AUGMENTED AND VIRTUAL REALITY IN COMBINATION WITH UNMANNED AERIAL VEHICLES: A LITERATURE REVIEW

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Abstract:

Augmented and Virtual reality technology has grown rapidly in recent years, as well as the application of Unmanned Aerial Vehicles in civil engineering. The documentation of projects delivers wide spread benefits and the addition of aerial images to current documentation processes shows potential from the literature. The potential in aerial documentation inspired the authors to conduct a literature review on UAVs and how they may be integrated with a virtual realty – as built interface. This article focuses on the state of the art application of UAVs to capture aerial images in various civil engineering fields such as construction management and transportation. Current civil engineering use of UAV aerial images includes construction management, transportation, surveying, and post-disaster. VRDoc, D^4AR, and VIRCON are interfaces that can provide up to date documentation of a project. VRDoc provides users the ability to complete virtual site visits, detailed photographic documentation, the opportunity to resolve project conflicts, and training opportunities. These interfaces have shown success in industry applications; further improvement, testing, and implementation are required. Current literature and how the application of UAVs can be integrated with UAVs are discussed, along with the authors future research objectives and recommendations.

1 Introduction

This is a literature review of unmanned aerial vehicles (UAV) in combination with augmented or virtual reality in civil engineering. The literature review presents a framework for augmented and virtual reality in the architecture, engineering, and construction (AEC) industry. Along with the categorization of the current literature in this section, the state of the art applications of UAVs to capture aerial images in civil engineering are presented (Section 2), interfaces of augmented and virtual reality are discussed (Section 3), as well as a discussion of the literature (Section 4).

Augmented reality (AR) provides the ability for users to gain an integrated understanding of AEC projects by combining 3D virtual models with real world images. Rankouhi and Waugh (2012) completed a literature review of AR technology in AEC projects that classified the current literature in the following categorizes: target audience, project phase, state of technology/maturity, application area, user experience, and device (Figure 1). Articles were found between 1999 to the end of year 2011 from three different academic journals. Of particular interest for future research is that *workers* were found to be the largest single target audience, rather then the *design team* or *project managers*, however when combined, the *design team* and *project managers* accounted for 49% of the target audience. With respect to an application area, *visualization or simulation* was found to be the top research focus of the literature reviewed, with *communication or collaboration* being the category which was third in respect to the number of articles classified. Finally, *stationary* was found to be the top research area within the device category, next being *mobile device*, however *mobile device* began a spike in frequency.

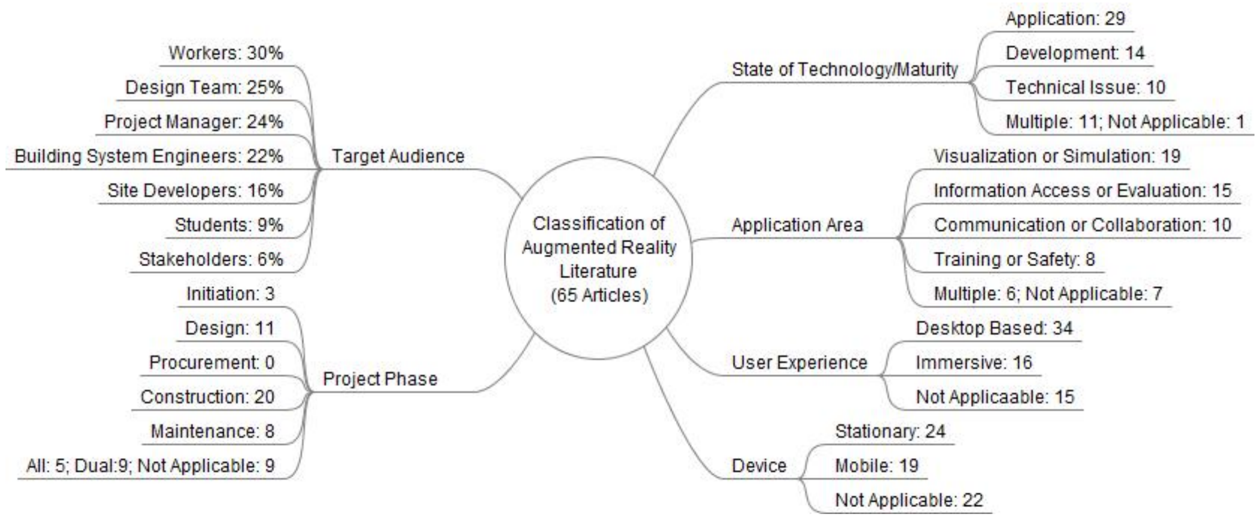

Figure 1: Augmented Reality Framework, Recreated from Rankouhi & Waugh (2012)

