equipment since this first use. Another author[2] built a see-through display using color liquid-crystal display (LCD), half-silvered mirrors, and magnifying lenses, while Sutherland's[1] display used a half-inch monochrome cathodic ray tube (CRT) and half-silvered mirrors. Another author[3] presented an application where the HUDSET was used to dynamically mark the position of a drill/rivet hole inside an aircraft fuselage. This technology was used to "augment" the visual field of the user with information necessary in the performance of the task, and therefore this technology got the name of "augmented reality" (AR).

In post-tensioned (PT) structures, many elements can cause interference, mainly in the anchorage zone. In the AR model, everything is reproduced in full and edges, beams, columns, and openings are carefully detailed, helping the user see conflicts more clearly. This paper aims to present general information about AR, identify differences between AR and virtual reality (VR), and explore one model with software for AR.

DIFFERENCE BETWEEN AR AND VR

In general, there is a difference between AR and VR, which was discussed by Caudell and Mizell[3] in relation to the complexity of the projected graphical objects. These two technologies can be described as:

- VR: A computer-generated simulation in which the user interacts with a 3-D environment using electronic devices, replacing reality and taking the user into a digital environment lacking interaction with the real world.[4] This technology is used nowadays, for example, in video games and 3-D movies.

- AR: Combines the real world with virtual elements. AR adds to reality, projecting information on top of what you're already seeing—that is, the superimposition of virtual objects upon, or composited with, the real world.[5]

USERS OF AR AND VR

Since its creation, AR has been inserted into our daily lives little by little—for example, in videos, photo filters, games, shopping, and interactions with the user through a device. This device can be a pair of glasses, a cell phone, a tablet, and the variety of applications is expanding as more consumers and businesses test out immersive experiences. By the end of 2021, it has been estimated that 58.9 million people will use VR and 93.3 million will use AR. Currently, the United States has 15% of all users of this technology in the world.[6] This number is expected to grow in the coming years. The pandemic has forced many people to test experiences with AR and VR to replace in-person visits both in the workplace and academically. However, supply chain and distribution issues temporarily disrupted shipments, delaying the growth of the number of devices.

AREAS IN WHICH AR IS USED—EXPECTED REVENUE OF THE INDUSTRY BY 2025

AR is being used in applications such as video games, healthcare, engineering, live events, video entertainment, real estate, retail, military, and education, among others. The growth of AR in two categories of the construction market is expected: engineering and real estate, resulting in an expected market size of $25 billion by 2025. Among the top 10 best-ranked sectors, engineering is number 3 ($4.7 billion) and real estate is number 6 ($2.6 billion). The number one is the gaming sector, with approximately $12 billion.[6] This highlights the importance of developing new applications for using AR in civil construction. The number of uses has been growing as in the examples: Chernick et al.[7] with model overlay using AR and model interaction as query system, Chai et al.[8] evidenced integration of AR in building information modeling (BIM), the Federal Highway Administration showed the use of augmented reality (AR) for highway construction,[9] and Zollmann et al.[10] reported use of AR for construction site monitoring and documentation. It is noteworthy that in PT structures, the use is embryonic—much more development is needed in this application and will be discussed in this article.

WHY USE AR IN PT STRUCTURES?

Over time, a lot of progress has been made. Thirty years ago, the drawings were made on a wooden drawing board with tracing paper; at the time, those were the best resources available. Later in the 1990s, there was an expansion in the use of computer-aided design (CAD) technology, with two-dimensional (2-D) emphasis. However, drawings made in 2-D were no longer sufficient for a better understanding of a project. In the 2000s, REVIT came out for use in civil construction, which was undoubtedly a revolution at that time because it was possible to easily visualize a 3-D model, carry out automatic slices, and render a graphic with great productivity. However, the information was not readily sharable, giving rise to the development of BIM.[11] The basis of a BIM system is a database that, in addition to defining the geometry of construction elements in 3-D, it stores their attributes and, therefore, transmits more information than traditional CAD models. Also, as the elements are parametric, one can change them and get instant updates across the entire project. This process encourages experimentation, reduces conflicts between construction elements, facilitates revisions, and increases productivity.[4] Note that BIM is not a specific software; BIM is a working platform for software. Given all exposed in this topic, it is clear that AR has become another advent to improve information transfer. As an example, a worker who could have questions about the assembly of an anchorage device, even though the drawing is on paper, could view and understand the drawing in AR and interacting with it in the project. All that is needed is to place a quick response (QR) code on the project sheet, point the cell phone or tablet to it, and the assembly appears on the screen; it will be possible see parts of the model, rotate it, make animations, or leave in wireframe mode. Figure 1 shows a drawing of stressing end anchor usually detailed in projects and Fig. 2 shows the same drawing in AR. Another interesting point of AR is related to structural analysis—the user could isolate an element, and check its displacements, stresses, deformations, and send it to the construction site. Figure 3 shows an analysis of a monostrand anchorage, taking into account the deformations in the initial stage of prestressing. There is also the possibility to visualize a full-size structure in the construction site with all the details (Fig. 4). Furthermore, it becomes possible to superimpose BIM models where the project team can compare what has been planned with what has been built and evaluate the work on the spot—more commonly called AR-BIM.

