

Exploratory Research into Potential Practical uses of Next Generation Wearable Wireless Voice-Activated Augmented Reality (VAAR) Devices by Building Construction Site Personnel

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The miniaturization and increased functionalities of next generation augmented reality (AR) devices, as well as advances in computing technology in the form of cloud computing, is moving the building construction industry closer to adoption of AR devices for use by building construction site personnel. There is therefore a need to understand the potential practical uses of next generation AR devices in building construction site work. A conceptualization of a next generation AR device suitable for use by site personnel is provided. Based on this conceptualization, a focus group of industry professionals and postgraduate researchers have determined that potential practical uses of such a device include: easy access to digital information to support work tasks, live streaming of videos of tasks being worked on, and easy creation of a repository of as-built photographs and videos. Potential applied research studies that will aid in the adoption of next generation AR devices by site personnel include those associated with usability testing, labor productivity measurement and improvement, and suitability testing based on nature of work tasks. The major implication of this exploratory study is that its findings will help to bridge the gap between next generation AR devices and practical use in building construction.

Keywords: Augmented Reality, Building Construction, Cloud Computing, Next Generation, Practical Use

Introduction

Augmented reality (AR) is an emerging technology that is increasingly acquiring greater relevance and usage. AR according to Goodrich (2013) refers to images and sounds being superimposed in real time over what is experienced in the real world. An easily comprehensible example of the use of AR technology is in live television sports broadcasts, e.g. the yellow first-down line that is superimposed on the football field during live broadcasts of NFL games. In addition to being used by the television broadcast industry, AR technology is being increasingly used for military applications (e.g. Livingstone et al. 2002), medical applications (e.g. Barfield and Caudell 2001) and by the video game industry (e.g. Graham-Rowe 2011). A wide-scale adoption and use of AR technology by the construction industry, more specifically by building construction site personnel, is for the most part non-existent. This is because current AR devices are less wearable in practice, and devices seem to lack the necessary data storage and computing capacity associated with construction-specific software applications (Kamat and El-Tawil 2007). This state-of-affairs, is however, about to change considering the many recent advances associated with next generation computing and wireless communication; in particular the commercialization and growing widespread adoption of cloud computing, and breakthroughs in the development of wearable wireless voice-activated augmented reality (VAAR) devices, e.g. Google's Glass. In fact, because of recent technological advances, there are efforts underway to develop and commercialize wearable AR devices that can be used by construction workers. For example, construction equipment manufacturer Caterpillar is currently investigating the use of a version of Google's Glass for use in construction and manufacturing (Grayson 2013), and at least two other mobile technology companies are attempting to develop head-worn AR devices for use by construction site workers (Olson 2013). It is apparent that building construction is on the verge of being revolutionized by attempts to leverage next generation AR devices and computing technologies. In particular, the way in which building construction site personnel, such as technicians and skilled trades access information and communicate while completing tasks is likely to change. Recognizing these breakthroughs and the likely implications they will have on the way building construction site personnel work and communicate, a non-technical exploratory study is being undertaken to begin to understand the potential practical uses of next generation wearable wireless VAAR devices by building construction site personnel. The overall goal of this exploratory study is to bridge the gap between next generation AR technology and practical use by building construction site personnel. The objectives of this exploratory study are: 1) conceptualize a wearable wireless VAAR device appropriate for use by building construction site personnel by adopting and adapting recent advances in AR, computing, and communication technology, 2) generate a list of practical uses of wearable wireless VAAR devices by building construction site personnel using the conceptualized device as a guide, and 3) propose future applied research studies into the adoption and use of next generation wearable wireless VAAR devices by building construction site personnel.

