A Literature Review on the Comparison Role of Virtual Reality and Augmented Reality Technologies in the AEC Industry

S. Rankouhi, and L. M. Waugh
Department of Civil Engineering, University of New Brunswick

Abstract: The application of Virtual Reality (VR) and Augmented Reality (AR) technologies in the Architecture, Engineering, and Construction industry has tremendously increased. These technologies play various roles in different stages of the construction projects, such as simulating construction performance, comparing as-built and as-planned statuses of projects, pre-empting schedule disputes, improving collaboration opportunities, and training for similar projects. This article provides an extended foundation for future research by presenting a review of the comparison role of virtual reality and augmented reality technologies. The review is based on articles found within four well-known journals in the AEC industry for the period 2000 to 2011 inclusive. The selected journal articles are classified in different comparison categories e.g., comparison modes, comparison by project phase, comparison purpose, comparison performer, comparison tools and techniques. 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 comparison role of VR and AR research in the construction industry. In summary, the literature has focused on the comparison role and its prominent purpose such as progress monitoring in the construction phases of a project; in parallel, the literature addresses issues faced by on-site individual audiences such as project managers and workers/technicians.

1 INTRODUCTION

In recent years, researchers have identified many beneficial capabilities for Virtual Reality (VR) and Augmented Reality (AR) technologies in the Architecture, Engineering, and Construction (AEC) industry including virtual site visits, comparing as-planned and as-built statuses of projects, pre-empting schedule disputes, enhancing collaboration opportunities, and planning/training for similar projects. These technologies have the ability to simulate and visualize as-planned and as-built statuses of the project in one place, allowing a user to easily compare and find discrepancies.

Within the various roles of VR and AR technologies, this paper focuses on the comparison role of these technologies since this is our future research direction. This paper provides insight on how project participants compare different dimensions of the work using virtual and augmented technologies. A thorough literature review was conducted to gather information on how researchers and practitioners have used, or have proposed use of different technologies to compare the statuses of projects.

This literature review encompasses the year 2000 through 2011 inclusive. The aims of this review are (1) to synthesize the current state-of-the-art of the comparison role of virtual and augmented reality technologies for construction projects, and (2) to identify key areas in which comparison could significantly impact the AEC industry. These aims are accomplished by classifying the literature in categories defined by the authors. Finally, a summary of the important points and conclusions are presented. The article classification in this review is based on author's perception; other researchers might have categorized the articles differently.

As indicated in Figure 1, this paper describes: our selection of journals and articles (section 2), our review and selection of articles with a focus on the comparison role (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 3 and section 4 iterate until the categories are defined. Section 6 presents summary and implications. This research methodology is similar to the methodology used by Rankouhi et al. (2012) on the topic of augmented reality in the AEC industry.

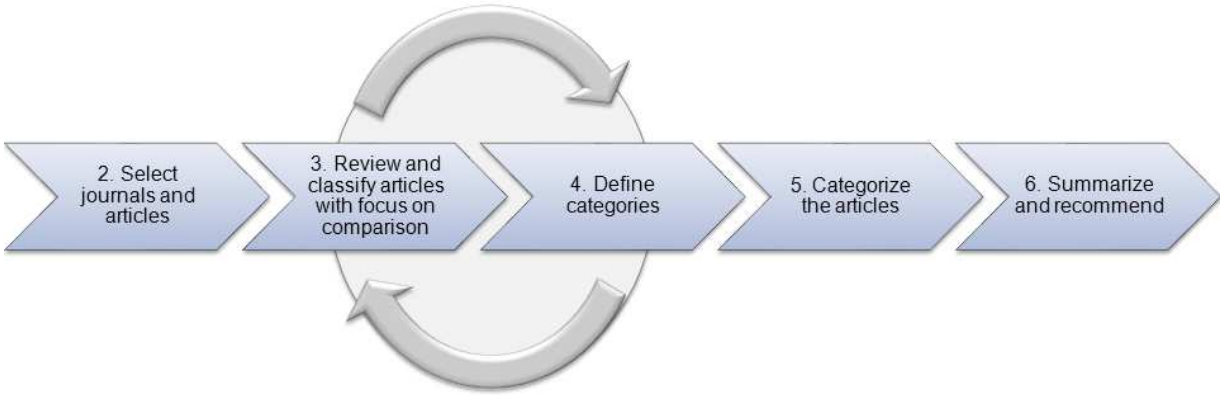


Figure 1: Research Methodology

2 SELECTION OF THE JOURNALS AND ARTICLES

2.1 Journal Selection

Four journals were selected to comprehensively capture the domain of construction engineering and management and to assess the comparison role of VR and AR technologies in the AEC industry: the Journal of Automation in Construction (AIC), the Journal of Information Technology in Construction (ITcon), the ASCE Journal of Construction Engineering and Management (CEM), and the ASCE journal of Computing in Civil Engineering (CCE). Selection of these journals is based on their prominence in the English language field of information technologies in construction engineering and management research.

