AUGMENTED REALITY TECHNOLOGIES FOR AEC PROJECTS: A LITERATURE REVIEW

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ABSTRACT: *Since 2006, researchers at the University of New Brunswick have used virtual and augmented reality technologies to document the construction phase of projects for facility owners. That research has identified the following beneficial capabilities: virtual site visits, comparing as-built and as-planned status of projects, pre-empting schedule disputes, enhancing collaboration opportunities, and planning/training for similar projects. This paper provides an expanded foundation for future research by presenting a review of augmented reality technology. The review is based on articles found within three well-known journals in architecture, engineering and construction (AEC) until the end of the year 2011: the Journal of Automation in Construction, the Journal of Information Technology in Construction, and the ASCE Journal of Construction Engineering and Management. The review further narrows the literature within these journals by considering only those 65 articles found through a key word search for "augmented reality." The selected journal articles are classified within the following dimensions: target audience (e.g., workers, design team, project managers, building system engineers, etc.), project phase (initiation, design, procurement, construction, maintenance), stage of technology maturity (technical issues, proposed system development, and application demonstration), application area (visualization or simulation, information access or evaluation, communication or collaboration, and training or safety), and hardware (e.g., immersive or mobile). The number of articles within these dimensions are used to identify maturing and emerging trends in the literature as well as to synthesize the current state-of-the-art of augmented reality research in the AEC industry. In summary, the AR literature has increasingly focused on the demonstration of visualization and simulation applications for use during the construction phase that address issues faced by on-site workers.*

KEYWORDS: *Augmented reality, AEC industry, project phase, construction management, literature review*

1. INTRODUCTION

The complex nature of the architecture, engineering and construction (AEC) industry and its appetite for access to information for evaluation, communication and collaboration, increases the industry's demand for information technologies. Recent visualization technologies are ideal in this environment. Augmented reality (AR), one of the newly developed visualization techniques, typically combines a virtual environment with a real environment by superimposing real images (of actual construction) on the digital images from a virtual model (of planned construction).

Augmented reality has many advantages, for example allowing the observer to interact with both the actual and the virtual objects and to monitor the construction progress by comparing the as-planned and as-built status of the project. Various applications of augmented reality have been recommended for AEC industry such as those by Dunston et al. (2005), Golparvar et al. (2009), and Vineet et al. (2011); these applications demonstrate the potential of this technology for future use in this domain.

This paper presents a literature review of augmented reality technologies in the AEC industry up to and including the year 2011. The aims of this review are (1) to synthesize the current state-of-the-art of augmented reality technologies for AEC construction projects, and (2) to identify key application areas which could highly impact the AEC industry. This goal is accomplished by classifying the literature in categories defined by the authors. Finally, a summary of the important points and conclusions are presented.

As indicated in Figure 1, this paper describes: our selection of three journals and subsequently 65 articles on the topic of augmented reality in the AEC industry (section 2), our review of the articles and identification of their characteristics (section 3), our definition of relevant categories for the classification of the articles (section 4), and our classification of the articles in the defined categories (section 5). Section 6 presents our conclusion. This research methodology is similar to the methodology used by Aziz et al. (2011).

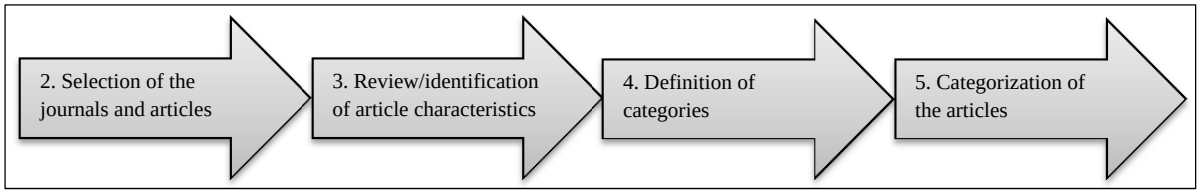


Figure 1: Research methodology

2. SELECTION OF THE JOURNALS AND ARTICLES

2.1 Journal Selection

Three diverse academic journals were selected within the domain of construction engineering and management to record the evolution of AR technology in the AEC industry: the Journal of Automation in Construction (AIC), the Journal of Information Technology in Construction (ITcon), and the ASCE Journal of Construction Engineering and Management (CEM). Selection of these journals was based on their prominence in the field of construction engineering and management research. AIC and CEM are SCI-indexed and included in the SCI-Expanded database and ITcon is a well-recognized open access journal on the use of IT in architecture and civil engineering.

2.2 Article Selection

A total of 94 articles were found in these three journals using the search phrase "augmented reality." The AIC search resulted in 61 articles, ITcon resulted in 21 articles, and CEM resulted in 12 articles, for a total of 94 articles. After excluding articles that were published in 2012 (due to the lack of a full year at this time) and articles such as Calendars, Editors Notes, Subject Index, and Contents of Volume, the total number of selected articles was 65. These 65 articles were distributed among the three journals as follows: AIC had 37 articles, ITcon had 18 articles and CEM had 10 articles. The article selection process is depicted in Figure 2.

