CONTRIBUTIONS OF AUGMENTED REALITY IN ARCHITECTURAL PROJECT REVIEW

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ABSTRACT

Already present in the fields of medicine and video games, augmented reality is now being employed in architectural design. We explore here the role that this new digital tool can play, as a means of interaction, in the review of projects. To do so, we work through experiments that immerse designers in three different environments: (1) a 2D environment, composed of plans and sections, (2) an augmented reality environment on a tablet and, finally, (3) an environment combining the two approaches. We can thus dissect how augmented reality can be a relevant tool and which functionality(ies) can enrich its current potentialities in architectural design.

KEYWORDS

Architectural design, Project review, Augmented reality, Evaluation of solutions, External representations.

1. INTRODUCTION

Today, the digital revolution is everywhere, even in the design professions. Augmented reality (AR) and virtual reality (VR) also offer great opportunities in architecture, engineering and construction (Noghabaei *et al.*, 2020). However, new tools exploiting the possibilities of augmented reality are not yet commonly operated, neither in architectural agencies nor in academia (Noghabaei *et al.*, 2020). In particular, project review is still often carried out in a « traditional » way using 2D plans and sections on paper.

Therefore, could these new tools bring added value to the design and review process? Do they allow for a better representation of the project and thus a better understanding of the architectural elements?

Let us specify that we are in a *post-WIMP* approach. We are looking for an intuitive tool with a fluid interface that does not require software to be manipulated.

2. AUGMENTED REALITY

Ronald T. Azuma (1997) defines augmented reality, AR, « as the set of applications that verify the following three properties: (1) the combination of the real and the virtual, (2) real-time interaction, and (3) the integration of the real and the virtual. » This differs from other technologies and virtual reality, by the environment in which the user evolves that is real and enriched by the addition of virtual information (Azuma, 1997).

It is important to consider that this technology is not yet considered mature (Arnaldi *et al.*, 2018). Indeed, commonly used headsets only allow a field of view of 100-110° to date. The image resolution is also not sufficient for such a closely viewed screen. The need for high resolution also means that more equipment is required than the few square centimeters of display space available. The equipment must also have a sufficient battery life to allow for mobile use. It also requires constant calibration between reality and virtual elements. For these reasons, our experiments will mobilize tablets rather than headsets.

The fields in which the most articles on AR have been published between 2001 and 2019 are education, engineering, science, mobile applications and medicine. Most of the papers, nearly 16% of the 1008 papers surveyed, covered the design and development of augmented reality applications or mobile applications (Tezer *et al.*, 2019). Since 2016, 235,030 scientific articles have been published, in French or English, on augmented reality, while virtual reality amasses 137,310 publications. If we focus only on the literature that combines AR and architecture, the number drops to 53,220. Most articles rarely specify the tool used for the research, but 24,724 publications specify the use of the tablet.

Therefore, it seems relevant to feature the exploitation of AR on the tablet in architecture.

3. ISSUE

At this stage, we question the opportunities of this technology, no more as a communication medium, but as an aid for the review of architectural design projects. We are therefore observing the activities of solution evaluation and not the generation of these solutions. We assume that AR on the tablet is a relevant tool in architectural design review, that it provides a better level of understanding and analysis of the project than « traditional » methods and that the additional information provided by AR serves the evolution of the architectural project.

4. METHODOLOGY

To confirm these hypotheses, we implment an experiment comparing different project representation methods and analyses the understanding of the project. We carry out this experiment through a simulation: the review of the same project by different architects to detect a maximum of errors that have been previously inserted.

4.1 Choice of AR-type and modeling software

The system must be accessible, both financially, in terms of availability and in ease of use, so that it can be employed by anyone. Secondly, since the employment of AR requires a 3D digital model of the architectural object, the system must have good software-hardware interoperability. Finally, as few applications allow interaction with digital models from architectural design, the system must be able to host a wide range of applications, to allow a greater choice. We conclude from these considerations that the use of a generalist system such as a digital tablet has several advantages. It is a mobile tool, whose onboard power is similar to a laptop and whose integrated components (camera, gyroscope, luminosity sensor, pressure sensor, etc.) make it possible to imagine all sorts of applications. This gives us a great freedom of choice when selecting the AR application to be used. This tool is also very fluid and does not require a training phase. The tablet is only a window into the virtual world.

As a software, we chose ArchiCAD because the 3D model is generated automatically which ensures consistency of information between the 2D and 3D deliverables. It also reduces the risk of uneven representations.

We consider the following criteria for the choice of the AR application: having a compatible import format to our modeling software (ArchiCAD), having a calibration system allowing to lock the 3D model in space, allowing resizing as well as movement in most possible axes, guaranteeing an accessible price or free availability and finally being able to generate sections in real-time, displaying textual information, interacting with the model by selecting elements or displaying a shading.