2.2 Article Selection

Article selection entailed three phases. In phase I, each journal was searched using the search phrases "virtual reality" and "augmented reality." In the remainder of this paper the term VR and AR are often used to delineate between the articles found with each search phase. In phase II, articles were excluded that had been published before 2000 and after 2011 (due to the lack of a full year in summer 2012, when the search were conducted) and articles such as Calendars, Editors Notes, Prefaces, Subject Index. In phase III, the articles from phase II were reviewed and articles which had a focus on the comparison role of virtual and augmented reality technologies were selected. The few articles that were found by both search phrases have been counted once. The total number of articles selected during each phase is shown in Table 1.

Table 1: Frequency of VR and AR Articles in each Selection Phase

Journal	Phase I		Phase II		Phase III	
	VR	AR	VR	AR	VR	AR
AIC	216	61	133	37	3	13
CCE	48	24	25	12	1	6
CEM	32	12	25	10	5	5
ITCON	27	21	24	18	1	3
Subtotal	323	118	207	77	10	27
Total	**441**		**284**		**37**	

3 REVIEW AND CLASSIFICATION OF THE ARTICLES WITH A FOCUS ON COMPARISON ROLE

Among all the articles in the four journals, only 13% (10% AR + 3% VR) of the articles focused on the comparison role of VR and AR technologies in construction industry. Virtual reality articles that did not focus on the comparison role comprise the highest percentage of the articles (69%), while augmented reality articles that did not focus on the comparison role comprise 18%. Figure 2 presents the proportions of the articles versus focus on the comparison role.