As stated by Rankohi and Waugh (2014) in their literature review of virtual reality (VR) in the AEC industry, **virtual reality** provides users with the ability to interact within a computer generated environment or real world scenes that are inclusive of three-dimensional objects and locations. Similar to their literature review on AR, the literature was classified into the following categories: improvement focus, project types, project phase, target audiences, technology maturity, technology role, and technology types (Figure 2). The first three of these categories are new categories from the AR literature review. Articles were found from the year 2000 to 2012 inclusive, in four different prominent journals. The bolding in Figure 2 represents items of interest for the author, such as the target audience top focus, which was the *design teams* with *project mangers* having a secondary focus. The highest number of articles for the technology role focused on *visualization/simulation* with *communication/collaboration* being the second highest focus and *progress monitoring* having limited focus. The variation between augmented and virtual reality may simply be due to the discrepancies in the time span of the literature search. However, the difference is more likely due to the features of augmented reality as compared to virtual reality.

With the above understanding of the current state of the research in augmented and virtual reality, the next section will discuss the literature found by the author with respect to UAV technology application and present a brief analysis of the literature followed by a categorization of the literature.

2 UAV Technology

Until recently UAVs have only been used for military applications and were considered a costly device to own or operate, however in recent years the commercialization of UAVs have made them a reasonably affordable way to capture aerial images. Many disciplines are already using UAVs for aerial documentation. As early as 2006 the wildlife management discipline began to publish articles on the use of UAVs for wildlife research, Jones et al. (2006). In archaeology there has been use of low altitude flying platforms to capture digital surface models for accurate topographic data according to Martinez-del-Pozo et al. (2012). With a range of disciplines researching the use of UAVs, it is understandable that the AEC industry is exploring the benefits of UAV application.