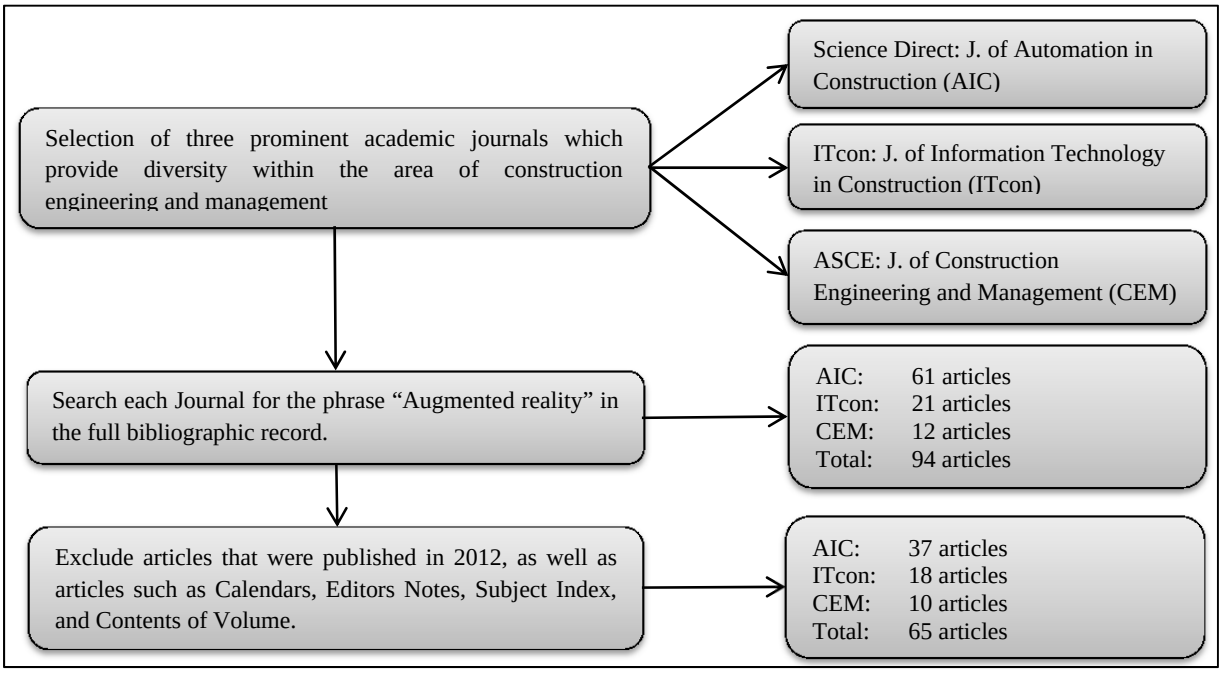


Figure 2: The process of selecting journal articles

3. REVIEW AND IDENTIFICATION OF THE ARTICLE CHARACTERISTICS

The number of articles by journal and by year are depicted in Figure 3. Among the three journals, AIC has the highest number of articles (57%) while ITcon and CEM have 28% and 15% respectively. The maximum number of articles in a single year were published in both 2008 and 2011 (18 or 28%).

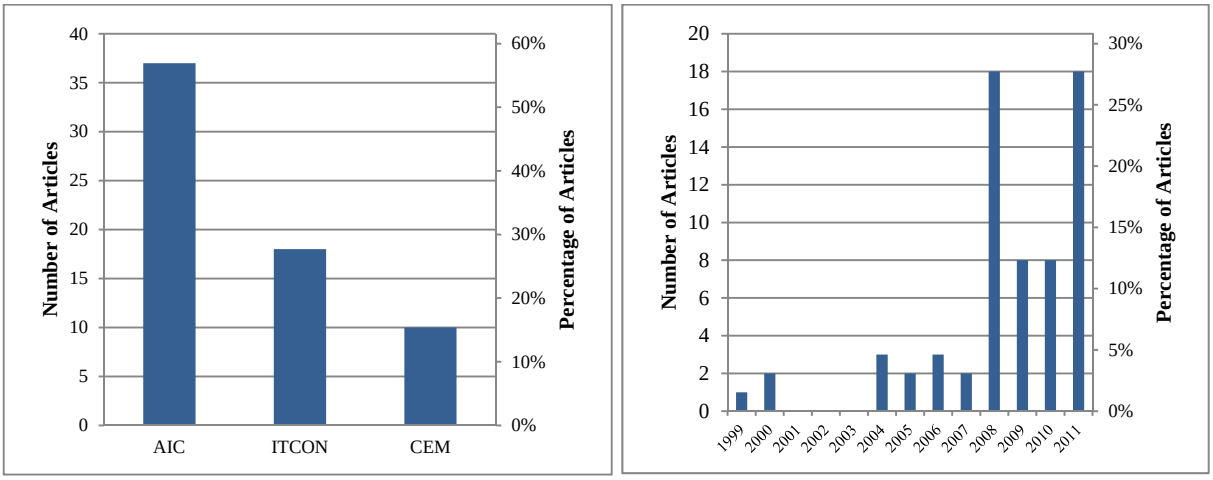
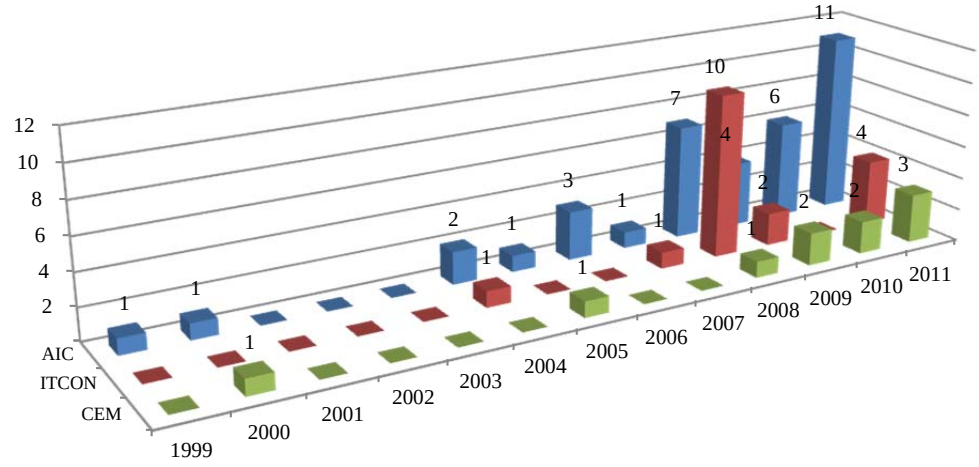