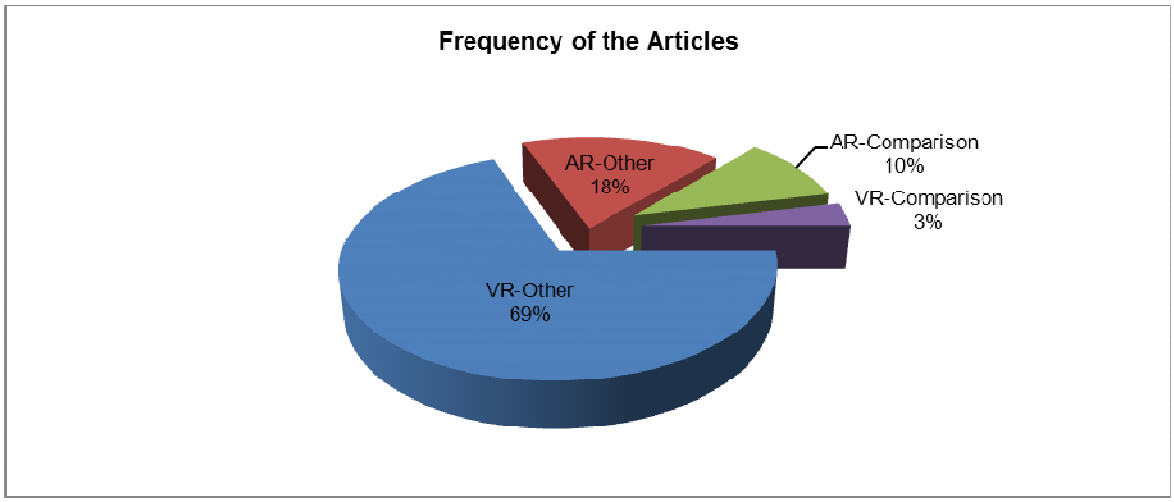
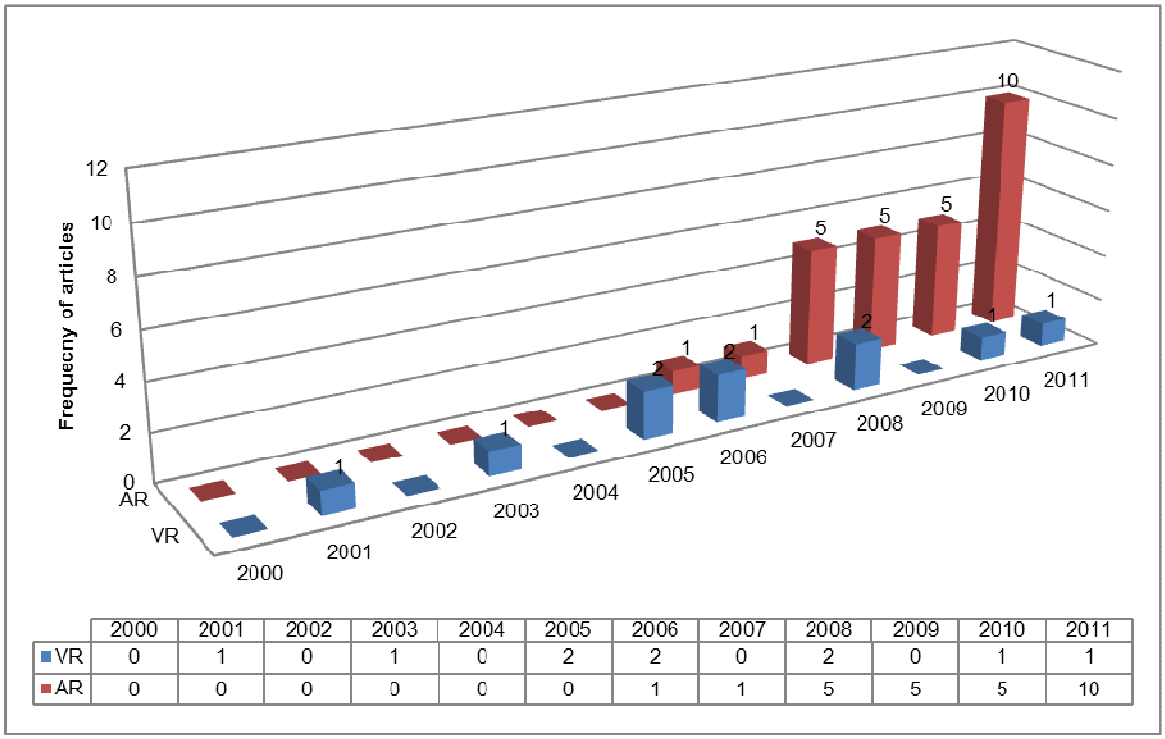


Figure 2: The Total Number of the Articles

Figure 3 presents the number of comparison articles by year of publication. The chart shows high numbers of AR articles for the year 2011.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
VR	0	1	0	1	0	2	2	0	2	0	1	1
AR	0	0	0	0	0	0	1	1	5	5	5	10

Figure 3: Number of Articles by Year of Publication

4 DEFINITION OF DIMENSIONS

To better understand and further segregate the literature, different dimensions are defined for use in this paper; in subsequent section of this paper each article is compared to these defined dimensions for identification of its principal focus area or in the case of section 5.5 we counted each of the 37 articles once or prorated each articles over several categories to determine the number of articles including reference to that dimension.

From a comparison modes perspective, the articles are divided into three categories: (1) reality versus reality, e.g., visualizing the 3D as-built point cloud of a concrete column and its periphery at the construction site (Golparvar-Fard al., 2011), (2) model versus reality, e.g., integrating sequential as-built and as-planned representation with D4AR tools (Golparvar-Fard et al. 2011), and (3) model versus model, e.g., the application of EVE (Experimental Virtual Environment) in the construction project of a new lecture hall (L. Savioja et al., 2003).

The life cycle of a construction project consists of a sequence of project phases to be completed in order to reach project goals and objectives. These phases are defined by Knutson et al. (2008) as: (1) initiation, (2) design, (3) procurement, (4) construction, (5) commissioning, and (6) maintenance.

Due to the collaborative nature of construction projects, different construction participants could use VR and AR technologies to compare construction models and realities. To classify the articles based on comparison performer the following categories are used: (1) design team, (2) project managers, (3) workers/technicians, (4) inspectors, and (5) project end users.

Construction participants use VR and AR technologies to compare different statuses of a project for different purposes as follows: (1) progress monitoring, (2) defect detection, (3) validating the model, (4) updating the model, and (5) evaluating the model.