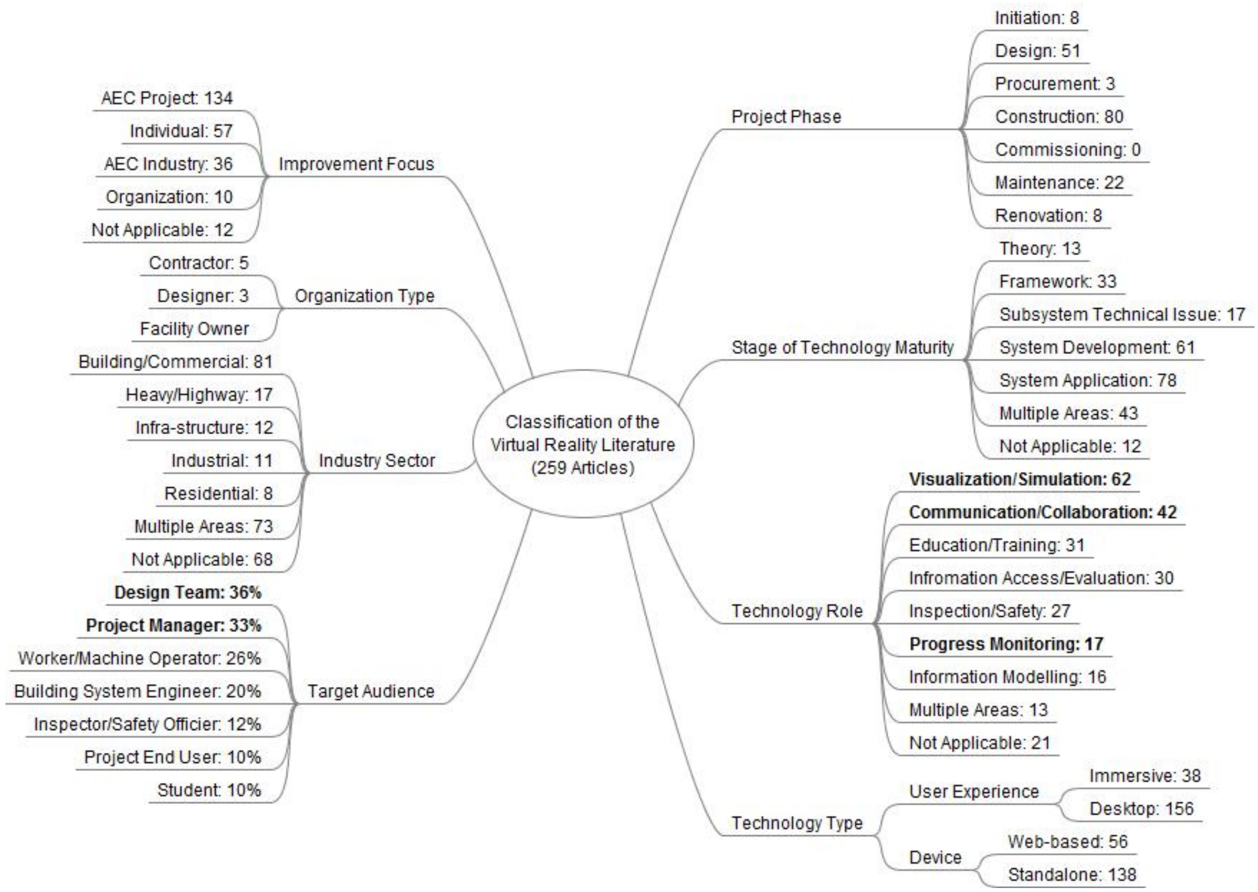

Figure 2: Virtual Reality Framework, Recreated from Rankohi & Waugh (2014)

2.1 UAV Application Literature Analysis

A total of 18 articles that were related to UAVs were found from seven prominent journals inclusive of: Journal Automation in Construction, Journal of Computer-Aided Civil Infrastructure, Journal of Highway Transportation Research and Development, Journal of Information Technology in Construction, Journal of Infrastructure Systems, Journal on Performance of Constructed Facilities, and Journal of Surveying Engineering. As well as seven different conferences proceedings inclusive of: Advances in Hurricane Engineering, Applications of Advanced Technology in Transportation, Computing in Civil and Building Engineering, Conference on Construction Applications of Virtual Reality, Construction Research Congress, Proceedings of the IEEE, and Transportation and Development Institute Congress. The search criterion was to find articles between January 2004 and December 2014 using the following keywords: Unmanned Aerial Vehicle, Micro Unmanned Aerial Vehicle, and Drone. Articles were selected that used a lightweight UAV in a civil engineering application through a review of the abstract. Figure 3 depicts the range in the publication years and shows that the selected articles first appeared in 2006, followed by a break in publications until 2011, after which a steady increase in publications began. Figure 4 shows the range of primary topics which include construction management, transportation, surveying, post-disaster, inspections, and flight planning.

