# VIRTUAL REALITY IN THE AEC INDUSTRY: A LITERATURE REVIEW

***Rankohi, S. & Waugh, L.M.***
*University of New Brunswick, Fredericton, N.B., Canada*

***ABSTRACT:*** *In recent years, the application of Virtual Reality technologies in the Architecture, Engineering, and Construction industry has tremendously increased. However, these virtual technologies are still developing and further investigation in this research domain is essential. This article provides an extended foundation for future research by presenting a review of virtual reality technology. The review is based on articles found within four well-known journals in the AEC industry for the period 2000 to 2012 inclusive: the Journal of Automation in Construction, the Journal of Information Technology in Construction, the ASCE Journal of Computing in Civil Engineering, and the ASCE Journal of Construction Engineering and Management. The review further narrows the literature within these journals by considering only those 259 articles found through a key word search for "virtual reality." The selected journal articles are classified in different dimensions e.g., improvement focus, organization type, industry type, project phase, target audience, stage of technology maturity, technology role, and technology type. The number of articles found to match each of these dimensions is used to identify emerging trends in the literature as well as to synthesize the current state-of-the-art of virtual reality research in the AEC industry. In summary, the VR literature has increasingly focused on technology production and applications and prominent technology roles such as visualization and simulation in the construction and design phases of the AEC projects; in parallel, the literature addresses issues faced by not-on-site audiences such as design team, and on-site audiences such as project managers in building/commercial projects.*

***KEYWORDS:*** *Virtual reality, AEC industry, Construction management, Literature review*

## 1. INTRODUCTION

The construction industry, due to its nature, continuously faces with major challenges. The rapid increase in globalization makes the construction industry dependent on Information and Communication Technologies (ICT) which address complications and difficulties that arise in a global environment. Virtual reality technologies with a wide range of capabilities in information management, simulation and visualization, communication and collaboration, can significantly meet construction industry needs in this arena.

Virtual Reality (VR) is defined as an interactive computer generated environment with three-dimensional objects and locations that can simulate both planned/designed models and real world scenes. Virtual reality technology greatly benefits AEC industry in terms of providing greater site safety, enabling construction professionals to test alternative construction methods, allowing more accurate sequencing of operations, and presenting a novel way of collaboration and communication between designers, suppliers and contractors (Dawood 2009). These beneficial applications demonstrate the potential of this technology for future use in this domain.

This paper presents a literature review of virtual reality technologies in the AEC industry up to and including the year 2012. The aims of this review are (1) to synthesize the current state-of-the-art of virtual 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 arising from the literature and defined by the authors. Finally, a summary of the important points and conclusions are presented.

The remainder of this paper is as follows: our selection of four journals and subsequently 259 articles on the topic of virtual reality in the AEC industry (section 2), our review of the articles and identification of their characteristics (section 3), our definition of relevant dimensions for the classification of the articles (section 4), and our classification of the articles in the defined dimensions (section 5). Section 6 presents our conclusion. This research methodology is similar to the methodology used by Rankouhi et al. (2012).

## 2. SELECTION OF THE JOURNALS AND ARTICLES

Four diverse prominent academic journals were selected within the domain of construction engineering and management to record the evolution of VR technology in the AEC industry: the Journal of Automation in Construction (AIC), the Journal of Information Technology in Construction (ITcon), the ASCE Journal of Computing in Civil Engineering (CCE), 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.

A total of 377 articles were found in these four journals using the search phrase "virtual reality." After excluding articles that were published in 2013 (due to the lack of a full year at the time when the search was conducted) and articles such as calendars, editors Notes, subject index, and content of volume the total number of selected articles was 259. The article selection process and article's distribution among the four journals is depicted in Figure 1.

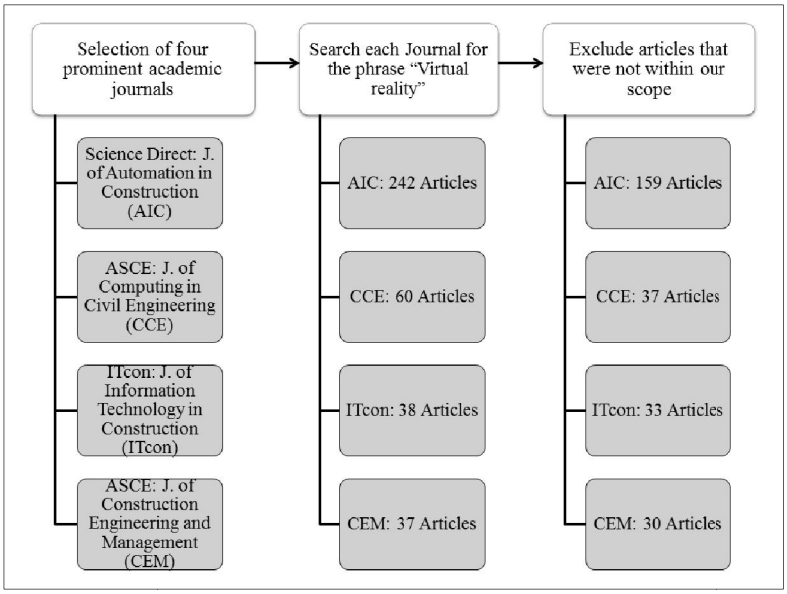



Figure 1: The process of selecting journal articles

## 3. REVIEW AND IDENTIFICATION OF THE ARTICLE CHARACTERISTICS

The number of articles by journal and by year are depicted in Figure 2. Among the four journals, AIC has the highest percentage of articles (61%), while CCE, ITcon and CEM have 14%, 13% and 12% respectively. The maximum number of articles in a single year were published in 2012 (52 articles or 20%).