Using virtual and augmented reality technologies, project participants use different tools and techniques to compare the statuses of a project. These VR and AR tools and techniques are categorized as follows: (1) manual comparison, e.g., exploring defect information using the digital workbench (Dong et al. 2009), (2) different windows or different frames within a window (split-screen), e.g., object-based interior construction progress monitoring system (Roh et al. 2010), (3) different hardware, e.g., different computers, smart boards and touch screens such as augmented reality system for urban planning review (Wang et al., 2008), and (4) automated overlay, e.g., D4AR - a 4-dimensional augmented reality model for automating construction progress monitoring data collection (Golparvar-Fard et al., 2009).

5 CATEGORIZATION OF THE ARTICLES

This section discusses the categorization of the current state of the comparison role of VR and AR technologies in the AEC industry. The articles are classified based on their principal focus and each article is counted once.

5.1 Comparison Modes

Figure 4 illustrates the number of articles within each comparison mode category. As shown, 24 articles (17 AR articles + 7 VR articles) have a principal focus on comparing a model with a reality, 7 articles (6 AR articles + 1 VR article) have a principal focus on comparing a reality with a reality, and 6 articles (4 AR articles + 2 VR articles) have a principal focus on comparing a model with another model.

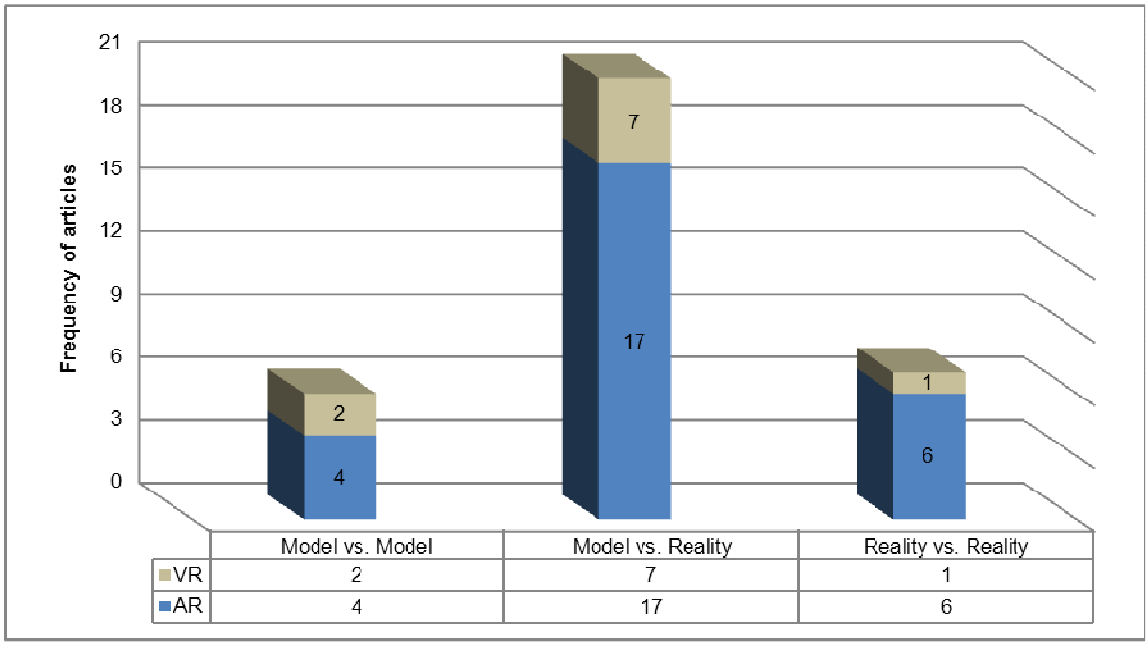


Figure 4: Number of Articles by Comparison Modes

5.2 Comparison by Project Phase

The number of the articles by project phase is depicted in Figure 5. Twenty-four articles have a principal focus on the construction phase, 6 articles have a principal focus on the maintenance phase, 6 articles have a principal focus on the design phase, and one AR article has a focus on initiation phase. There are no articles with a principal focus solely on the procurement and commissioning phase, but it is worth noting that some articles did discuss procurement and commissioning phases; however, they did not have a principal focus on these phases.