Literature Review

In perhaps one of the first notable studies to be implemented on AR in construction, Webster et al. (1996) developed two AR systems to improve methods for construction, inspection, and renovation of architectural structures. The first AR system developed and tested by Webster et al. (1996) provided "x-ray vision" by overlaying a graphical representation of portions of a building's structural systems over a user's view of the room in which they were standing. The second AR system was developed to be an aid for workers engaged in space frame construction by providing an augmented view of a limited 3D computer model of a space frame, an ordered list of assembly steps, and digital audio files that contained instructions for each step. Kamat and El Tawil (2007) developed and tested an AR system to investigate the feasibility of using augmented reality to evaluate earthquake induced building damage. As part of their experiment, large-scale cyclic shear wall tests were done in a laboratory and CAD images of the walls were superimposed onto the wall specimens and viewed through an AR device. Yabuki and Li (2007) developed and tested an AR system as part of a cooperative reinforcing bar arrangement support system to overcome problems in planning and design of reinforcing bar works on bridge projects. In their system, Yabuki and Li (2007) used open source AR software from ARToolKit and head mounted displays (HMDs) to simulate the arrangement of reinforcing bars as an alternative to having to draw and modify many reinforcing bar plans to achieve optimum reinforcing bar arrangement. Berlo et al. (2009) developed and tested an AR system referred to as C2B to help construction workers gain insight into intended construction on a construction site. This system combined the real world with a building's virtual design to provide an AR view at the construction site through a handheld tablet PC. Talmaki et al. (2010) developed and tested a geo-referenced AR system to provide an excavator operator with information on the location and type of utilities that exist in the excavator's vicinity as a means of improving safety of excavating work. Kirchbach and Runde (2012) developed and tested an AR system for construction control by attaching sensors and RFID chips to replicas of earthwork equipment to gather productivity data based on actual operation. A mobile camera phone installed with AR software was used to view current operation and productivity information by pointing the phone's camera at the equipment. Dong et al. (2013) developed and tested an AR system to accommodate collaborative visualization of computer-generated engineering design models. This was done by developing a construction specific AR software application, ARVita, and testing it by having multiple participants wearing head-mounted displays sit around a table to observe and interact with dynamic visual simulations of engineering processes. From the aforementioned, it is clear that research studies on AR in AEC are wide ranging and follow a general theme of developing AR system architectures for use in construction, and testing the developed systems to improve layout, control, inspections, and safety in construction. It appears that there are no research studies on the use of AR devices by construction site workers. In particular, there are no applied research studies focusing on assessing the usability and suitability of AR devices and systems for use by building construction site personnel, such as technicians and trades personnel. One reason for this void in research is that current AR technology and supporting computing systems may not have the capabilities and functionalities to be effectively used by building construction site personnel. It appears that the AR systems developed and tested in research studies to-date are too cumbersome for practical application on construction sites. This is supported by Berlo et al. (2009) who found that one of the main barriers that kept AR from being implemented on construction sites was that AR devices were too cumbersome for workers to walk around with, much less use when completing work tasks. In addition, there appear to be limitations associated with localization technologies such as GPS, RFID and barcodes used to provide the functionality of automatically displaying augmented information based on the AR device's location and view. This deduction is supported by the findings of Kamat and El Tawil (2007), Berlo et al. (2009) and Talmiki et al. (2010). In fact, Hung-Lin Chi et al. (2013) in their review of AR applications in AEC found that localization approaches used by AR applications are limited by environmental complexity, thus making it difficult for AR applications to accurately superimpose the correct information based on the user's location. In addition to issues associated with capabilities of localization technologies, past research studies have indicated that current AR devices and systems appear unsuitable for use by building construction site personnel because of limitations associated with storage and retrieval of digital data. This is mentioned by Kamat and El-Tawil (2007) who argued that better systems of data management were needed for AR to be successfully integrated on construction site operations, since for AR systems to work accurately; accurate and up-to-date geometrical and position data of building elements are needed. At the site level, for AR to be successfully used by building construction technicians and trades personnel, more convenient methods for accessing huge and disparate amounts of building information such as building models, schedules, installation instructions and videos, to name a few, are required. In essence, for AR to find practical use by site personnel, ubiquitous access to building information is required.