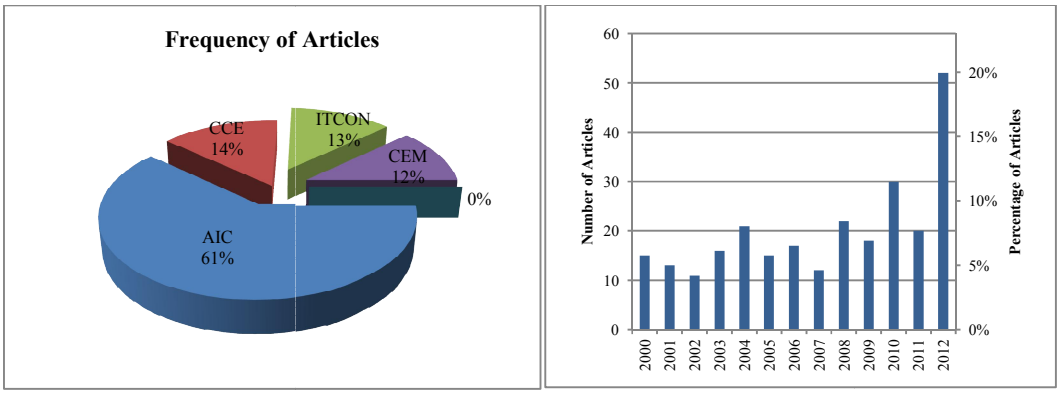



Figure 2: (a) Total percentage of articles by journal; (b) Total number of articles by year

The final characteristic identified in this section is the number of articles based on the first author's country of residence. Of 259 articles, first authors residing in the USA (65 articles) have the highest number of the articles about VR technology in the AEC industry among the other countries. The total number of articles by first author's country of residence is shown in Figure 3. Other consists of countries with one or two articles.

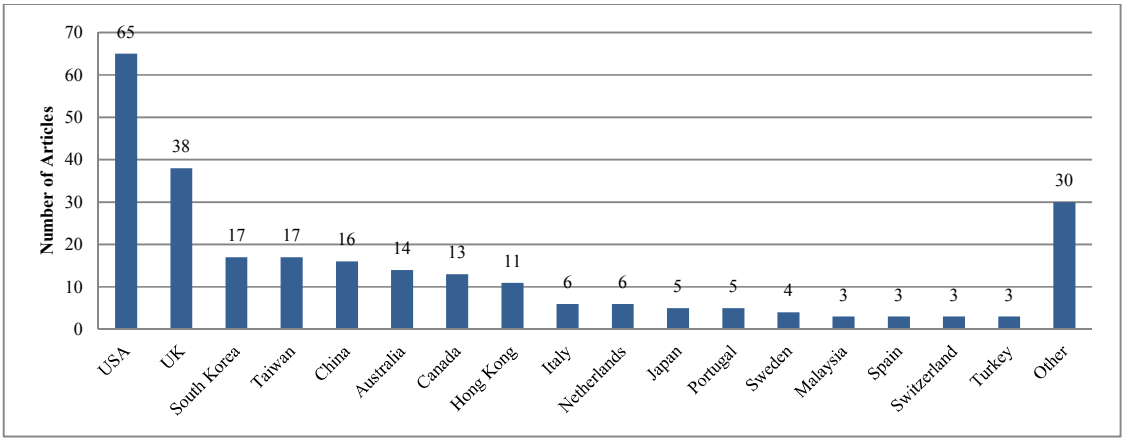



Figure 3: Total number of articles by first author's country of residence

## 4. DEFINITION OF CATEGORIES

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

Articles are classified based on their *improvement focus* in four categories: (1) industry, (2) organization, (3) AEC projects, and (4) individuals. Moreover organization category is divided into three subcategories of organization type including: (a) facility owner, (b) designer, and (c) contractor.

In the construction industry various *project types* can benefit from VR technologies including: (1) municipal/infrastructure e.g., evaluation of dynamic city models and an emission model for transportation (Aschwanden et al., 2012), (2) residential e.g., virtual reality for designing and customizing mass housing (Duarte, 2005), (3) building/commercial e.g., visualizing high-rise building construction strategies (Russell et al. 2003), (4) heavy/highway e.g., developing virtual reality system for optimized simulation of road design data (Kang L. S. et al. 2010), and (5) Industrial e.g., application areas for augmented reality in industrial construction (Shin D. H. et al. 2008).

*Project phases* or project sequences which should be completed to reach project final goals and objectives are: (1) feasibility and initiation, (2) design development, (3) procurement, contract and pre-construction, (4) construction, (5) commissioning, (6) maintenance, and (7) renovation and reconstruction.

Virtual reality technologies have a wide range of *target audiences* in the AEC industry including: (1) Design team, (2) project managers, (3) workers/machine operators, (4) building systems engineers, e.g., structural, mechanical, and electrical engineers, (5) inspector/safety officer, (6) project end users, and (7) students. If an article proposed a change in the work of one of these audiences, it was assigned to that subcategory for this classification.

From a *stage of technology maturity* perspective, the articles are divided in five categories: (1) theory, (2) framework, (3) sub-system technical issues, (4) proposed system development, (5) production and system application.

Virtual reality technologies have various roles in the construction industry. The VR *technology role* dimension is divided in seven categories as follows: (1) visualization/simulation e.g., a virtual prototyping system for simulating construction processes (Huang et al. 2007), (2) communication/collaboration e.g., improving megaprojects through collaboration with ICT (Chung et al. 2009), (3) education/training e.g., educational simulation in construction

(Nikolic et al. 2011), (4) information access/evaluation e.g., improving spatial ability using a web-based: virtual environment (WbVE) (Rafi et al. 2005), (5) safety/inspection e.g., VR-based program for conveyor belt safety (Lucas et al. 2008), (6) progress monitoring e.g., application of D4AR for construction progress monitoring (Golparvar-Fard et al. 2011), and (7) information modeling e.g., on-site building information retrieval by using projection-based augmented reality (Yeh et al. 2012).