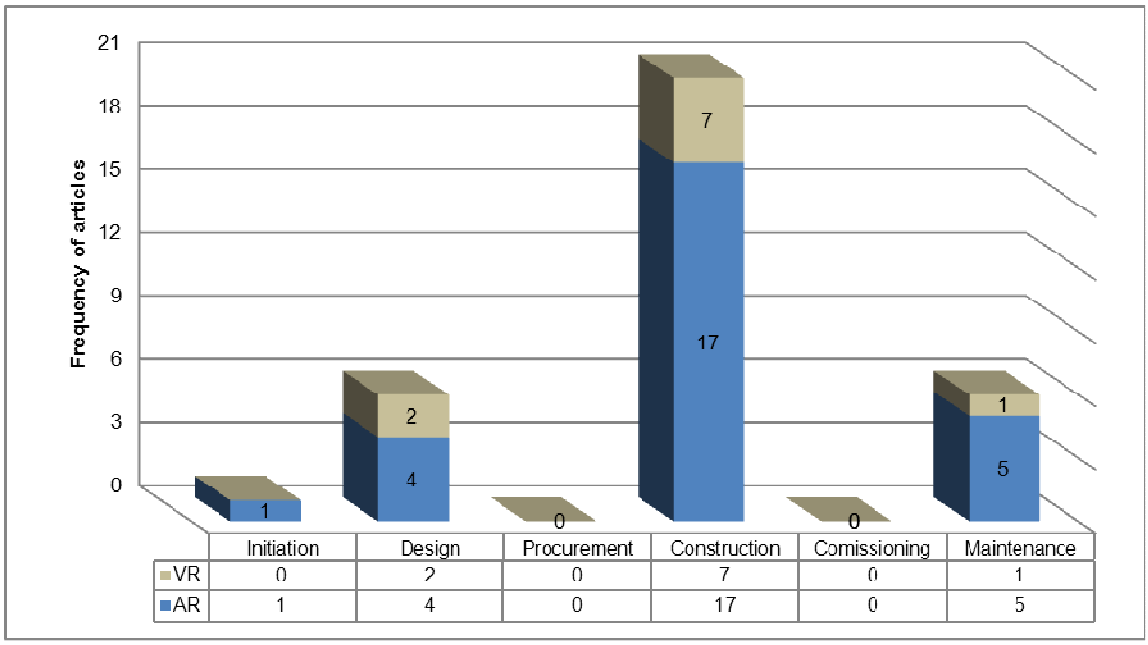


Figure 5: Number of Articles by Project Phase

5.3 Comparison Performer

Figure 6 illustrates the number of articles based on who the article referred to as the person performing the comparison. As shown, project managers with 15 articles, are the major comparison performers in the AEC industry. The design team with 8 articles, workers/technicians with 6 articles, inspectors with 6 articles, and project end users with 2 articles were the other comparison performers in the AEC industry.