Figure 3: (a) Total number of articles by journal; (b) Total number of articles by year

Figure 4 presents the number of articles by journal and year of publication. The chart shows high numbers of articles for individual years in both the AIC (11 in 2011) and the ITcon (10 in 2008) jounal.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
AIC	1	1				2	1	3	1	7	4	6	11
ITCON						1			1	10	2		4
CEM		1					1			1	2	2	3

Figure 4: Number of articles by journal and year of publication

The final characteristic identified in this section is the number of articles based on the first author's country of residence. With 34 articles, first authors residing in the USA have the highest number of the articles about AR technology in the AEC industry among the other countries. The remaining counts are: 9 first authors residing in

Australia; 5 in South Korea; 2 in each of Canada, Germany, Japan, Spain, and UK; and 1 in each of Austria, Greece, Israel, Netherlands, Saudi Arabia, Taiwan, and Turkey.

4. DEFINITION OF CATEGORIES

To better understand and further segregate the literature, we defined categories to be used in this paper; each article was then compared to these defined categories for identification of its principal focus area or to determine the percentage of articles including reference to that classification.

Due to the complexity of construction projects and the collaborative nature of the AEC industry, the application of AR systems could have a wide range of *target audiences.* To classify these articles the following audiences were chosen: (1) workers, e.g., machine operators and technicians, (2) design team, e.g., architects, interior and exterior designers, (3) project managers and other construction professionals, (4) building systems engineers, e.g., structural, mechanical, and electrical engineers, (5) site developers, e.g., planners, civil engineers, and landscape architects, (6) engineering students, (7) stakeholders, e.g., clients, and building owners (K. Muramoto, 2008). If an article proposed a change in the work of one of these audiences, it was assigned to that subcategory for this classification.

The life cycle of a construction project consists of a sequence of steps or *project phases* to be completed in order to reach project goals and objectives. These phases are defined by N. Dawood (2009) as: (1) initiation and outline design, (2) design development, (3) [procurement], contract and pre-construction, (4) construction, and (5) maintenance.

From a *stage of technology maturity* perspective, the articles are divided in three subcategories: (1) technical issues, e.g., investigation of tracking, positioning and orienting issues for AR-based technology for steel column inspection (D. H. Shin et al., 2010), (2) proposed system development, e.g., development of ARVISCOPE (AR animation scripting language) and ROVER a mobile computing framework for information modeling and simulation of construction operation (Behzadan et al. 2011), and (3) application demonstration, e.g., application of D^4AR for construction progress monitoring (Golparvar-Fard et al. 2011), application of AR Training System (ARTS) for training the operation of heavy construction equipment (X. Wang et al., 2007).

Augmented reality technology has many applications in the AEC industry. We group AR *application areas* in the AEC industry as follows: (1) visualization or simulation, (2) information access or evaluation, (3) communication or collaboration, and (4) training or safety.

Augmented reality technology, which typically layers virtual information on a real scene, utilizes different *hardware* (personal computers (PC), laptops, head mounted displays (HMD), GPS, data gloves, smartboards, etc.) and software (AutoCAD, Photoshop, AC3D, 3D Studio, building information model (BIM), etc.). From a user experience perspective AR environments are: (1) immersive or (2) desktop-based, i.e., non-immersive. Devices such as HMD and data-gloves create immersive AR systems, in which users feel immersed in a virtual environment just as they usually feel in a real environment. Due to the improving performance of handheld devices and recent solutions to technical difficulties such as tracking, there is an opportunity for augmented reality systems to become portable, as well there is a growing interest in the use of mobile AR applications. From a technology device perspective augmented reality devices are classified as (1) mobile or (2) stationary.