Virtual reality utilizes different *technologies' types* in construction industry. From a user experience perspective VR environments are: (1) immersive or (2) desktop-based, i.e., non-immersive. Devices such as HMD and data-gloves create immersive VR systems, in which users feel immersed in a virtual environment just as they usually feel in a real environment. From a technology delivery perspective virtual reality devices are classified as (1) web-based or (2) standalone.

## 5. CATEGORIZATION OF THE ARTICLES

This section discusses the classification of the current state of VR technology literature in the AEC industry. The articles are classified based on their principal focus and each article is counted once (except for section 5.5 where articles may be counted more than once).

### 5.1 Improvement focus

Figure 4 illustrates the number of articles within each improvement focus category. As shown, 134 articles (52%) have a principal focus on AEC projects, while 67 articles (26%) have a principal focus on individual in construction industry. In addition, 36 articles (14%) and 10 articles (15%) have a principal focus on AEC industry and organization respectively.

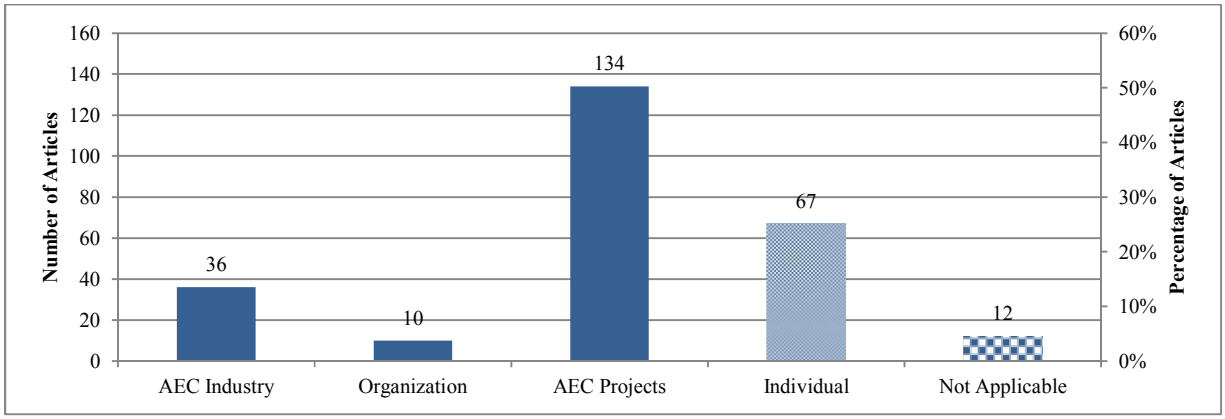



Figure 4: Number of articles by improvement level

Figure 5 presents the number of articles within each organization type category. As shown, among those 10 articles with an improvement focus on organization, five articles have a principal focus on contractor, while three articles focus on designers, and two articles focus on facility owners.

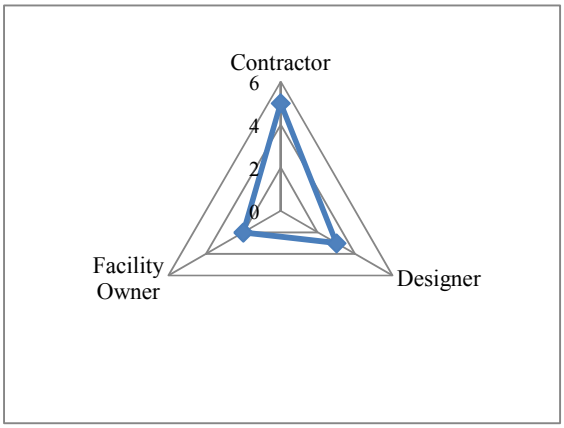



Figure 5: Number of articles by organization type

### 5.2 Industry sector

Figure 6 presents the number of articles within each industry sector dimension. As shown, 81 articles (31%) have a principal focus on building/commercial as an industry type for VR technology. Heavy/highway, municipal/infra-structure, industrial, and residential categories have 17

articles (6%), 12 articles (5%), 11 articles (4%) and 9 (3%) articles respectively. Seventy-three articles focus on multiple areas while these categories were not applicable for 68 articles.