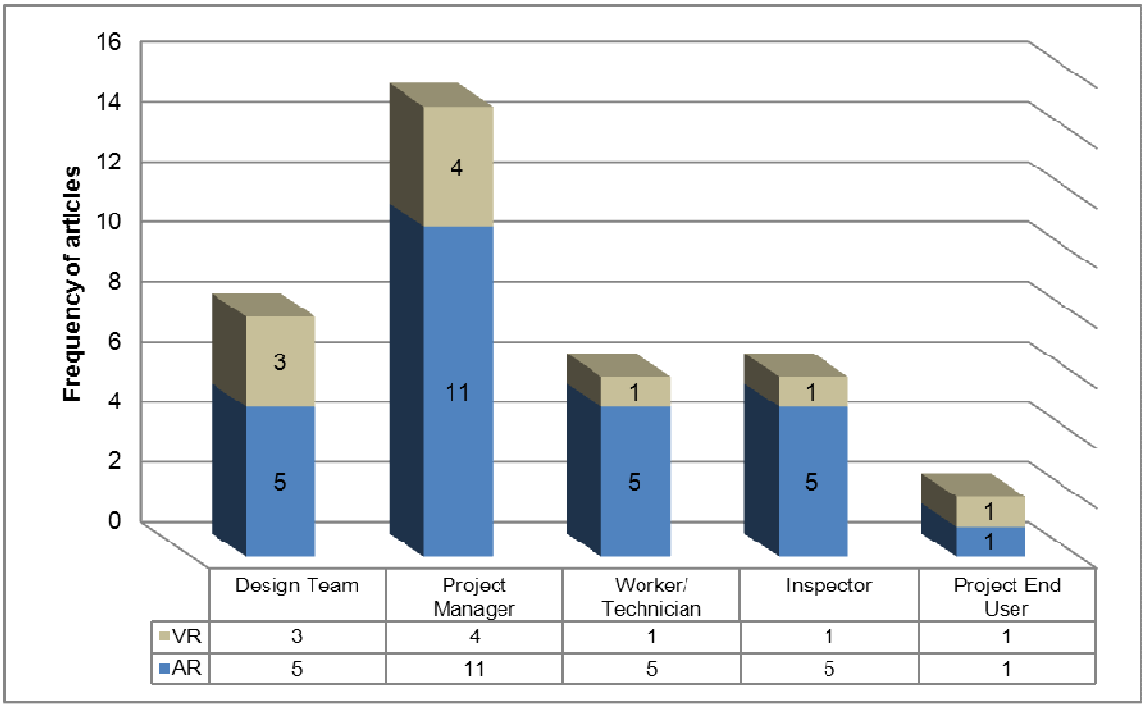


Figure 6: Number of Articles by Comparison Performer

5.4 Comparison Purpose

The number of articles by comparison purpose is depicted in Figure 7. Seventeen articles have a principal focus on progress monitoring, 6 articles have a principal focus on evaluating the model, 6 articles have a principal focus on validating the model, 5 articles have a principal focus on defect detection, and 3 articles have a principal focus on updating the model.

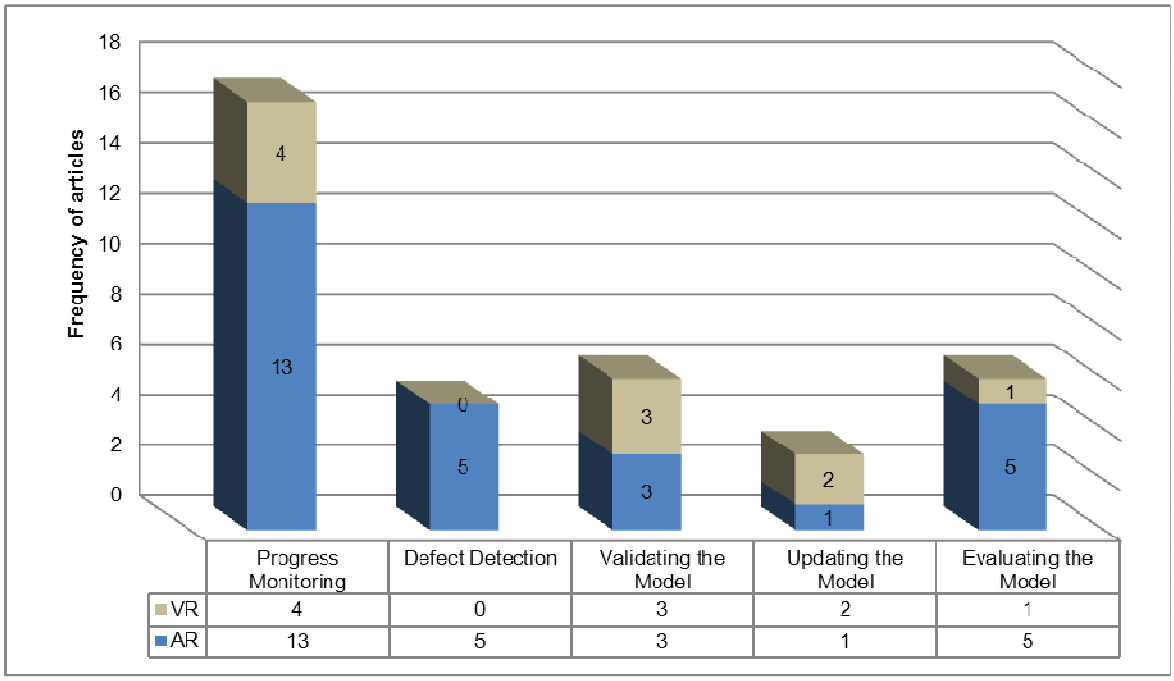


Figure 7: Number of Articles by Comparison Purpose

Within the articles with a focus on progress monitoring, 76% indicated that project managers were the comparison performer, while 18% indicated workers/technicians, and 6% indicated inspectors. In each case the comparison performer compared as-planned and as-built statuses of the project to monitor construction.