5. CATEGORIZATION OF THE ARTICLES

This section discusses the classification of the current state of AR technology literature in the AEC industry. The articles are classified based on their principal focus and each article is counted once (except for section 5.1 where articles may be counted more than once).

5.1 Target Audience

In this section instead of giving the number of articles with a "principal focus on" a subcategory, we report the percentage of articles "including reference to" that subcategory, since in this section each article may refer to more than one subcategory. Figure 5 presents the percentage of articles by target audience. The results indicate that 30% of articles include reference to workers as the target audience (as defined in section 4), 25% refer to design teams, 24% refer to project managers, 22% refer to site developers, 9% refer to students, and 6% refer to stakeholders.

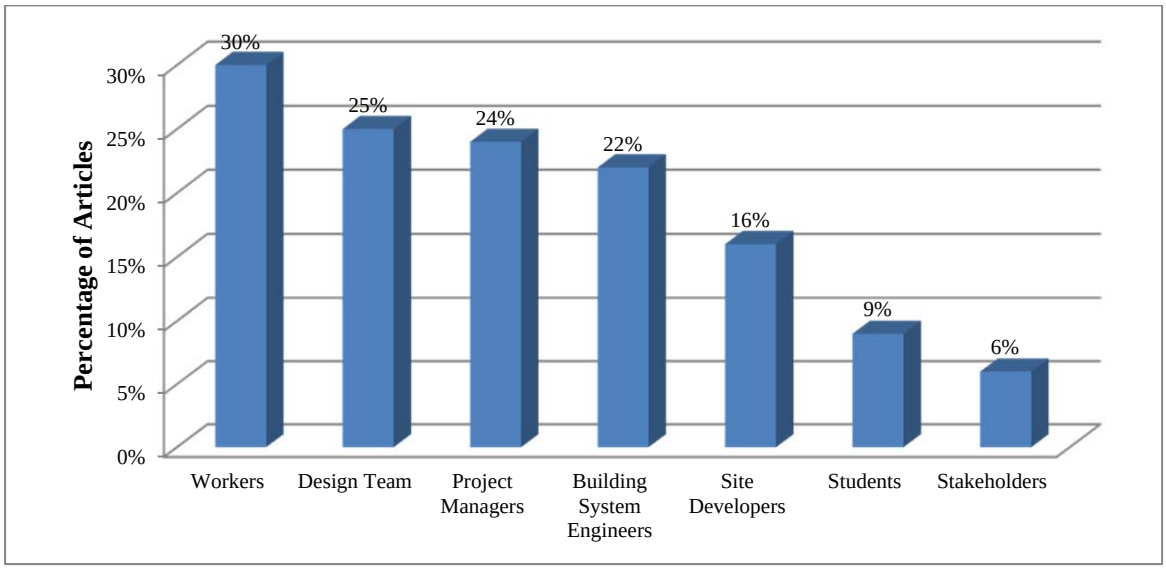


Figure 5: Percentage of articles by target audiences

5.2 Project Phase

The number of the articles by project phase is depicted in Figure 6. Twenty articles (31%) have a principal focus on the construction phase and 11 articles (17%) have a principal focus on the design phase. There are no articles with a principal focus solely on the procurement phase. Nine (4+1+4, 14%) articles focus on two project phases, and 5 articles (8%) focus on all 5 project phases.