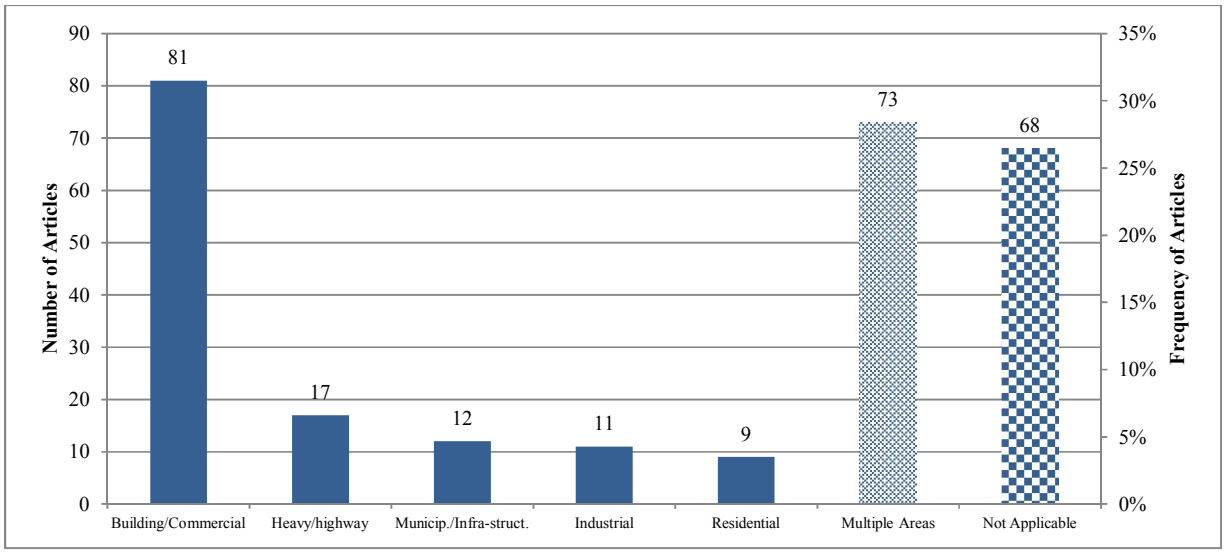



Figure 6: Number of articles by industry sector

## 5.3 Project phase

The number of the articles by project phase is depicted in Figure 7. Eighty articles (31%) have a principal focus on the construction phase and 51 articles (20%) have a principal focus on the design phase.

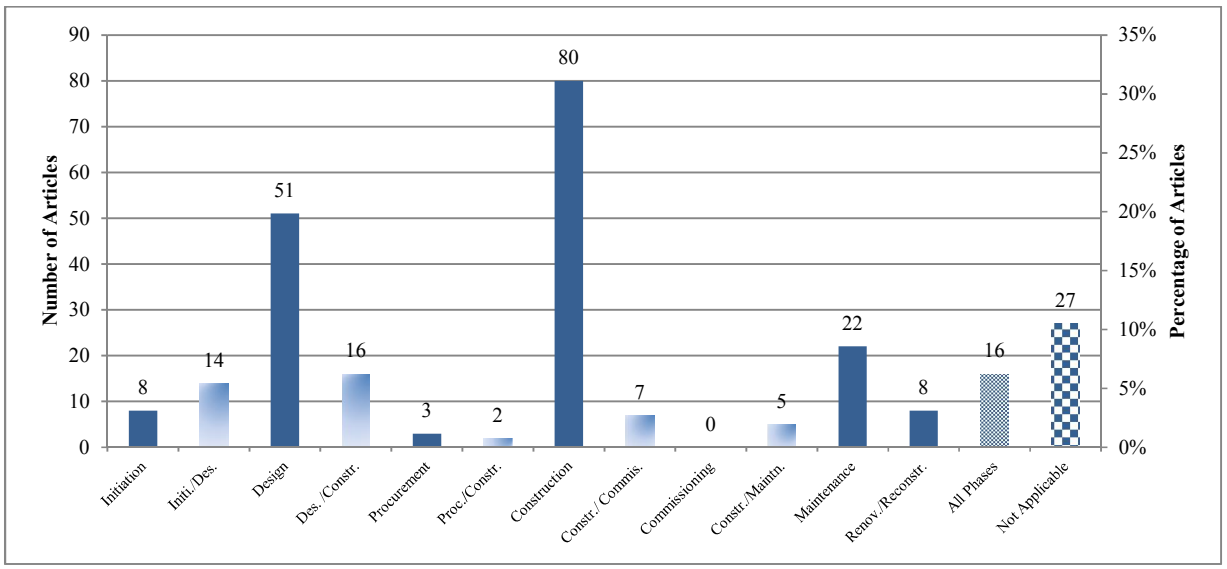
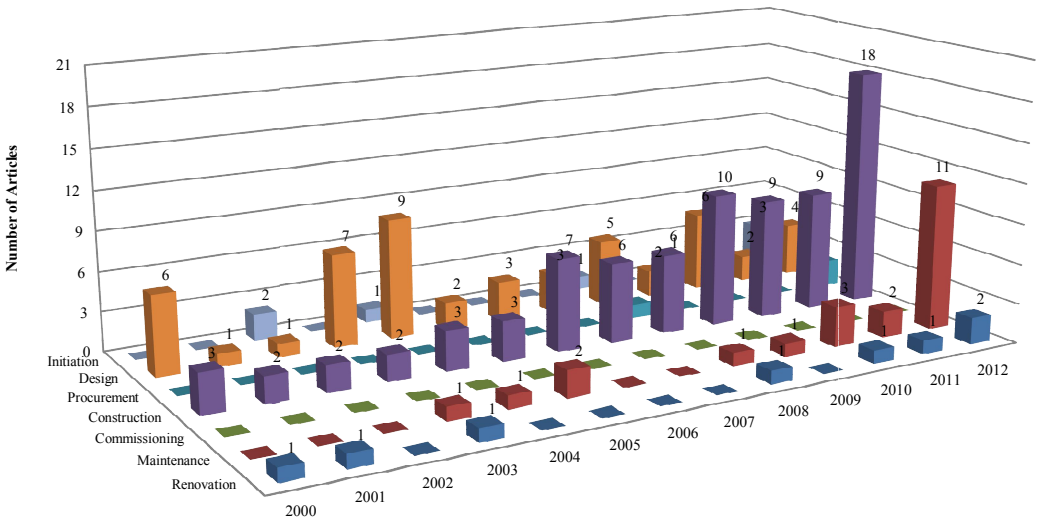