5.5 Comparison Tools and Techniques

In this section instead of giving the number of articles with a "principal focus on" a category, we report the number of articles "including reference to" that category, since in this section each article may refer to more than one category. However when an article include reference to multiple tools or techniques we prorate the article over these tools and techniques as shown in Table 2.

Table 2: Frequency of Articles by Comparison Tools and Techniques

	Different Hardware	Different Windows	Automated Overlay	Manual Comparison	**Sum**
Reality Vs. Reality	0.33 {(1/3)}	0.83 {(1/2)+(1/3)}	3.83 {3+(1/2)+(1/3)}	2	7
Model Vs. Reality	8	3.5 {3+(1/2)}	8.5 {8+(1/2)}	3	23
Model Vs. Model	2.67 {2+(2/3)}	1.67 {1+(2/3)}	1	0.67 {(2/3)}	6
Sum	11	6	13.33	5.67	36

Figure 8 display the results of Table 2. The results indicate that two-thirds of the articles (11+13.33 articles) use either the automated overlay technique or the different hardware tool to perform comparison; and these categories are mostly used to compare models versus realities.

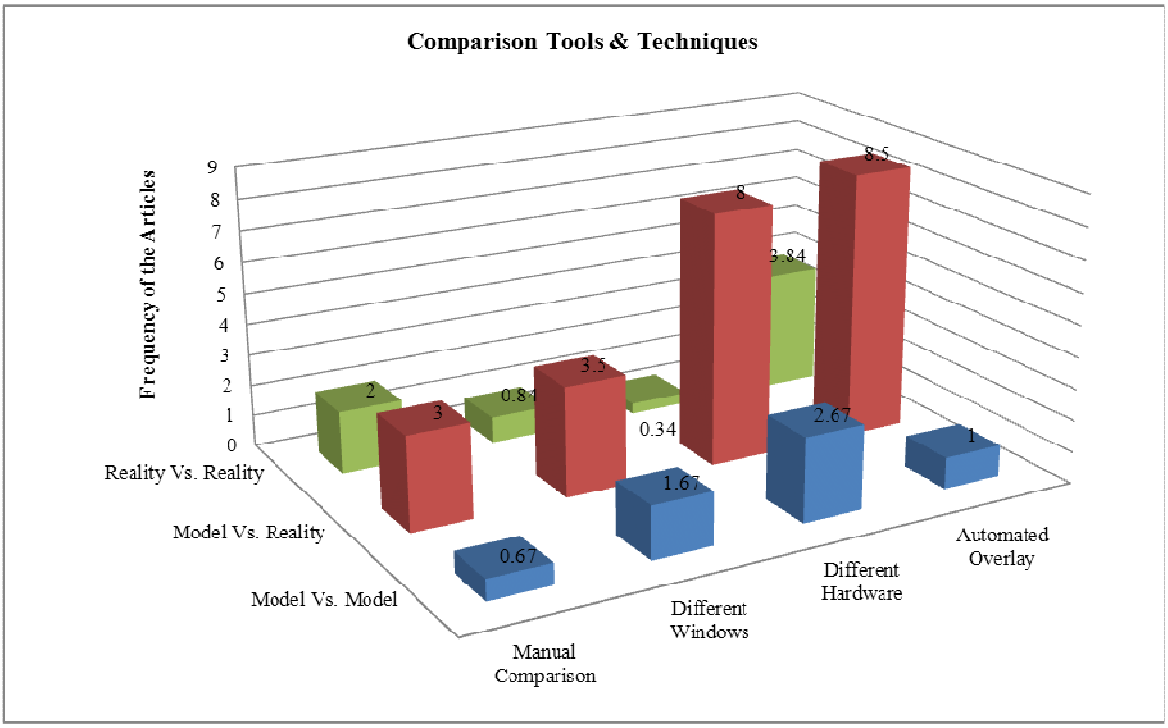


Figure 8: Frequency of Articles by Comparison Tools and Techniques

6 SUMMARY AND RECOMMENDATIONS

A structured methodology was used to identify 37 articles with a focus on the comparison role of virtual and augmented reality from four prominent AEC industry journals. Five interpreted categories were developed for categorization of these articles: comparison mode, project phase, comparison performer, comparison purpose, and comparison tools and techniques. Articles were classified and insight on the current state of the comparison role of AR and VR technologies in AEC industry research was gained.