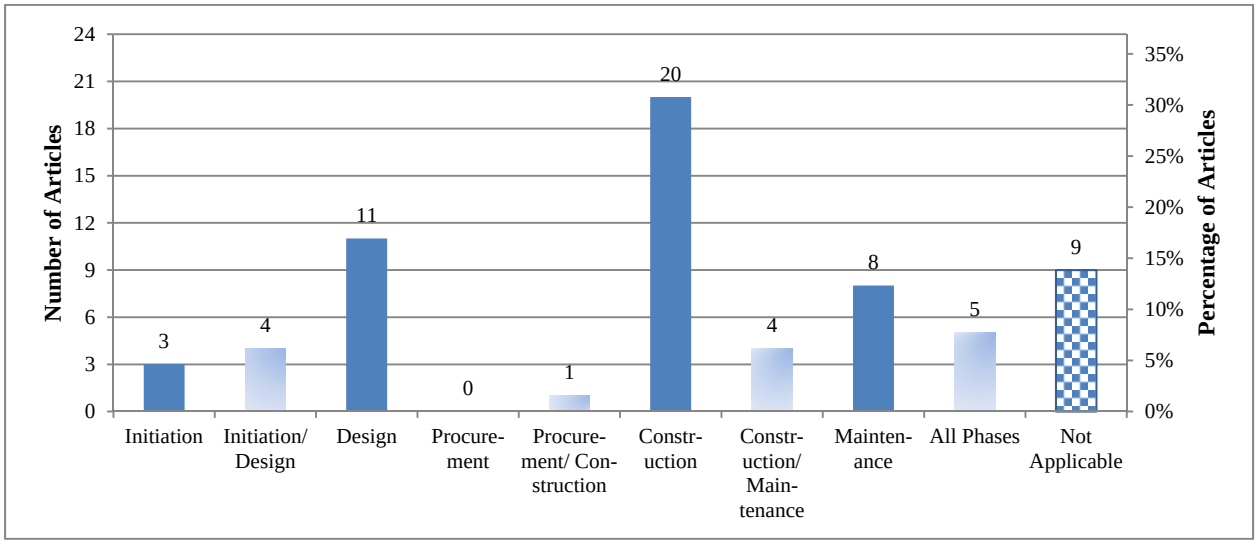
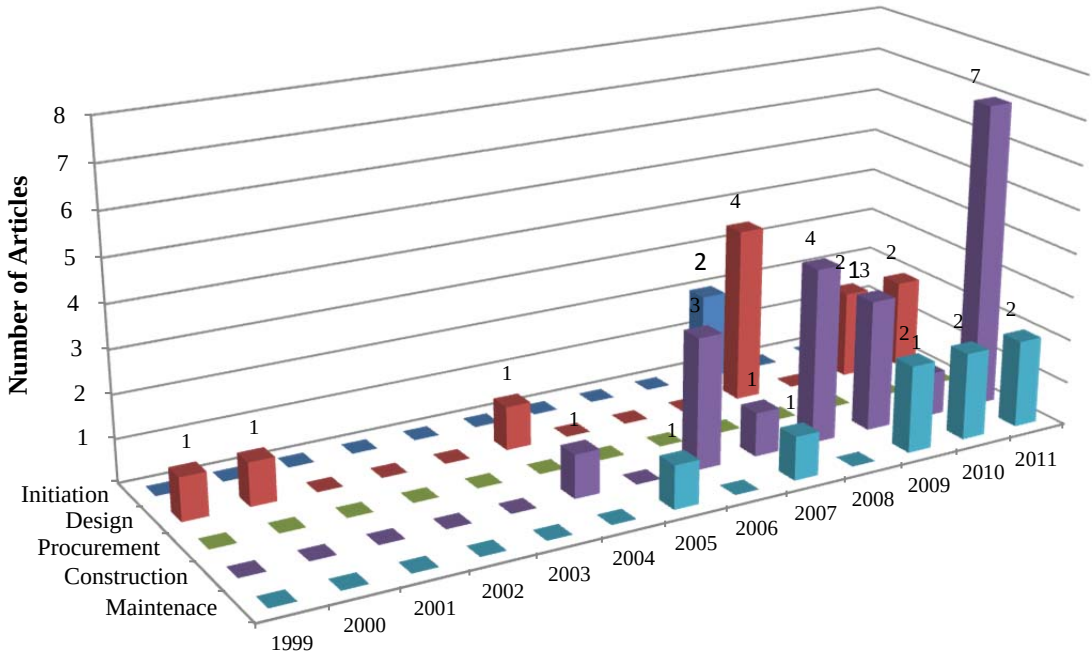


Figure 6: Number of articles by project phase

Figure 7 illustrates the number of articles for each project phase by year of publication. In this diagram articles with a focus on multiple phases are excluded (reducing the total to 42 articles). The highest number of articles in a single year is for the construction phase in the year 2011. The focus on the design phase of a project started with 1 selected article in 1999 and reached its highest number (4 articles) in the year 2008. Figure 6 and Figure 7 show that the highest number of articles occur in the design and construction phases of a project for AR technologies and applications.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Initiation										2			1
Design	1	1				1				4		2	2
Procurement													
Construction						1		3	1	4	3	1	7
Maintenace							1		1		2	2	2

Figure 7: Number of articles by project phase and year (articles spanning multiple phases are excluded)

5.3 Stage of Technology Maturity

Figure 8 illustrates the number of articles within each stage-of-technology-maturity subcategory. As shown, 29 articles (45%) have a principal focus on augmented reality application demonstration in AEC industry, while 14 articles (21%) and 10 articles (15%) have a principal focus on AR proposed system development and technical issues respectively. Eleven articles (17%) have a focus on multiple areas (i.e., more than one of the previous stages); these multiple areas are typically a combination of application demonstration and proposed system development.