HOW TO USE AR IN PT STRUCTURES

The first step is to build a 3-D/BIM model in a software package while maintaining awareness of the second step, which is the importance of opening the 3-D model in the AR application (app). Each AR app opens a range of formats of 3-D models; it is important to check compatibility before investment in an application. It is more and more important to develop new
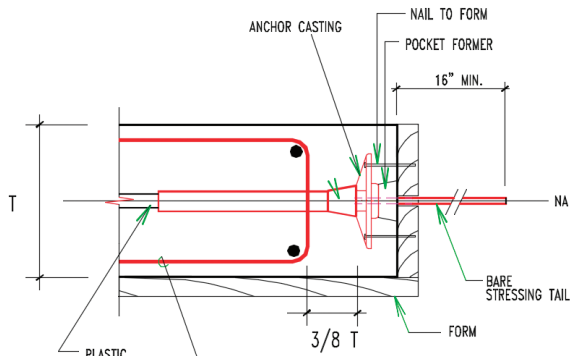
Fig. 1—Stressing anchorage. (Note: 1 in. = 25.4 mm.)

Fig. 2—Stressing anchorage in AR.

Fig. 3—Single-strand anchorage: deformations in AR.

applications so that a wide range of formats is supported. The third step is simple: just print the QR code and place it at the point where you want to manipulate the object. Once the QR code is scanned, the element will appear on the screen of the device, and you will be working in AR. Then, the element can be analyzed and explored: rotating, moving, and even making an animation. Again, all these features will depend on the application features, and some points are still limited. It is believed that with the arrival of 5G cellular networks, higher cloud storage capacity, and the development of new applications, it will be possible to advance further. Figure 5 shows the workflow for using PT structures in AR.

HANDS-ON

First step: choose the app

Let's get hands-on now. The QR code from Fig. 6 will direct you to the download links for the E-Drawings app on Android devices. Please note that the app is not available free of charge on iOS devices at this time.

Second step: choose the app

To generate the image in AR, download the pdf with the target using the QR code in Fig. 7, and then download the model using the QR code in Fig. 8.

Third step: open 3-D model

When the 3-D model is downloaded, the phone will automatically recognize that the model is supported by E-Drawings and it will suggest this app. Figure 9 shows the model inside the E-Drawings app.

Fourth step: accessing augmented reality – E-Drawings

As the target has already been downloaded using the QR code, it can be printed and placed where you want to
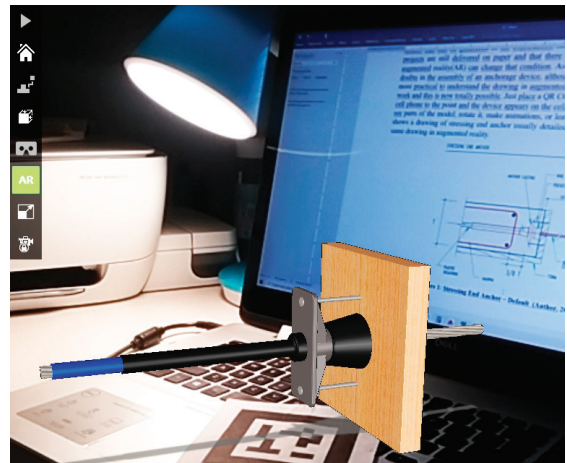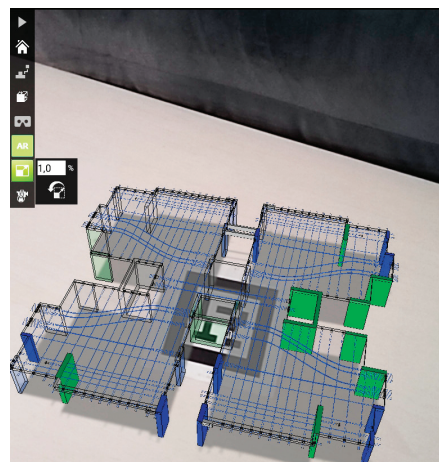