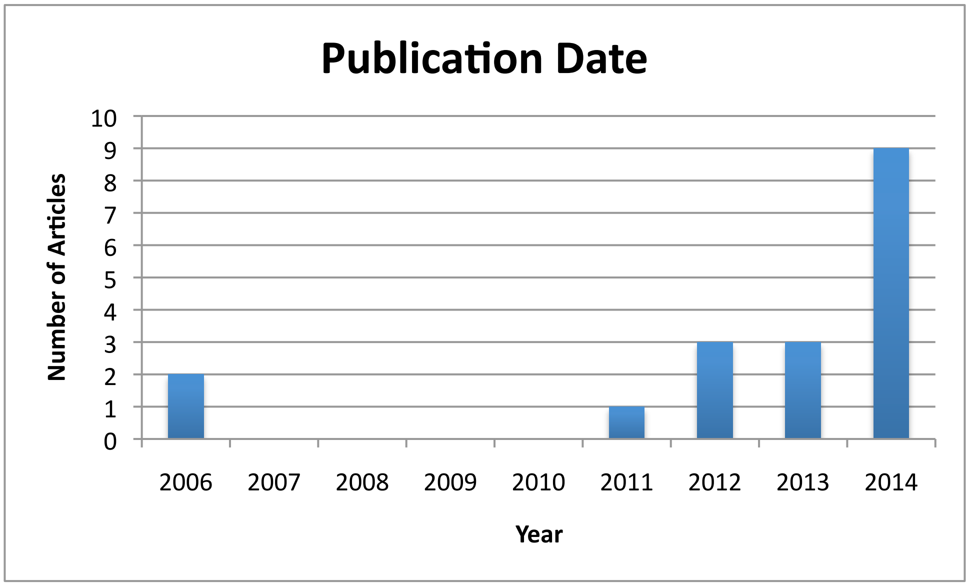

Figure 3: Publication Date

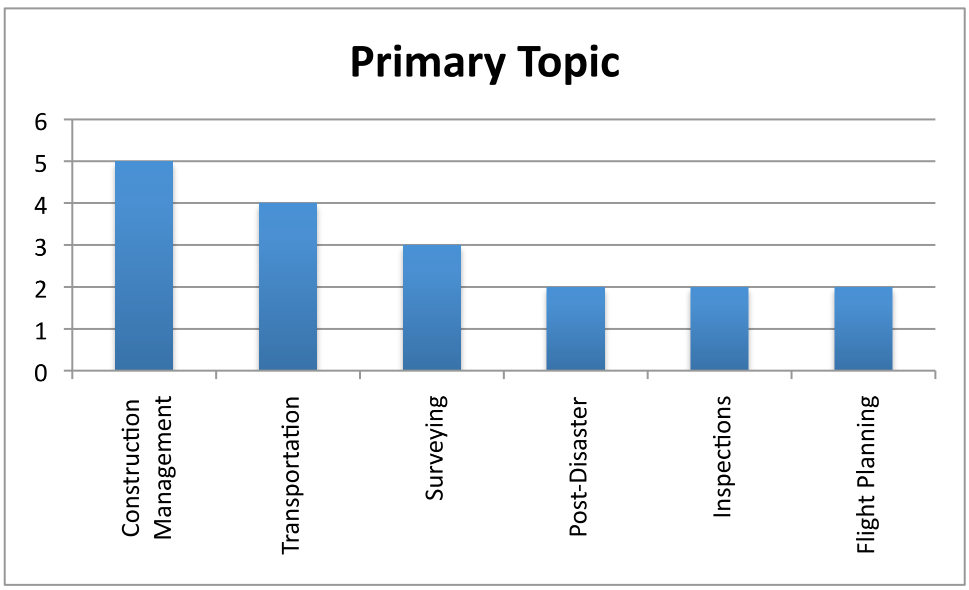

Figure 4: Primary Topic

The purpose of the analysis was to provide a better understanding of the research and to understand the relevant information, as well as to identify the primary focus of the research. With an increase in the number of articles published from 2011 onward, it appears that the area for research is growing and therefore continued research into the literature is required.

2.2 Construction Management

Construction management is the most frequent research focus within the current UAV application search criteria. Irizarry et al. (2012) and Gheisari et al. (2014) used the Parrot AR Drone to study the potential benefits of UAVs for safety managers. The authors felt it was important to have a system that was easy to learn and simple to operate. A two part case study was completed to test the UAV system, as well as to test three different image-viewing options. Through part one of the study various benefits and deficiencies were noted and through the second part of the study, it was found that the iPad was the best platform to utilize the technology for capturing and detecting safety management data. Wen et al (2014b) completed a case study to determine if UAV images could be utilized to construct Digital Terrain Models (DTM) as a low-cost and time saving tool. The authors constructed a six propeller UAV, utilized with a digital camera capable of transferring images back to the ground. The results showed this method to be more efficient and affordable, while maintaining accurate DTM reconstruction.

Wen et al. (2014a) used aerial images captured from a UAV to create AR scenes for planning and detecting unforeseen construction problems. A field test was completed by capturing a photo at approximately 150-200m altitude and integrating the image into an AR scene in combination with 3D models. Zollmann et al. (2013) also completed a study of using UAV in combination with AR technology. With the use of aerial 3D reconstruction the authors showed how AR could be used to support monitoring and documentation of a construction site. Their developed AR system was used with an AscTec Falcon 8 Octocopter that was equipped with a standard consumer digital camera. Through several field tests, the advantages and a variety of unresolved issues were identified.

2.3 Transportation

A variety of transportation groups are studying the use of UAVs for data collection or to create applicable 3D models. Coifman et al. (2006) performed a case study using a UAV to fly over the Ohio State University to collect traffic data for LOS (Level of Service) measurements and AADT (Annual Average Daily Traffic) estimations, intersection operation, and one directional flows on a small network. The study used a combination of approximately two hours of aerial video and ground video to gather data. A majority of the effort was required to analyze the videos manually, along with the use of computers to simplify many tasks.