It appears that next generation AR devices and computing technologies have overcome the above mentioned barriers to practical use of AR by building construction site personnel. Firstly, next generation AR devices are wearable, e.g. Google's Glass is in the form of a spectacle frame. This has resulted in AR devices being less cumbersome and easy to be incorporated in building construction work processes. Secondly, next generation computing technology in the form of cloud computing allows for the ubiquitous access to information from anywhere. Cloud computing also allows for the storage of vast amounts of data without the cost of having to invest and maintain database servers. These two advances, when combined as an AR system, will make the use of AR by building construction site workers practical, and in this regard, has established the need for an understanding of the potential practical uses of next generation wearable AR devices by building construction site personnel. This is the subject of discussion in the remainder of the paper.

Method

The method used in implementing this exploratory research study consisted of three parts. Firstly, a literature review of research studies on the use of AR in construction was done to ascertain the current direction and state-of-the-art of AR in construction. In addition, a review of next generation wearable AR devices was done to understand the functionalities and capabilities of these devices. Secondly, based on the findings of the literature review and an understanding of the functionalities, capabilities and operation of next generation wearable AR devices, a wearable wireless VAAR device for use by building construction site personnel was conceptualized. Thirdly, using the conceptualized device as a guide, a focus group consisting of a three industry professionals and seven postgraduate researchers specializing in construction IT, through a brainstorming session, generated a list of potential practical uses of next generation wearable wireless VAAR devices by building construction site personnel. The three industry professionals were project managers, two of which work for contracting firms and one being the owner of a construction management firm. All three of the professionals utilize IT as part of their work activities on a daily basis, while the graduate students are currently undertaking research studies or have undertaken research studies that included the use of IT in construction. Based on a vote by the members of the focus group, the ideas of practical uses were placed into two groups, i.e. "practical and possible", and "practical but not possible". A number of potential applied research studies were generated based on the ideas that were classified as "practical and possible".

Results and Discussion

A Conceptualization of a Next Generation Wearable Wireless VAAR Device suitable for use by Building Construction Site Personnel

There are three next generation wearable augmented reality devices that are commercially available or close to becoming commercially available. These include: Steve Mann's Eye Tap, MIT's Sixth Sense, and Google's Glass. Eye Tap is the first wearable augmented reality device, with the first version being developed in 1981. The current version of Eye Tap is in the form of a metal frame that is worn by the user in the same way as a spectacles frame would be worn. The device is worn in front of one of the user's eyes and has a built-in camera that records the scene available to the eye, as well as a display that superimposes the computer-generated imagery of the scene available to the eye (Bergstein, 2004). In essence, the Eye Tap device intakes the world around it and augments the image the user sees by overlaying computer generated data on top of the normal view the user would perceive (Eye Tap, n.d.). MIT's Sixth Sense is different from Eye Tap, being a combination of a camera, small projector, Smartphone and mirror that hangs around the user's neck (Goodrich, 2013). The device is controlled by hand gestures (Mistry, 2010) and projects visual information onto physical surrounding objects. It appears that this device is more cumbersome and less functional than Eye Tap, in some regards. Google's Glass is the most recent and possibly the most advanced next generation augmented reality device. Its shape is similar to Eye Tap, i.e. it has the form of a spectacles frame (Goodrich, 2013). According to Google (2013), Glass displays images and videos on the user's lens in the form of a head-up display (HUD), overlaying the real image the user is seeing. In addition, it has a built-in speaker for the user to receive audio information. Google's Glass also has the functionality of recording videos and taking photographs of the scene that the user is seeing. Unlike Sixth Sense and Eye Tap devices, Google's Glass is voice activated and has a touchpad located on its side for navigating images and videos projected on the lens (Google 2013).