Only 13% of virtual reality and augmented reality literature is focused on the comparison role in construction industry, but the trend toward using these technologies to compare different statuses of construction projects has increased rapidly in recent years.

In summary, the majority of articles focused on the application of virtual and augmented reality technologies for project managers to compare model versus realities with automated overlay techniques for monitoring progress during construction phase of the project. Specific results are described below and are further summarized in Figure 9.

- Comparison mode: The most frequent focus is the model versus reality mode which includes approximately half of the articles.

- Project phase: The most frequent focus is the construction phase with approximately 50% of all articles. The maintenance phase and design phase are next highest. There were no article for which the procurement or commissioning phase was the principal focus.

- Comparison performer: The majority of articles focus on project managers with approximately 40% of all the articles.

- Comparison purpose: Approximately half of the articles had a principal focus on progress monitoring as the reason to compare different project statuses using virtual and augmented technologies.

- Comparison tools and techniques: The majority of articles refer to using different hardware and automated overlay methods for comparing a model with a reality.

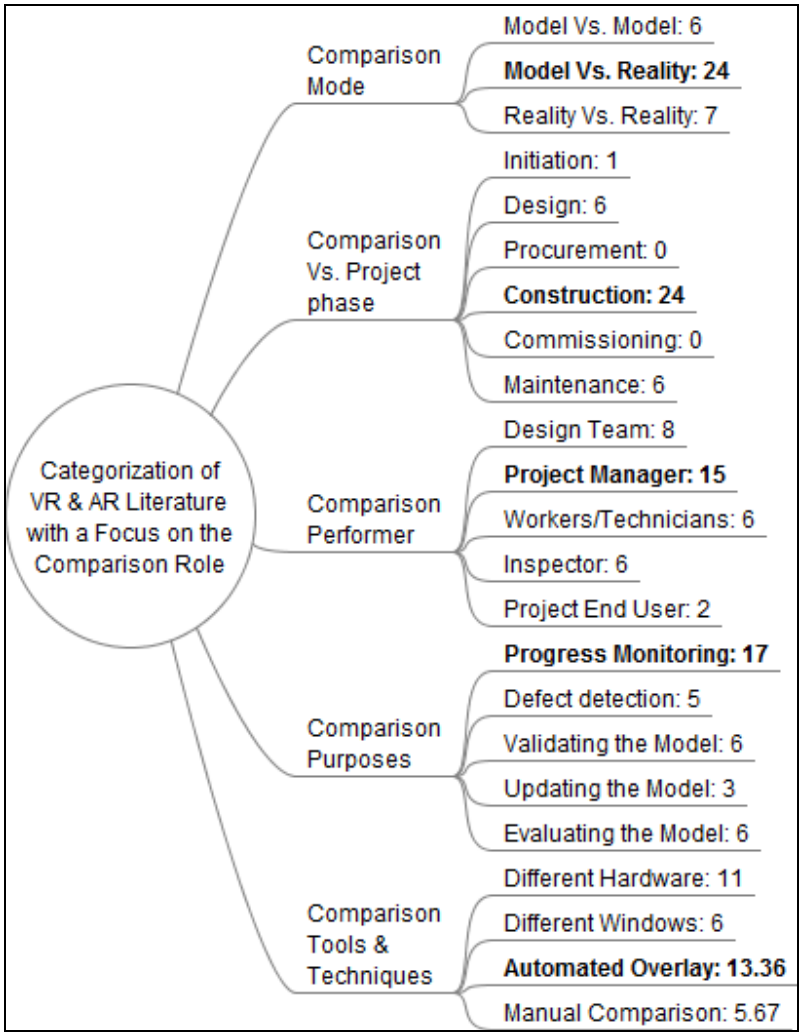


Figure 9: Literature Review Summary

Our recommendation for researchers is that there is an opportunity for more research in the area of using VR and AR technologies during the procurement phase of construction projects, as literature shows a lack of research in these phases of project.

We recommend that construction practitioners test the software and hardware available; in particular to monitor progress during the construction phase by comparing a model with a reality. Comparison techniques such as a split screen interface or automated overlay software are developing quickly. We predict continued growth of comparison role of AR and VR technologies from the construction phase to other phases with the need to rely on walking around the construction site with plan in hand to compare as-built and as-planned statuses will slowly disappear.

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