Figure 7: Number of articles by project phase

Figure 8 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 172 articles). The highest number of articles in a single year is for the construction phase in the year 2012. The focus on the maintenance phase of a project started with zero articles in 2000 and reached its highest number (11 articles) in the year 2012. Figure 7 and Figure 8 show that the highest number of articles occur in the design and construction phases of a project for VR technologies.




| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Renovation | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 2 |
| Maintenance | 0 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 1 | 1 | 3 | 2 | 11 |
| Commissioning | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Construction | 3 | 2 | 2 | 2 | 3 | 3 | 7 | 6 | 6 | 10 | 9 | 9 | 18 |
| Procurement | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 |
| Design | 6 | 1 | 1 | 7 | 9 | 2 | 3 | 3 | 5 | 2 | 6 | 2 | 4 |
| Initiation | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 3 |

Figure 8: Number of articles by project phase and year of publication

## 5.4 Target Individual Audience

In this section only 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 9 presents the percentage of articles by target audience. The results indicate that (among others) 36% of articles include reference to design team as the target audience, 33% refer to project managers, and 26% refer to worker/machine operator.

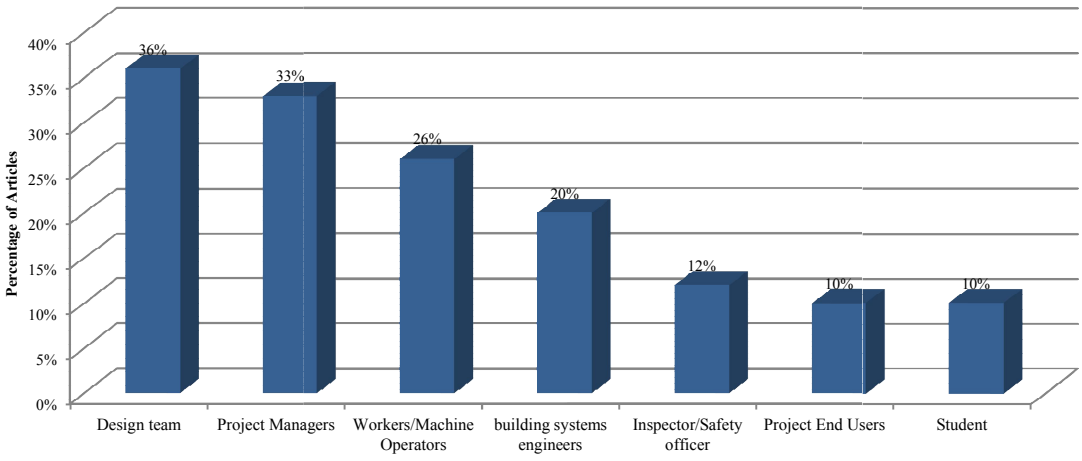



Figure 9: Percentage of articles by target audiences

## 5.5 Stage of Technology Maturity

Figure 10 illustrates the number of articles within each stage-of-technology-maturity subcategory. As shown, 78 articles (30%) have a principal focus on virtual reality application demonstration in AEC industry, while 61 articles (24%) and 35 articles (14%) have a principal focus on VR proposed system development and framework respectively. Forty-three articles have a focus on multiple areas (i.e., more than one of the previous stages); these multiple areas are typically a combination of framework and system application.

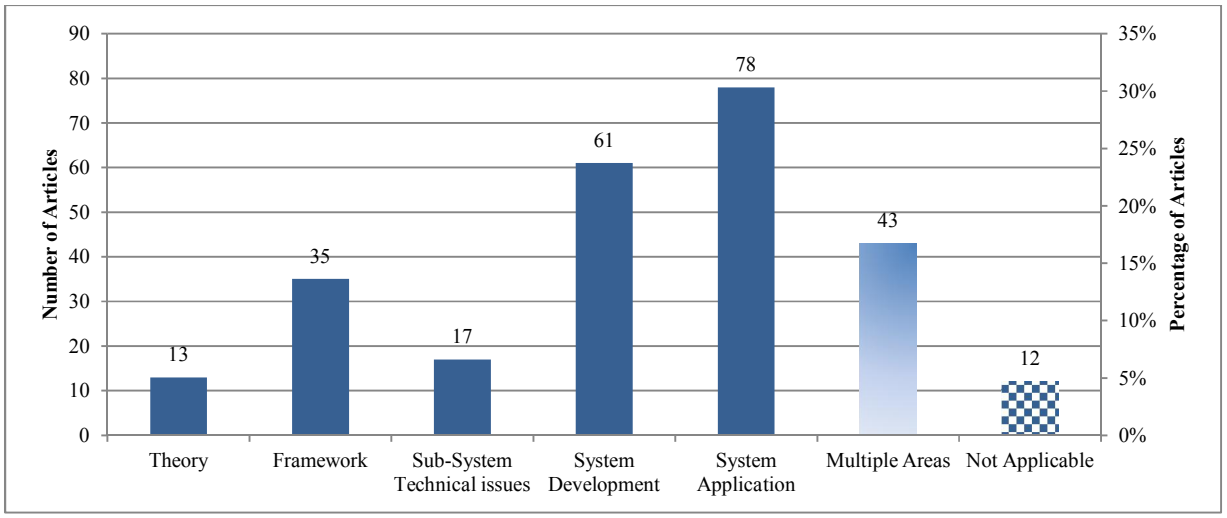



Figure 10: Number of articles by stage of technology maturity

## 5.6 Technology Role

Figure 11 presents VR "technology's role" in the AEC industry. As shown, 62 articles (24%) have a principal focus on simulation/visualization as VR technology role. Communication/collaboration, education/training, information access/evaluation, safety/inspection, progress monitoring, and information modeling have 42 articles (16%), 31 articles (12%), 30 articles (11%), 27 articles (10%), 17 articles (7%), and 16 (6%) articles respectively. Thirteen articles focus on multiple application areas while these subcategories were not applicable for 21 articles.