Based on the abovementioned next generation wearable AR devices, it is envisioned that a suitable wearable AR device for use by building construction site personnel should adopt features and functionalities associated with Google's Glass device. In this regard, it is proposed that a suitable device will be a wearable wireless voice-activated device. The primary requirements of such a device are: 1) the device should not be cumbersome, and 2) the device should utilize a computing and communication system that is capable of supporting communication requirements associated with building construction work. The device should therefore be a head worn hands-free device that utilizes cloud computing for data processing and information storage and retrieval. In fact, it is proposed that the device will be connected to a mobile phone with wireless connection capabilities that will serve as the interface between the device and the cloud network. Unlike Google's device, it is envisioned that this device will be detachable from the spectacle / safety glass frame. This will allow the AR unit to be used on standard construction safety glasses, which can easily be replaced if damaged. Figure 1 is an artistic impression of what the proposed device would look like. The proposed device will consist of a commercially available AR unit mounted on the frame of standard construction safety glasses. An example of such a commercially available unit is Brother's AirScouter (Brother 2010). The AR unit will consist of a prism which will display augmented images in the user's line of sight, a camera with a built-in microphone that is capable of recording and streaming videos, as well as taking photographs, and a touchpad for navigating the AR display. In addition, the AR unit will have built-in speakers that will be in close proximity to one of the user's ears and a USB chord to connect the AR unit to a mobile phone, which will be the AR unit's power source and wireless transmitter.

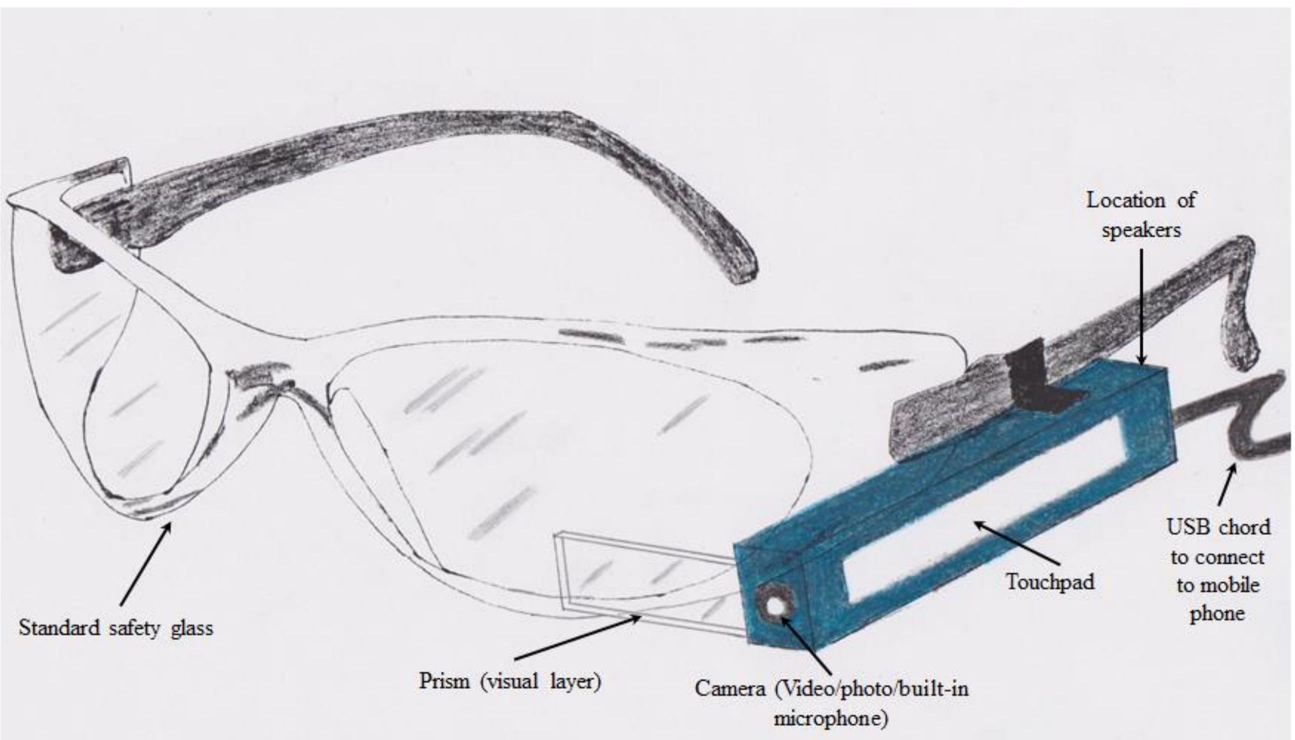

Figure 13: An artistic impression of a next generation wearable wireless VAAR suitable for use by building construction site personnel