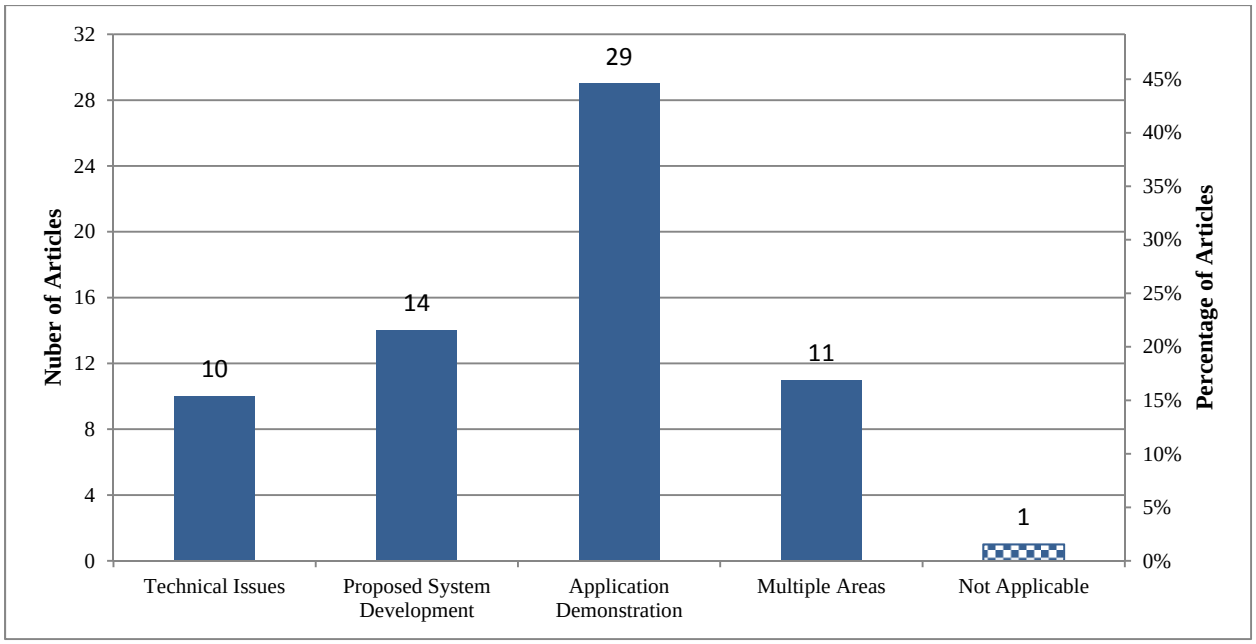


Figure 8: Number of articles by stage of technology maturity

5.4 Application Area

Figure 9 presents application areas for AR technologies in the AEC industry. As shown, 19 articles (29%) have a principal focus on visualization and simulation as an application area for AR technology. Information access and evaluation, communication and collaboration, and training and safety subcategories have 15 articles (23%), 10 articles (15%) and 8 (12%) articles respectively. Six articles focus on multiple application areas while these subcategories were not applicable for 7 articles.

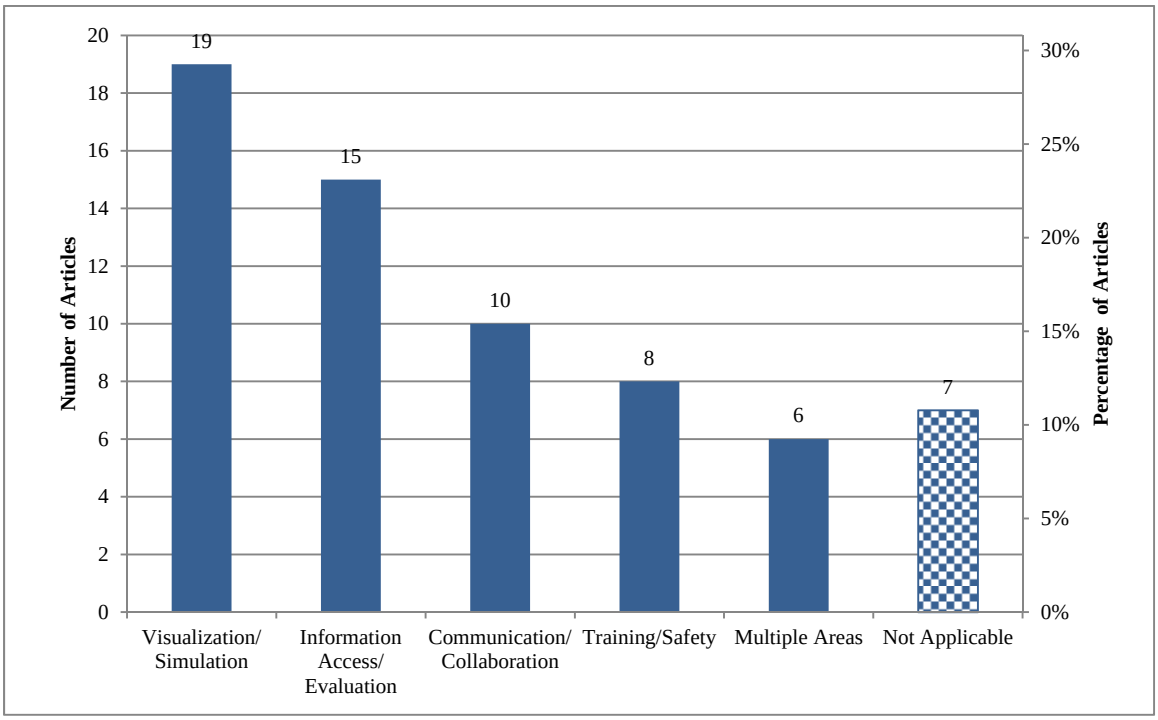
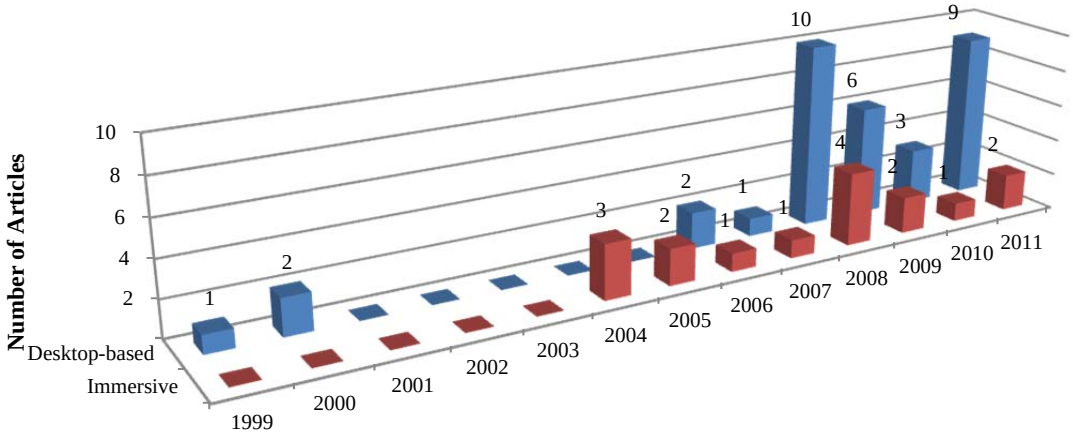