Xiao-Feng et al. (2013) completed a study to determine the usefulness of UAVs for traffic surveillance in sparse road networks of China. The authors developed a framework for UAV deployment, route planning, and monitoring. Two case studies were performed and it was found to be beneficial, but more UAVs were identified as a requirement to increase the response time. Hart (2011) used UAVs to collect data for roadside condition assessments. A LOS field test was performed on 10 road samples using both aerial video, photos, and onsite inspectors. The study used a Dragon Fly X6 helicopter and found that optimal images were created between 8 am-12 pm with winds speed under 5 mph. The authors found that the results from the onsite data and the data collected from aerial images, matched 81% of the time. Zhang et al. (2012) did further research on road conditions to create 3D models of a road surface. A low cost helicopter was equipped with a digital camera, GPS (Global Positioning System), INS (Inertial Navigation System) and geomagnetic sensors. A field test was performed and the developed 3D model was compared to ground truth data resulting in 0.5 cm accuracy.

2.4 Surveying

Articles with a primary focus on surveying (as defined by the authors) include a paper by Hugenholtz et al. (2014) where a UAV was used as a surveying tool to estimate a stockpile size. The UAV technology was described, as well as federal regulations and the guidelines were noted. A study was performed by gathering data on a stockpile before and after removal and it was determined through proper aerial images with photogrammetry, that the vertical accuracy of volumetric estimates are comparable or better to the use of LIDAR. Another surveying application was done by Gonzalez-Horge et al. (2014) to test the potential of UAVs to complete aerial surveys to monitor shoreline rubble mound breakwaters. Images were captured with a 75% overlap and processed through an algorithm that detected the characteristic changes and as a result the authors were able to detect a 1º-rotation change in the breakwater rubble mound cubes. Similarly Rodriques-Gonzalvez et al. (2014) used aerial images acquired from UAVs to create 3D imagery of electrical substations, which eliminated problems of shadows, physical limitations, and safety concerns.

2.5 Post-Disaster

Applications of UAVs are being explored for post-disaster scenarios because of their manoeuvrability and rapid recovery rate. Adams et al. (2012) completed a study using a UAV to capture images of a neighbourhood and individual buildings after a tornado strike for further post-disaster studies. An Oktokopter XL quad-copter with a high resolution camera was used, the quad-copter was capable of 20-30 minutes of flight time. During the flight, winds were high and as a result it was decided that no image overlap would be performed, however the high resolution images provided the ability to identify select images and individual bricks. Yamamoto et al. (2014) performed two case studies on disaster sites. The first case study was to use aerial images to create 3D data with use of Agisoft PhotoScan software which resulted in an accuracy of 10-34mm. The second case study used aerial images to develop a post-disaster plan as well as to develop approximate construction costs from CAD (Computer Aided Design) drawings along with use of Photog-CAD. The UAV used was a Aibot X6 with a single-reflex camera mounted on the bottom of the UAV.

2.6 Other Research Areas

Other areas of UAV application research include inspections as done by Roca et al. (2013) to create 3D model point clouds, or for remote sensing capabilities by Ellenberg et al. (2014). In conjunction with the other applications of UAVs, researchers have created various flight planning algorithms such as the ones completed by Siebert et al. (2014) for the creation of 3D point clouds and for monitoring structures, Metni et al. (2006).

3 AR & VR Technology

Augmented and virtual reality technology is not new to the AEC industry, however the popularity of the technology has increased. With an increasing amount of research showing the benefits of 4D (3D + time) modeling and specifically the benefits of AR and VR technology, the applications are widespread. The following provides a brief summary of some AR and VR interfaces. The VRDoc interface is summarized here because it was developed by the UNB CEM Group and is the interface of choice for the authors future research. The D^4AR and the VIRCON system are also studied and were found through typical research methods and determined to be, to some extent similar to the VRDoc interface.

3.1 VRDoc (Virtual Reality Documentation)

VRDoc is a virtual reality documentation interface that was developed by the Construction, Engineering, Management (CEM) Group at the University of New Brunswick (UNB). VRDoc allows a user to follow the progress of a construction project through web-based virtual reality panoramas. With the use of VRDoc, users have the ability to: conduct virtual site visits, obtain detailed as-built photographic documentation of the project, resolve project conflicts, and provide training of future project managers (UNB-CEM 2015).

VRDoc has shown to be useful for projects located in remote areas, such as the Arctic. Waugh et al. (2012) conducted a case study with VRDoc on the construction of a new school located in the Canadian Arctic, Inuvik, NT. Various challenges were faced including the time required to capture the images. Full and free access was granted to all major participants of the project and as a result an approach of “information sharing” developed between participants rather than organizations keeping their own records of project progress.