Potential Practical Uses of Next Generation Wearable Wireless VAAR Devices by Building Construction Site Personnel

The following are ideas generated by the focus group that are classified as being “practical and possible” with respect to the use of next-generation wearable wireless VAAR devices by building construction site personnel:

1. Accessing task and activity information while completing project work tasks: it appears that next generation AR technology will allow for hands-free access and reading of digital CAD drawings and 3-D building models while completing work tasks. In addition, building construction site technicians and trades personnel such as HVAC and electrical technicians will be able to have their view/vision augmented with instructional videos when completing tasks for which they need guidance. Through the use of voice commands, the wearable AR device will display the requested drawings / instructions / videos as a head-up-display in the user’s line of vision. This functionality will allow users to access task drawings and other information without having to stop working on their tasks for a significant amount of time, thereby decreasing downtime of work tasks and processes, resulting in increased labor productivity. This functionality will be possible because cloud computing will serve as a database for up-to-date drawings, building models, and instructional videos. The cloud network will be accessed through the user’s mobile phone, to which the AR device will be connected. The mobile phone and AR device will not need to have installed software to access the many formats of construction drawings, as this will be made available through the cloud network in the form of software as a service (SaaS).
2. Receiving instructions from supervisors and foremen while completing project work tasks: this will be in the form of voice conversations initiated without the site technician or trades personnel having to stop work to hold a mobile phone. In this regard, site technicians and trades personnel will receive real-time audio instructions and guidance from supervisors with respect to project work tasks being completed. This will likely result in less rework being required and shorter task completion time. This functionality will be possible by having the mobile phone to which the head worn AR device is connected, be manipulated / operated using voice commands, such as “call supervisor”. The head-worn AR device will provide audio using speakers located at the back of the device close to the user’s ears. It should be noted that the participants debated as to whether the aforementioned was augmented reality. In the end, it was accepted that augmented reality was more than visual augmentation and that audio augmentation of the user’s reality was relevant.
3. Allowing supervisors to remotely monitor project work tasks: it appears that this will be possible by streaming live videos of tasks being completed so that supervisors / engineers can view them in real-time. Supervisors will be able to monitor and observe various project work tasks, such as electrical installation, masonry work, demolition work etc. from an office or another remote location using their mobile phones, for example. This will save both time and cost of having supervisors travel to and from the project site. This functionality will be possible by having the camera of the AR device record videos of tasks being completed from the view of the technician. Through the use of a cloud network, these recordings can be streamed live to viewers on and off the project site.
4. Allowing for the creation of a repository of as-built photographs and videos: this will be done by storing videos of task completion on the cloud network. The benefit of this is that these types of videos can be accessed and used by facilities management technicians when doing maintenance work after the building has been put into use. This functionality will be possible by having the camera of the AR device record videos of tasks being completed from the view of the technician, and directly store these videos on the cloud network.

With respect to ideas classified as being “practical but not possible”, the brainstorming group agreed on one use that would be very practical in the context of building construction, but is not possible given the current state of immediate next generation AR technology. This practical use of the proposed wearable VAAR device is concerned with automatically augmenting the site technician or trade personnel’s view with relevant information based on the location and orientation of the individual on the project site. That is, through the use of a localization system such as GPS, the trade personnel’s view will be automatically augmented with information that is relevant to the specific view. The challenge according to the members of the brainstorming group is that the building site is continuously evolving, i.e. new components such as beams, columns, HVAC systems etc., are incorporated over a short period of time. This in essence, requires a database to be updated in real-time with both positional data of new building components and construction attributes of those components. In addition, studies reviewed as part of this exploratory research have indicated that there are still challenges associated with devices recognizing building elements and displaying pertinent information about those elements. It should be mentioned that members of the brainstorming group recommended adapting face recognition technology as currently being refined by Google as a possible alternative to identify building components instead of relying on positional data of building components to automatically provide the user with augmented information relevant to the user's view.