Figure 9: Application areas for AR technology

5.5 Hardware

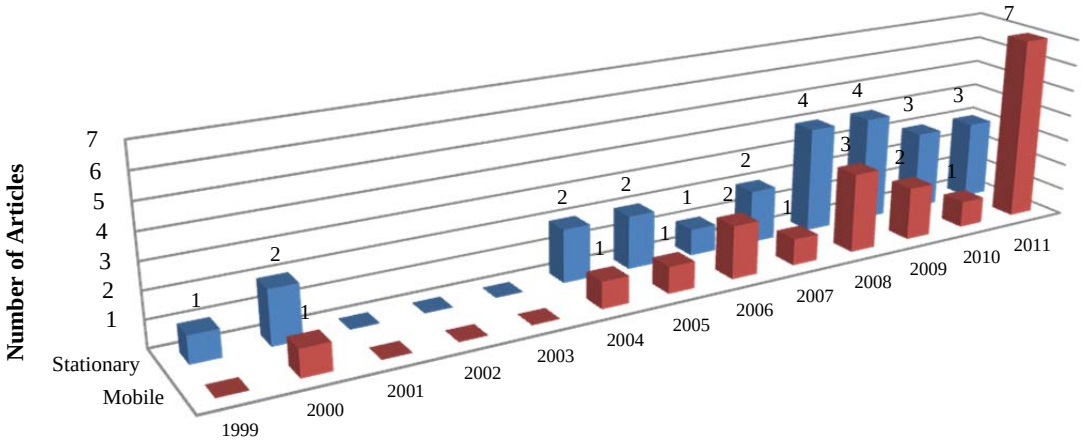
Within the hardware category, 16 articles had a principal focus on immersive AR technologies, 34 articles (52%) had a principal focus on desktop-based AR technologies, while 15 articles were not applicable. Figure 10 presents the number of articles with immersive and desktop-based technologies as a principal focus by year.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Desktop-based	1	2						2	1	10	6	3	9
Immersive						3	2	1	1	4	2	1	2

Figure 10: Immersive and desktop-based AR technology by year

Figure 11 presents the number of articles within the hardware category that had a principal focus on stationary and on mobile AR technologies in the AEC industry. The diagram implies an increasing trend in mobile AR technologies in AEC industry. Of the selected articles, one was published in 2000 that discussed mobile AR technology, while 7 articles (10%) focus on mobile AR technologies in the year 2011; 22 articles were not applicable to this category.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Stationary	1	2				2	2	1	2	4	4	3	3
Mobile		1				1	1	2	1	3	2	1	7

Figure 11: Number of articles for mobile and stationary AR technology by year

6. CONCLUSION

A structured methodology was used to identify 65 articles on the topic of augmented reality from 3 prominent AEC industry journals. The first article was published in 1999; a significant increase in the number of articles on this topic occurred during 2008. In addition to statistics on the counts of articles by year and the first author's country of residence, five interpreted categories were developed for classification of these articles: target audience, project phase, stage of technology maturity, application area, and hardware (including both user experience and device). Articles were classified and insight on the current state of AR technology in AEC industry research was gained. The following results are concluded for the categories shown in Figure 12.