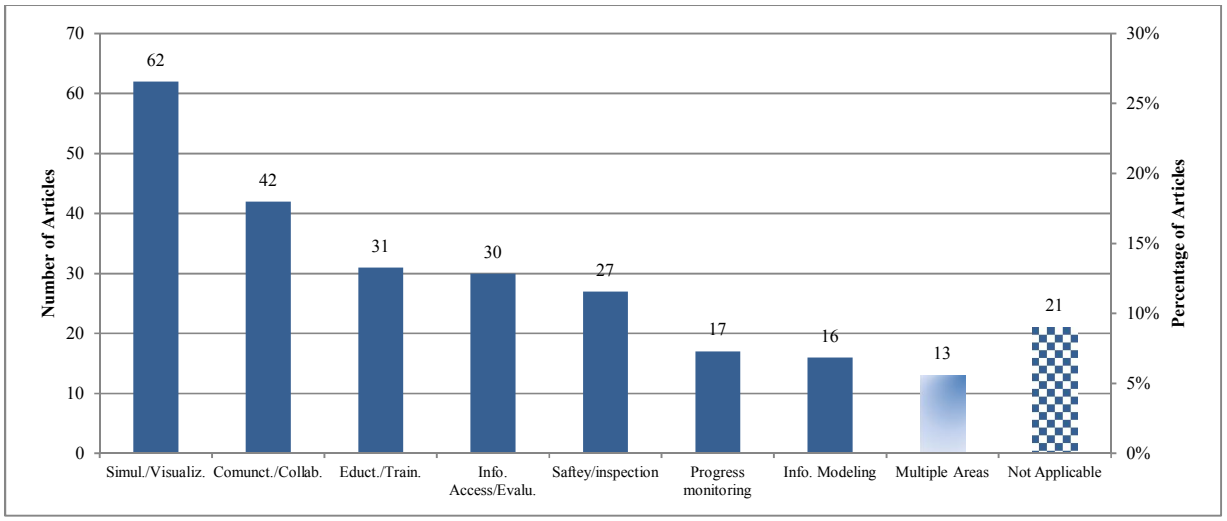
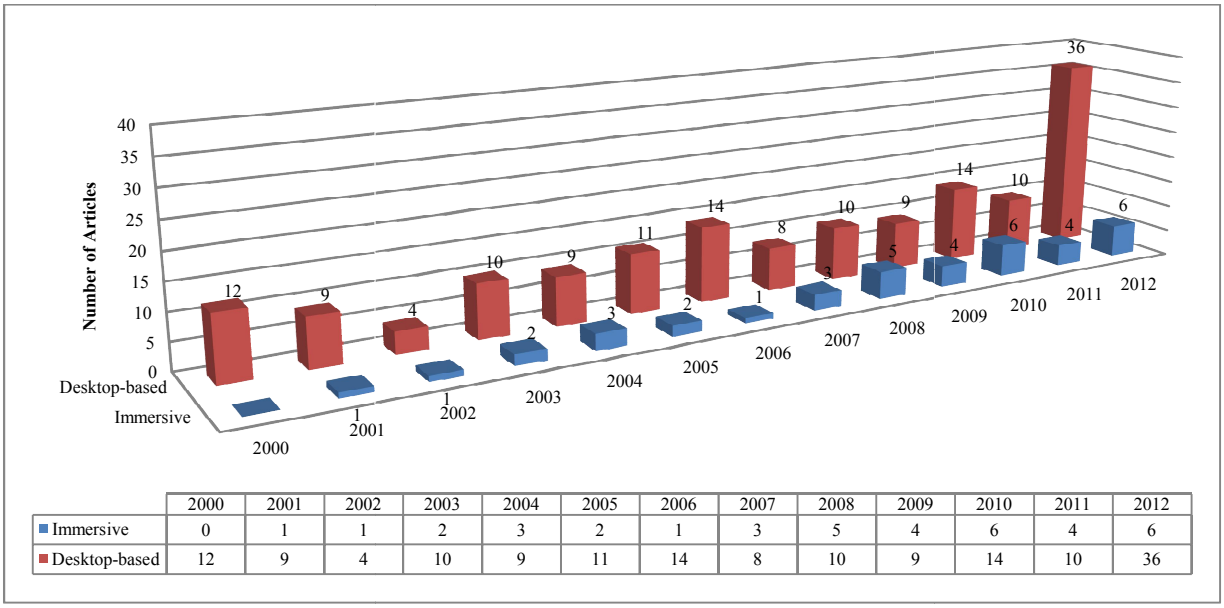