Rankohi et al. (2014) performed a case study using VRDoc with a group of fourth year civil engineering students to test the capabilities of VRDoc for visualization, detection, monitoring, and documenting construction progress. The result was that students on-site found more changes, however the students that used VRDoc required less time. As a result the authors found that the VR technologies can reduce the time spent for monitoring project status and detecting project changes, but at that time the traditional methods were more accurate.

3.2 D^{4}AR (4-Dimensional Augmented Reality)

Research conducted by Golparvar-Fard et al. (2009) resulted in the development of a 4-dimensional augmented reality (D^{4}AR) model. The D^{4}AR uses unsorted construction photos as a data collection technique and uses the photos to extract data and develop a reconstructed scene over as-planned 4D models. D^{4}AR was initially understood to provide the user with the ability to complete a virtual walk through of an as-built scene, visual detection of progress, interior and exterior progress monitoring, daily updates with construction photographs, and correction of augmented realty occlusion. Augmented reality occlusion is when the perspective of the model is changed in comparison to the real world.

As the authors completed further research on the D^{4}AR, other capabilities were observed or perceived and are described in Golparvar-Fard et al. (2011) as progress monitoring and work schedule, quality assurance and control, safety management and education, site layout and analysis of construction operations, remote decision making, and contractor coordination meetings. Recently D^{n}AR (similar to the D^{4}AR model) is being explored as a tool for benchmarking, monitoring, and visualization of the carbon footprint on a construction project and future work will be conducted to integrate the D^{n}AR and the D^{4}AR model, (Memarzadeh and Golparvar-Fard 2012).

3.3 VIRCON (Virtual Construction Site)

VIRCON is a virtual construction site that provides a range of tools for construction planners. The VIRCON tools include setting up project data, space planning, analysis and optimization, and visualization. The authors conducted an evaluation with ten industry collaborators through a case study. As a result it was found that the planning and visualization features that were developed were practical. Along with the features identified as useful, the industrial evaluators also identified the limitations and possible improvements, Dawood et al. (2005). Note that further articles were published on VIRCON and the authors planned to commercialize the product according to Teesside (2015).

4 Discussion

The categorization of the AR & VR literature in Section 1 provides an overview of the research area and the different aspects in the research. Both Figure 1 and Figure 2 show that there exists a wide range of research opportunities. From Figure 2 it can be seen that there exists a need for further research with a focus on project managers as the target audience, and the technology role having a parallel focus on communication/collaboration and progress monitoring. Section 2 first provides a brief analysis of the literature that illustrates that research into the application of UAVs in the industry has only truly begun since 2011 and that there exist a range of application disciplines. With an increasing number of articles on UAV applications, this will result in a fast paced research area. The categorization of the UAV literature into disciplines shows that as the technology into UAV begins to develop more applications are being explored, however no one discipline has created a refined procedure. As a result, there exists an opportunity for further testing and development of the application of UAVs.

Three different AR/VR interfaces are presented in section 3, the VRDoc, D^{4}AR, and VIRCON interface. These interfaces have been tested and the benefits of their current capacities have begun to emerge; however further development of these interfaces could include aerial images captured by UAVs to provide the combined benefit of AR or VR.

5 Conclusion & Recommendations

The goal of the this literature review was to provide the basis for future research. This paper presented a current categorization of AR & VR technology that has been accepted by the authors of this paper and provides a context for how our future research relates to the overall field. The preliminary analysis of the literature on UAV applications in civil engineering depicts the current status of the research, along with the various research focuses. As well, the categorization of UAV applications into various disciplines have been presented along with a brief description of three different AR/VR interfaces.

This literature review has provided insight for the authors for their future research of integrating aerial images captured from a UAV into the VRDoc interface. The following research objectives have been identified and will be carried out by the authors over the next year.

- Complete a motivating case on improving progress report submissions by reviewing the opportunities of new technology
- Develop a new documentation process inclusive of UAV images and the VRDoc interface
- Testing of a new documentation process through a case study derived from the motivating case
- Analysis, discussion, conclusion, and recommendations.

It is recommended that researchers continue to explore the benefits of UAVs and how they may be applied in the AEC industry. As well, it is important to narrow the research focus and begin to develop or integrate user-friendly interfaces that offer the benefits of AR or VR with the application of UAVs. For industry practitioners, the technology is not yet mature at this stage; however to reach a maturity stage continued testing and development must proceed which may be done in a research-industry partnership. Interested industry practitioners are encouraged to monitor current research and seek partnerships with universities and research institutes.

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