Potential Applied Research Studies to Aid in the Adoption of Next Generation Wearable Wireless VAAR Devices by Building Construction Site Personnel

Based on the ideas that were generated concerning practical and possible uses of the proposed AR device, the following three applied research topics were generated by the group and appear to be pertinent:

1. A building construction site is usually noisy. In this regard, an understanding of the impact of the building construction site environment on the operation of wearable wireless VAAR devices is necessary. For instance, what impact will background noise have on building construction site personnel using voice commands to access task information? What impact will smoke and dust have on the ability of building site personnel to properly view augmented images and videos? This is an applied research study focusing on usability testing.
2. Building construction work tasks often require access to up-to-date information. In this regard, an understanding of the ease and extent to which cloud computing will allow the ubiquitous access to up-to-date task information by building construction site personnel while completing work tasks will inform as to the type digital content and size of digital files than can be efficiently accessed by building construction site workers using these devices. Also, an appreciation of the issues associated with using cloud computing in the form of software as a service (SaaS) by the wearable wireless AR device will inform as to which software will need to be installed on the device for optimum performance. This is an applied research study focusing on testing and refining components of the AR system architecture.
3. Labor productivity of building construction site personnel is influenced by many factors. One critical factor that affects labor productivity is a worker's access to pertinent information and guidance with respect to task completion. In this regard, an assessment of the impact of the use of wearable wireless VAAR devices by workers of the different trades is needed. It is hypothesized that use of wearable wireless VAAR devices by building construction site workers will lead to improved labor productivity. This is an applied research study focusing on labor productivity measurement and improvement.
4. Communication and information requirements are different between building site personnel based on the nature of the work being undertaken. In this regard, an understanding of the types of work for which the use of wearable wireless VAAR devices is most suitable is needed. This will lead to a better understanding of the suitability of using wearable wireless VAAR devices in building construction work. This is an applied research study focusing on suitability testing based on nature of work.

Conclusion

The commercialization of next generation AR devices that are less cumbersome than their predecessors, e.g. Google's Glass, and advances in communication and computing technologies, such as cloud computing, have set the stage for an impending adoption of wearable AR devices by building construction site personnel. A conceptualization of one such next generation wearable AR device that appears to be suitable for practical use by building construction site personnel, is a wearable wireless VAAR device that is similar in functionalities and capabilities to Google's Glass. The use of such a device in conjunction with cloud computing will present many opportunities for use by building construction site personnel in completing their work tasks. Ideas of potential practical uses of such a device have been presented in this paper and range from accessing drawings and building models without work interruptions, to live video streaming of the task being performed to be remotely viewed by supervisors, architects and engineers. This impending shift in communication and data access by site personnel will require applied research studies to be undertaken to aid in adoption of these next generation devices and technology. Applied research studies in this regard should focus on usability testing, testing of AR system architecture, i.e. combined use of AR device with cloud computing; measurement of changes in labor productivity, and level of appropriateness of this impending evolution of communication and data access with various types of building construction project work. Future work associated with this exploratory research study includes implementing the proposed system using a commercially available device as part of a private sector and University funded innovation project. It is the author's opinion, that the adoption of next generation wearable wireless VAAR devices in conjunction with cloud computing will be rapid, and therefore underscores the pertinence of this non-technical exploratory study.

References

Barfield, W. & Caudell, T. 2001. Fundamentals of Wearable Computers and Augmented Reality, Lawrence Erlbaum Associates, Mahwah, NJ.

Bergstein, B. 2004. Professor's 25 years of Cyborg Life Mirrors Tech Advances. *USA Today*. [WWW Document]. URL http://usatoday30.usatoday.com/tech/news/2004-01-12-steve-mann_x.htm

Brotherton, B. 2008. *Researching Hospitality and Tourism: a Student Guide*. Sage Publications Ltd. London.