Figure 11: Percentage of articles by technology role

## 5.7 Technology type

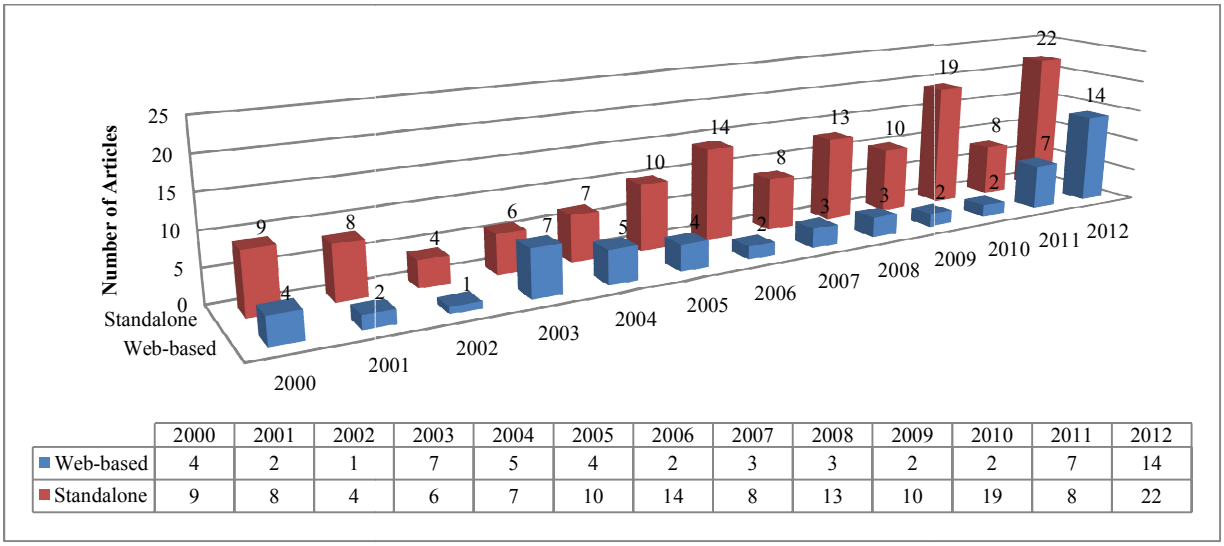
Within the technology type dimension, 38 articles (15%) had a principal focus on immersive VR technologies, 156 articles (60%) had a principal focus on desktop-based VR technologies, while 65 articles were not applicable. Figure 12 presents the number of articles with immersive and desktop-based technologies as a principal focus by year.




| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Immersive | 0 | 1 | 1 | 2 | 3 | 2 | 1 | 3 | 5 | 4 | 6 | 4 | 6 |
| Desktop-based | 12 | 9 | 4 | 10 | 9 | 11 | 14 | 8 | 10 | 9 | 14 | 10 | 36 |

Figure 12: Immersive and desktop-based VR technology by year

Figure 13 presents the number of articles within the technology type category that had a principal focus on web-based and standalone VR technologies in the AEC industry. Fifty-six articles (22%) had a principal focus on web-based VR technologies, while 138 articles (53%) had a principal focus on standalone VR technologies. Sixty-five articles (25%) were not applicable to this category.




| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Web-based | 4 | 2 | 1 | 7 | 5 | 4 | 2 | 3 | 3 | 2 | 2 | 7 | 14 |
| Standalone | 9 | 8 | 4 | 6 | 7 | 10 | 14 | 8 | 13 | 10 | 19 | 8 | 22 |

Figure 13: Web-based and standalone VR technology by year

## 6. CONCLUSION

A structured methodology was used to identify 259 articles on the topic of virtual reality from four prominent AEC industry journals. In addition to statistics on the counts of articles by year and the first author's country of residence, seven interpreted dimensions were developed to classify these articles. Figure 14 displays the counts of articles for each of the categories within these dimensions. The category with the highest count (within a dimension) is shown in bold and categories with obviously increasing trends are designated with an up arrow.

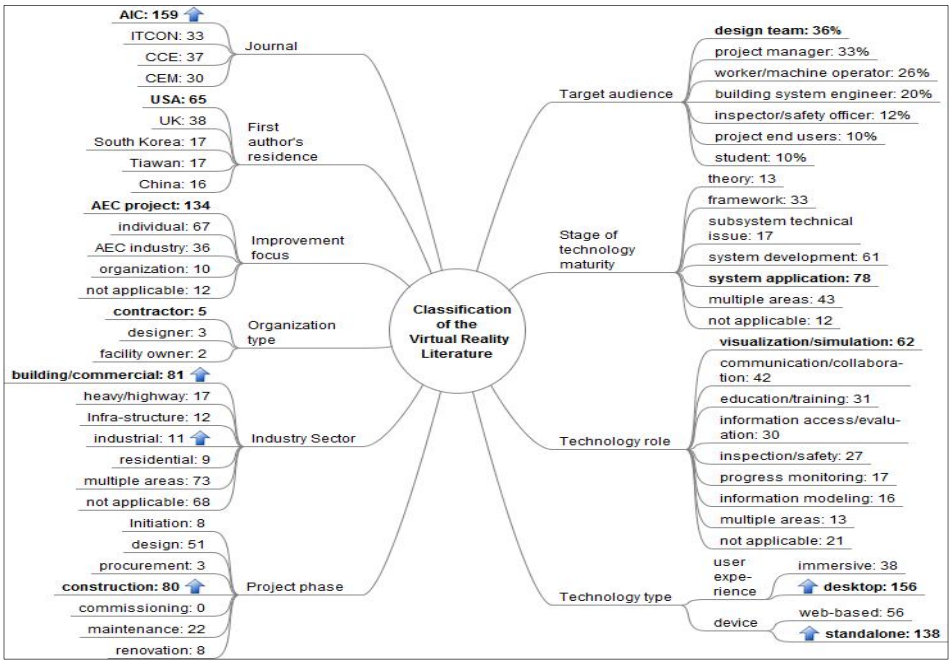



Figure 14: Literature Review Summary

The following results are concluded for the categories shown in Figure 14.

