WHAT IS HAPPENING TO VIRTUAL AND AUGMENTED REALITY APPLIED TO ARCHITECTURE?

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Abstract. This paper presents the results of a comprehensive survey of activities on research and development of Virtual and Augmented Reality applied to architecture. 200 papers were reviewed, taken from annual conferences of the Association for Computer Aided Design In Architecture (ACADIA) and its sibling organizations in Europe (ECAADE and CAAD Futures), Asia (CAADRIA), the Middle East (ASCAAD) and South America (SIGRADI). The papers were grouped in research areas (design method, architectural theory and history, performance evaluation, human interaction, representation and process & management), emphasis (education, application, collaboration, visualization, practice and theory) and technology development stage (specification, development, application demonstration and evaluation). The period of study comprises 11 years, from 2000 to 2011. Findings for each category are described and key publications and authors are identified.

Keywords. Virtual Reality; Augmented Reality; study of activity.

1. Introduction

Virtual Reality (VR) and Augmented Reality (AR) are technologies that add potential benefits from initial planning and conceptual construction design to facility management and operation phases. Moreover, these technologies improve the visualization and interaction of a building or infrastructure design and construction process and also the communication and innovation within projects.

VR is known as a technology that adds the dimensions of immersion and interactivity to three-dimensional computer generated models and offers an exploration that is not viable with the traditional form of representation (Burdea and Coiffet, 2003, p. 2). For the designer in Architecture, Engineering and Construction (AEC), one example of advantage in VR use is when applying virtual reality systems as CAVEs that offer the opportunity for direct perception of the forms and
spaces through immersion inside an imaginary, computer-generated “virtual world”, large enough to walk through (Okeil, 2010).

AR can be summarized as a technology that uses VR to add virtual objects to real environments in real-time, using technological devices for the overlapping of images (Azuma, 1997; Höhl, 2009; Kirner et al., 2004). In architecture and construction this technology can assist in the design and visualization of architectural forms, results of simulation and analysis of energy issues as well as in the manufacturing of structural components or directly in the construction, for example, at the construction site or during Post-Occupancy Evaluation (Amin, 2007).

Despite VR and AR potentials there are still difficulties which withhold their use in AEC. According to Kalisperis et al. (2002), even though VR application has increased in general, in architecture professors are not using its potential. If this technology was applied in the early years of undergraduate courses, the status of the student from observer to a real participant in the learning process could be changed. In architecture and engineering practice, difficulties such as costs and need of training for familiarization with unconventional devices (trackers, gloves, glasses) can be adoption limiting aspects. As for AR, the drawback is the fact that most research is still in computer science and there is lack of motivation and funds for applied research (Wang et al., 2008).

Both technologies are now almost 45 years old, what motivates a comprehensive survey of activities on research and development of Virtual and Augmented Reality applied to architecture. In order to understand this context, a study of activity was carried out for the period from 2000 to 2011. 200 papers were reviewed, taken from annual conferences of the Association for Computer Aided Design in Architecture (ACADIA) and its sibling organizations in Europe (ECAADE and CAAD Futures), Asia (CAADRIA), the Middle East (ASCAAD) and South America (SIGRADI). Important, previous research effort have applied data mining techniques to find research patterns in Computer Aided Architectural Design (CAAD) (Chiu et al., 2002) or have developed machine-assisted infrastructure and metrics to explore CAAD corpus (Bhatt and Martens, 2009). Therefore, this study being another comprehensive study on CAAD, considering ACADIA articles, may appear to commit one of the seven deadly sins of CAAD (Maver, 1995), the sin of Déjà vu. However, this study is intended allow knowledge discovery specific to virtual and augmented reality applied to architecture considering specific aspects as: Brazilian architectural graduate program research areas, technology development and research emphasis.