Fig. 4—PT slab: tendon layout in AR.

manipulate the object. Because this object is small, you may leave the target on your desk. Now just press the AR button on the screen in E-Drawings and read the target QR code that is on your desk. The model will appear in AR and can now be moved from one point to another, rotated, and also adjusted to the scale you want. Figure 10 shows the model in AR using E-Drawings.
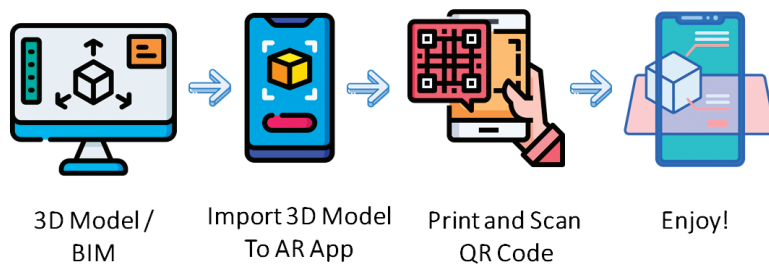
Fig. 5—Workflow for use of PT structures in AR.

Fig. 6—Download the E-Drawings app.

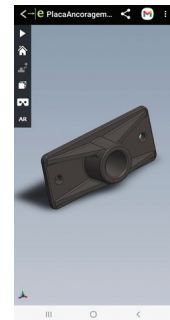*Fig. 7—Download QR code E-Drawings.*

Fig. 8—Download 3-D model.

Fig. 9—3-D model inside E-Drawings.

Fifth step: accessing augmented reality – E-Drawings

To view the 3-D model in the cell phone browser, simply scan the QR code you see right now. You can see parts of the model, rotate it, make animations, or leave it in wireframe mode. Can you imagine a QR code like this inserted in your project? It will certainly facilitate the visualization of the models in the work and all of it with accessible resources such as an internet connection and any browser in your phone. This was a sneak peek of what we can do in AR or even facilitate the day-to-day processes of PT projects. Figure 11 shows the QR code to access the model by cell phone browser.

WHAT CAN WE EXPECT IN THE NEAR FUTURE?

Mixed reality (MR) combines the best aspects of two realities: virtual and augmented. It allows the user to see the real world (as in AR) while seeing virtual objects (as in VR), allowing anchoring of virtual elements to a point in real space and allowing the user to manipulate and interact with the elements. There is room for improvement, but it is very important to contribute to the construction of 3-D models because through them, we can have a powerful tool for education and communication in PT construction.

CONCLUSIONS

- Augmented reality (AR) can be an ally and help to better understand a post-tensioned (PT) concrete project.
- The number of users of AR has been growing in recent years with prospects of moving billions of dollars in real estate and engineering.
- There is a need to develop new applications with more advanced features and compatible with more three-dimensional (3-D) models, to have a faster internet and higher cloud storage capacity so that we can enter a new era.
- It is believed that mixed reality (MR) will help further interact with the user in the near future.

ACKNOWLEDGMENTS

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10. Zollmann, S.; Hoppe, C.; Kluckner, S.; Poglitsch, C.; Bischof, H.; and Reitmayr, G., "Augmented Reality for Construction Sit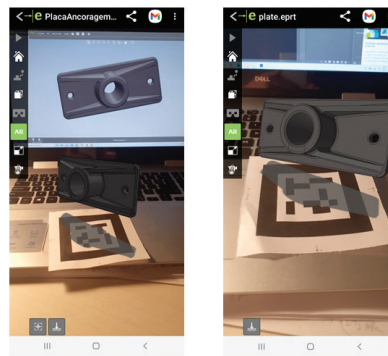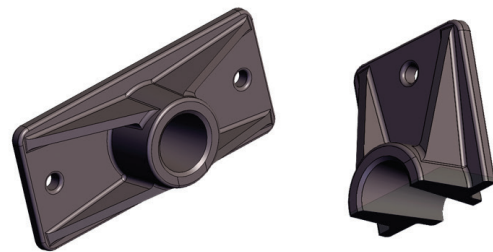e: Monitoring and Documentation," *Proceedings of the IEEE Special Issue on Applications of Augmented Reality Environments*, 2014.

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Fig. 10—Accessing AR from E-Drawings app.

Fig. 11—Accessing model by cell phone browser.

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