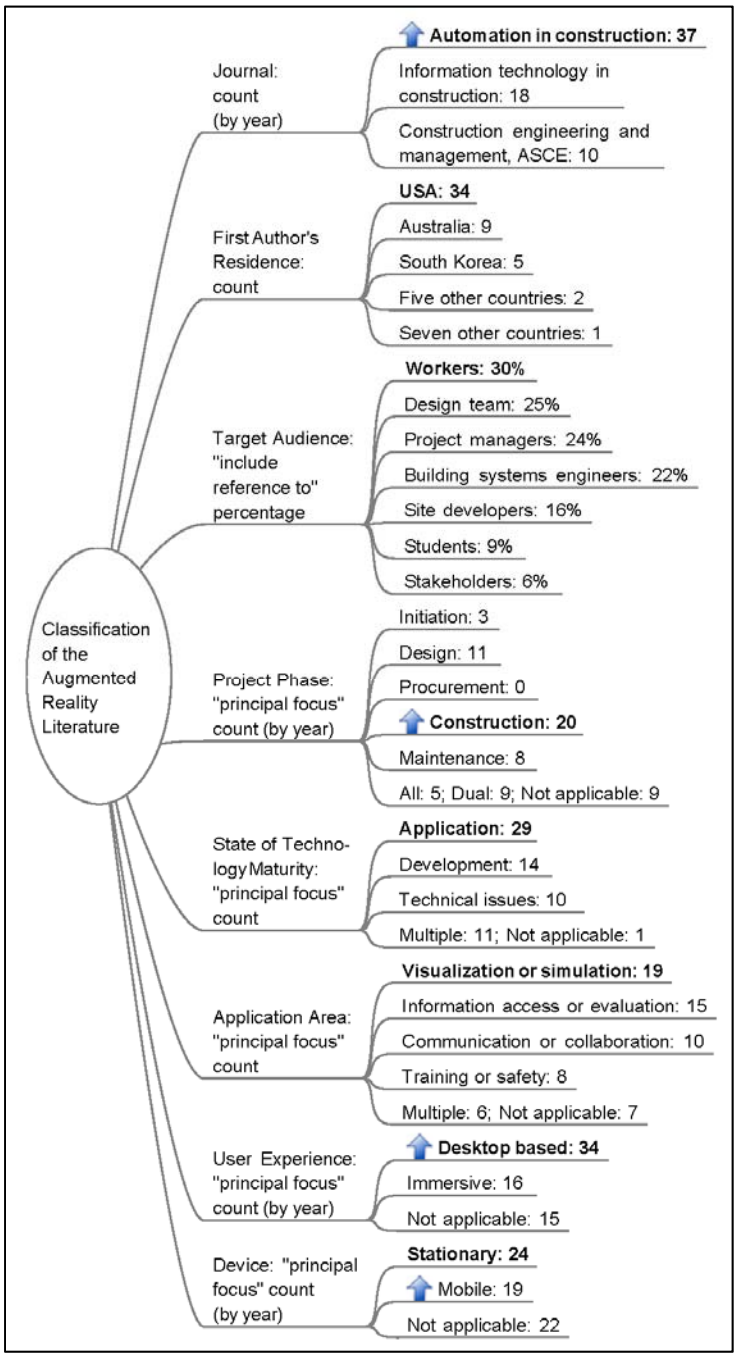


Figure 12: Literature Review Summary

- Journals: AIC has the highest overall number of articles among the journals, while ITcon has the second highest number of articles. The maximum number of AR technology articles published in these 3 journals in a single year, occurred in both 2008 and 2010.
- First authors: USA was the dominant residence of the first authors.
- Target audience: The most frequent focus is the workers (e.g., machine operators and technicians).
- Project phase: The most frequent focus is the construction phase with the design phase being next with approximately half as many articles; this is most obvious in recent years. Twenty-two articles cover two phases (e.g., initiation/design) or all phases.
- Technology maturity: The majority of articles focus on AR application demonstration in the AEC industry, with approximately half as many focusing on proposed system developments.
- Application areas: Over half of the articles had a principal focus on visualization/simulation or information access/evaluation.
- Hardware system: A spike in the number of articles focusing on mobile technologies occurred in 2010. From the perspective of immersive and desktop-based technologies most of the articles discussed desktop-based technologies.

In summary, the AR literature has increasingly focused on the demonstration of visualization or simulation applications for use during the construction phase that address issues faced by on-site workers. With respect to other target audiences, "design team," "project managers," and "building systems engineers" (as opposed to "workers") were strong contenders.

We predict expansion of AR technologies from a principal role in the construction and design phases to other phases (especially the procurement and maintenance phases) as the ability to compare virtual models with previous virtual models (and realities with previous realities) rather than the narrow focus of comparing a current construction phase reality with a final design phase model. We predict continued growth in the use of mobile devices to display (and capture) models and realities.

We also speculate that the cost of immersive hardware is, and will continue to be, an impediment to its widespread use.

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