2. Comprehensive Survey of Activity

The survey of activity was developed in the following stages: theme definition, preliminary review, problem formulation, reference source identification, search
plan, reference collection, material booking, reading and filtering, material classification and analysis. The theme definition stage limited the scope of the study where the research question and period of review was posed. The preliminary research involved unstructured search in citation and scientific databases. This first experimental search was driven by the terms Virtual Reality and Augmented Reality, in fields such as abstract, title and keywords; limited to the subject of social science and arts & humanities. The problem formulation stage was dedicated to specifying parameters that would allow a comprehensive survey. Therefore, three aspects were defined: graduate program research areas, research emphasis and technology stage development. Since the study may indicate research trends and voids, Brazilian architectural graduate program research areas were selected so that findings may guide research directions. The Brazilian agency for Coordination of Improvement for Higher Education (CAPES) which is a government organization that plays a key role in the expansion and consolidation of graduate studies in the country was selected for areas of research definition. Therefore, the areas of research in architecture were defined as: design method, architectural theory and history, performance evaluation, human interaction, representation and process & management. Still in the problem formulation stage, considering results from the preliminary research, it was observed that studies in VR/AR applied in architecture presented specific emphasis. The emphasis observed were in: education, application, collaboration, visualization, practice and theoretical discussion. Finally, since VR and AR are intrinsically related to technology: software, hardware and communication, the stages of maturation as specification, development, implementation, demonstration and evaluation were also defined for observation.

In the stage of reference source identification the journals International Journal of Architectural Computing, Virtual Reality, Automation in Construction and the Cumulative Index of Computer Aided Architectural Design (CUMINCAD) were selected in order to represent sources where peer review articles related to architecture, computer science and engineering could be found. Since initial article samples were not homogenous in time and size, the digital library (CUMINCAD) was chosen in order to drive sample study to proceeding papers, with architectural emphasis.

The survey sample resulted from searching works with the phrase virtual reality and/or augmented reality in articles’ title or abstract. References were exported to the online bibliographic database ENDNOTE WEB in order to organize, treat and manipulate. The abstracts of collected papers were read and classified considering the comprehensive parameters defined. This process resulted in the material classification. Once classified the analysis took place by developing publication distribution in function of time, quantification of publication in
comprehensive parameters and extraction of findings examples from full paper. The period of survey comprised 11 years, from 2000 to 2011.

3. Comprehensive Parameters

3.1. RESEARCH AREAS

It was observed that the research areas interested in VR and AR applied to architecture are design methods, architectural theory and history and performance evaluation (Figure 1). Research on VR and AR alone in Human interaction, representation and process & management was observed in smaller percentage. However, there is an integration of these last three areas with design method.

Design Method was addressed by 46% of the articles. Methods present the use of these technologies taking place in different phases of the design in addition to being applied in different ways during the process. An example is the method of exchanging ideas between members of multidisciplinary teams in early design development assisted by VR/AR. Analysis of cities, in digital models, are supported by these technologies in order to promote the development of standards and guidelines during creation of city models (Boudakis, 2001).

Theory, history and architectural critique are cited in 23% of articles. Ahmad Rafi and Karboulonis (2000) theorize on the dichotomy between art and science related to design creativity throughout time and point out that improvements in design solutions are necessary when adopting new technologies to provide effective visualization and communication of ideas and concepts.

20% of researched articles focused on human interaction with the space and artefacts (considering ergonomics and perception). This subject is shown in

![Figure 1. Distribution of publications according to the research areas of: (1) Design method, (2) Architectural theory and history, (3) Performance evaluation, (4) Human interaction with space and artefacts, (5) Representation, (6) Process & management.](image-url)
Guimarães (2007) where user perception of Information and Orientation Systems using different VR technologies was compared with traditional in loco system.

3.2. EMPHASES

The most observed studies emphases were on how to apply VR and AR, with focus on how to use them for visualization and how to use in practice (Figure 2). Other highlights consist in studies that emphasize VR and AR applied to education.

18% of the reviewed articles emphasize VR/AR associations applied for visualization purposes. Fukuda et al. (2006) describe VR applied to simulation visualization, where real-time simulation based on virtual reality technology is developed for environmental design evaluation. Portillo, Amen and Flores (2010) present the development of an AR application for Smartphone to reformulate the vision of the society on urban and archaeological heritage in relation with new technologies.

17% of the articles address applications of VR and AR in architecture. Balakrishnan, Kalisperis and Sundar (2006) apply immersive VR associated with psycho-physiological measures in order to capture the affective component of the digital architectural experience. Seichter (2003) applies AR to support a collaborative sketching application.

13% of papers presented a theoretical discussion about VR and AR technologies. In this classification falls Seichter (2005) which analyzes perception and collaborative work using tangible interfaces with AR in a design studio, discussing the concept of usability evaluation with a focus on fundamental theories.

Visualization with VR and AR is mentioned in 10% of the total sample. Wu (2009) examines VR being widely used to present architectural design in space.