Berlo, L.V., Helmholt, K.A., & Hoekstra, W. 2009. C2B: Augmented Reality on the Construction Site. *Proceedings of the 9th International Conference on Construction Applications of Virtual Reality*, November 5-6 2009.

Brother, 2010. Brother officially named Retinal Imaging Display "AiRScouter™", [WWW Document]. URL http://www.brother.com/en/news/2010/airscouter/index.htm

Dong, S., Behzadan, A., Chen, F., & Kamat, V. 2013. Collaborative Visualization of Engineering Processes using Tabletop Augmented Reality. *Advances in Software Engineering*, Elsevier. Vol. 55, pp 45-55.

EyeTap, n.d. EyeTap: The Eye itself as Display and Camera [WWW Document]. URL http://www.eyetap.org/research/eyetap.html

Furht, B. 2011. Handbook of Augmented Reality. *Springer*.

Goodrich, R. 2013. What is Augmented Reality? LiveScience.com, [WWW Document]. URL http://www.livescience.com/34843-augmented-reality.html

Graham-Rowe, D. 2011. Sony Sets its Sights on Augmented Reality [WWW Document]. URL http://www.technologyreview.com/news/424147/sony-sets-its-sights-on-augmented-reality/

Grayson, W. 2013. Caterpillar granted early access to Google Glass, working on ways to improve interaction with equipment, Equipment World, [WWW Document]. URL http://www.equipmentworld.com/caterpillar-granted-early-access-to-google-glass-working-on-ways-to-improve-interaction-with-equipment/#sthash.nvcyLoCC.dpuf.

Google, 2013. Get to Know Glass. [WWW Document]. URL https://www.google.com/glass/help/#getting-to-know-glass

Chi, H., Kang, S., & Wang, X. 2013. Research Trends and opportunities of Augmented Reality Applications in Architecture, Engineering, and Construction. *Automation in Construction*, Elsevier. Vol. 33

Kamat, V. & El-Tawil, S. 2007. Evaluation of Augmented Reality for Rapid Assessment of Earthquake-Induced Building Damage. *Journal of Computing in Civil Engineering*. ASCE, September/October 2007, pp 303-310.

Kirchbach, K. & Runde, C. 2012. Augmented Reality for Construction Control. *Proceedings of the 16th Annual Conference on Information Visualization*. Montpellier, France.

Livingstone, M., Rosenblum, L., Julier, S., Brown, D., Baillot, J., Swan, J., and Gabbard, D. 2002. An Augmented Reality System for Military Operations in Urban Terrain. *Proceedings of the Interservice/Industry Training, Simulation, and Education Conference*. National Training and Simulation Association, Arlington, Virginia. 2002, pp 89-96.

Mistry, P. 2010. SixthSense: Integrating Information with the Real World. [WWW Document]. URL http://www.pranavmistry.com/projects/sixthsense/

Olson, P. 2013. Why you'll See Google-Glass Competitors in Construction Zones before Starbucks. *Forbes.com*. [WWW Document]. URL http://www.forbes.com/sites/parmyolson/2013/03/11/why-youll-see-google-glass-competitors-in-construction-zones-before-starbucks/

Talmiki, S., Dong, S., & Kamat, V. 2010. Geospatial Databases and Augmented Reality Visualization for Improving Safety in Urban Excavation Operations. *Proceedings of the 2010 Construction Research Congress*, Banff, Alberta, Canada.2010.

Webster, A., Feiner, S., & MacIntyre, B. 1996. Augmented Reality in Architectural Construction, Inspection, and Renovation, *Proceedings of Conference on Computing in Civil Engineering*.

Yabuki, N. & Li, Z. 2007. Cooperative Reinforcing Bar Arrangement and Checking by Using Augmented Reality, *Proceedings on the 4th International Conference on Cooperative Design, Visualization, and Engineering*. Shanghai China. 2007.