- Journals: AIC has the highest overall number of articles among the journals, while the other journals roughly split the remaining 39% of articles. The number of VR articles published in these four journals in a single year, increased abruptly in 2012 to over 50 from a maximum of 30 in previous years.
- First authors: The USA and UK (comprising 40% of all papers) were the dominant residence of the first authors.
- Improvement level: The most frequent focus was projects, rather than industry, organization, or individual.
- Industry sector: Over 30% of all articles published (or over 60% of articles that were determined to have an industry sector) focused on the building/commercial sector.
- Project phase: Although the design and construction phases dominate with approximately 20% and 30% of all articles respectively, a large number (over 20%) of articles address multiple phases.
- Target audience: Approximately one-third of the articles made reference to the design team with approximately one-third also making reference to project managers and approximately one-quarter making reference to on-site workers (in this case, the same article could be counted in more than one category).
- Stage of technology maturity: The largest number of articles focus on VR system application in the AEC industry, with the system development being next and with these two categories comprising approximately half of all the articles. Few articles had theory or technical issues as their principal focus.
- Technology role: The most frequent focus is on visualization/simulation and communication/collaboration.
- Technology type: Sixty percent of the articles had a principal focus on desktop-based VR technologies. From the perspective of web-based and standalone technologies most of the articles discussed standalone technologies.

Table 1 provides a complete list of the categories for which there was a significant and consistently-increasing trend. There were no categories for which the number of articles was consistently-decreasing over the 12 year period.

Table 1: Significant trends

| Dimension | Category | 2000 | 2012 | Factor |
|---|---|---|---|---|
| Journal | AIC | 11 | 26 | 2.4 |
| Industry sector | Building/ commercial | 5 | 20 | 4.0 |
| Industry sector | Industrial | 2 | 9 | 4.5 |
| Project Phase | Construction | 5 | 21 | 4.2 |
| Device | Standalone | 9 | 22 | 2.4 |
| Total number of articles | NA | 15 | 52 | 3.5 |

We speculate that the stage of maturity of VR technologies is the key factor influencing several of the trends concluded above; our interpretation is as follows. Although VR technologies provide proven benefits especially in the areas of visualization/simulation and communication/collaboration, these benefits are not yet widely adopted by AEC industry participants nor have they been incorporated into industry-wide workflow processes. As a result, industry participants choose to pilot (i.e., system development and application) VR technologies on a few projects rather than adopting or piloting the technology across their organization.

Building/commercial projects provide a good test bed for visualization and communication of different perspectives of a project, since these projects typically entail more complexity and need for integration than an infrastructure, heavy/highway, or residential project. However, we speculate that use on industrial projects will grow rapidly as confidence is gained. The uniform distribution of target audiences among the design team, the project management team, and on-site personnel reflects integration being the essential purpose of VR technologies. We predict continued growth in the use of internet and web-based devices to enhance integration of perspectives. We also speculate that the cost of immersive hardware is, and will continue to be, an impediment to its widespread use.

## 7. REFERENCES


Aschwanden G. D. P. A., Wullschleger T., Müller H., Schmitt G. (2012). Agent based evaluation of dynamic city models: A combination of human decision processes and an emission model for transportation based on acceleration and instantaneous speed, *J. of Automation in Construction*, Elsevier, Vol. 22, 81–89.

Chung J. K. H., Kumaraswamy M. M., Palaneeswaran E. (2009). Improving megaproject briefing through enhanced collaboration with ICT, *J. of Automation in Construction*, Elsevier, Vol. 18, 966–974.

Dawood N. (2009). VR-Roadmap: a vision for 2030 in the built environment, *J. of Information Technology in Construction,* ITcon, Vol. 14, 489-506.

Duarte P. J. (2005), A discursive grammar for customizing mass housing: the case of Siza's houses at Malagueira, *J. of Automation in Construction*, Elsevier, Vol. 14, 265–275.

Golparvar-Fard M., Peña-Mora F., and Savarese S. (2011). Integrated sequential as-built and as-planned representation with $D^4AR$ tools in support of decision-making tasks in the AEC/FM industry, *ASCE J. of Construction Engineering and Management*, ASCE, Vol. 137, No. 12, 1099-1116.

Huang T., Kong C. W., Guo H. L., Baldwin A., Li H. (2007). A virtual prototyping system for simulating construction processes, *J. of Automation in Construction*, Elsevier, Vol. 16, 576–585.

Kang L. S., Moon H. S., Dawood N., Kang M. S. (2010), Development of methodology and virtual system for optimised simulation of road design data, *J. of Automation in Construction*, Elsevier, Vol. 19, 1000–1015.

Lucas J., Thabet W., Worlikar P (2008), A VR-based training program for conveyor belt safety, *J. of Information Technology in Construction,* ITcon, Vol. 13, 381-407.

Nikolic D., Jaruhar S., Messner J. I. (2011). Educational Simulation in Construction: Virtual Construction Simulator, *ASCE J. of Computing in Civil Engineering,*, ASCE, Vol. 25, No. 6, 0887-3801

Rafi A., Anuar K., Samad A., Hayati M, Mahadzir M. (2005). Improving spatial ability using a Web-based: Virtual Environment (WbVE), *J. of Automation in Construction*, Elsevier, Vol. 14, 707–715

Rankouhi M. S., Waugh L. M. (2012). Augmented reality technologies for AEC projects: A literature review. 12th International Conference on Construction Applications of Virtual Reality, Taipei, Taiwan

Russell A., Staub-French S., Tran N, Wong W. (2009). Visualizing high-rise building construction strategies using linear scheduling and 4D CAD, *J. of Automation in Construction*, Elsevier, Vol. 18, 219–236.

Shin D. H., Dunston P. S. (2008), Identification of application areas for Augmented Reality in industrial construction based on technology suitability, *J. of Automation in Construction*, Elsevier, Vol. 17, 882–894.

Yeh K. C., Tsai M. H., Kang S. C. (2012). On-Site Building Information Retrieval by Using Projection-Based Augmented Reality, *ASCE J. of Construction Engineering and Management*, ASCE, Vol. 26, No. 3, 342-355.