Figure 2. Distribution of publications according to emphasis in: (1) Education, (2) Application, (3) Collaboration, (4) Visualization, (5) Practice, (6) Theoretical discussion.
without the users’ knowledge on the subject, facilitating the understanding of the
built environment through realistic visualization.

9% of the read articles deal with technology in education. Navarro, Fonseca
and Puig (2011) define and evaluate a method for using AR applied in disciplines
of graphical representation. It was observed that the use of new technologies pro-
 motes student’s motivation in the learning process in a practical and intuitive way.
However, the accuracy of the result is variable. Nevertheless, faster visualization
increases interest in improving errors.

3.3. TECHNOLOGY DEVELOPMENT

The reviewed studies, when look through the lenses of technology development,
demonstrate focus on evaluating VR and AR systems, followed by system or tool
implementation effort and its demonstration and finally presenting the specifica-
tion of a wished VR or AR system (Figure 3).

Technology evaluation was described in 26% of the analysed articles. Huang
et al. (2001) addressed a discussion about technology assessment by investigating
the similarities and variations between computational techniques, principles of
interaction and its application in order to understand the process and allow design-
ers to adopt different means of communication during the design phases.

21% of read articles described system or tool implementation effort and its
demonstration. Ucelli, Conti and De Amiccis (2005) argue that design environ-
ments based on VR should be connected to repositories to facilitate the access and
reuse of information. These authors describe the development of a framework for
incorporating a VR based design environment and a knowledge management sys-
tem for multimedia content. The main objective of the research was to propose an

![Figure 3. Distribution of publications according to stage of technology development as:
original and innovative approach to assist the design process through the use of new media and technology solution.

System or tool specification was addressed in 15% of the sample read articles. As an example of paper with focus on technology specification Hirschberg et al. (2006) explain the technical aspects of tracking technology with VR/AR and give an overview of possible use in architectural design.

14% of the articles address the development phase to VR/AR. Wang (2007) presents a systematic framework that proposes the concept of mutual increase, i.e., the co-existence of entities of AR and AV (Augmented Virtuality), creating a new integrated and shared space.

4. Featured Authors

Figure 4 presents the top five positions in number of publications featuring 12 main authors in VR and AR in annual conferences of the ACADIA and its sibling organizations over the period from 2000 to 2011. By searching for the institution where these authors were at the time of publication or are now, the related knowledge silos on VR and AR can be drawn to be at: University of Strathclyde (UK), Osaka University (Japan), University Weimar (Germany), Graz University of Technology (Germany), Technische Universitat Muchen (Germany), University of Thessaly (Greece) and University of Sydney (Australia).

5. Publication Distribution in Time

Despite the extension of the analytical period (11 years) and the number of articles found addressing VR/AR in this survey, it was observed that the rhythm of VR/AR articles published in annual conferences of the ACADIA and its sibling
organizations was irregular. It is possible to infer a pattern of decrease or maintenance of publications in the subject. However, caution must be taken in transforming this result in a tendency, for the statistical correlation between articles published in function of time is weak. However, a similar pattern in decrease of publication of articles related to VR/AR was encountered in Avery Index to Architectural Periodicals (Figure 5).

Analyzing the events separately, also with caution, it was observed that publishing patterns differ among conferences. While ACADIA, CAADRIA and ECAADE show decrease of interest in VR and AR, CAAD Futures, SIGRADI and ASCAAD slightly point in the direction of maintenance or increase.

6. Conclusions

Surprisingly, it was observed that the rhythm of VR and AR articles published in annual conferences of the ACADIA and its sibling organizations was irregular over the period of study and that there is a slight pattern of decrease or maintenance of publication. Since central concepts in CAAD change with time (Bhatt and Kishore, 2008), a closer look must be taken in order to understand if the decrease in VR/AR publications denotes a decrease of research interest or a more precise delimitation of the topic.

In terms of research study areas, most articles address transformation in design process with the incorporation of VR and AR. In these studies there is emphasis on tool appliance and its use for visualization followed by theoretical discussion over technology, application in education, application in collaboration and practice. The technology is in most cases evaluated, but also implementation efforts are presented; which indicates the constant need for innovation follow-up.
The survey of activity demonstrates that possible benefits of these technologies, when applied in design process to understand and communicate ideas, are noticeable. However, VR and AR have not been yet fully incorporated in architectural practice, despite its almost half century existence and evolution in other technical areas. Education is an important driving forces promoting technology appropriation in practice.

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