The Augment application[1], based on ARcore technology used in Industry 4.0 and especially studied by Jakl *et al*. (2018), best meets these criteria and is therefore chosen to generate the augmented reality model.

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1 Augment (2019). https://www.augment.com/

4.2 Choice of representation media

There are several categories of representations, that play different roles in our perception of architectural information. To conduct this experiment, we choose to apply two of the seven existing ones (Baudoux *et al.*, 2019): 2D plans and sections: this is the usual basic support in design, they are still today the most mobilized elements to support reflection and communication; and 3D immersion: this support allows the use of an AR application in analogy with the physical model, another usual support in design, and will be compared to our basic support. These two methods are thus integrated into 3 types of project review: an analysis using 2D plans and sections, an analysis using a 3D model in augmented reality and finally an analysis using both of the above methods.

4.3 Choice of project composition and incorporated errors

The reviewed project is a fictive family dwelling. We made this choice because the designers are experts in the design and evaluation of this type of project and because its program remains fairly standard and compatible with the experiment.

As written above, this building incorporates errors that are deliberately slipped in. By errors we mean elements that generate a solution that is incompatible with the characteristics of the problem or with functionally, technically or culturally effective proposals (Blavier *et al*, 2008). Ten errors are included. They concern the architectural program (*e.g.* a requested room not appearing), the functionality of a place (*e.g.* a door not opening in the right direction), the implantation of the building (*e.g.* the access to the terrace not being possible from the living rooms) or the information necessary for any plan (*e.g.* an unspecified bay height). They can also be errors in representation (*e.g.* the inconsistency between the garage door drawn in plan and the solid wall at the same place in section). Figures 1 to 3 present the project and point out the errors that have been inserted. Note that the number of errors is not known to the participants. The subjective appreciation of the notion of error by each participant makes the number of errors to be pointed out variable. We will therefore not evaluate the percentage of errors detected.

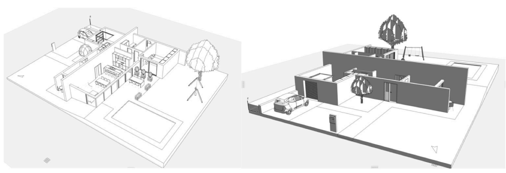

Figure 1: 3D views of the project (without roofs)

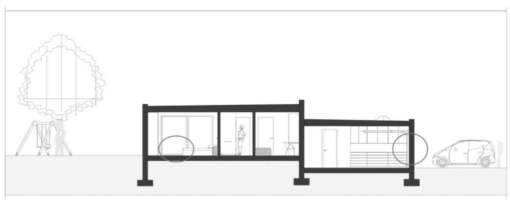

Figure 2: Longitudinal section of the project

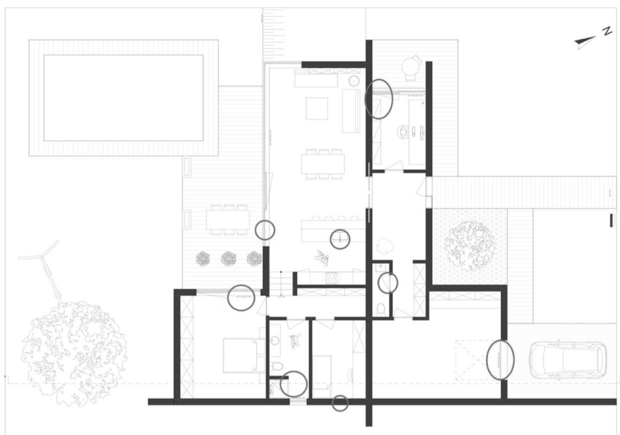

Figure 3: Project plan with the location of errors to be detected

4.4 Selection of participants

Finally, we select the subjects for our experiment. We need designers who are trained in project review and have mastered the design of a family dwelling. Furthermore, designers under 25 years of age are more likely to be comfortable with technology (Elsen *et al.*, 2018). We therefore selected 15 students in 3rd bachelor and 2nd master, engineer-architects at the University of Liège.

5. EXPERIMENTAL PROTOCOL

5.1 Experimental space and data collection

We carry out all three types of experiments at the same location. We prepare two different stations for this purpose:

- A 2D station: consisting of a desk on which a 1/50 scale plan and section are placed, as well as measuring and drawing tools and a computer acting as a timer.
- An RA station: consists of a desk, height-adjustable, on which a marker is fixed, a circulation area allowing movement around the model, and a tablet to work with the RA model.

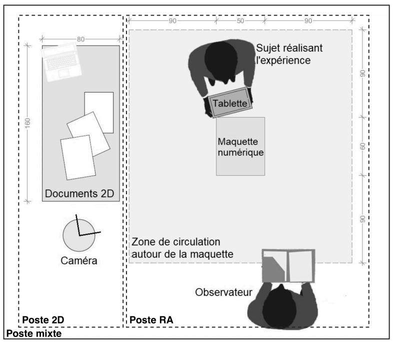

Figure 4: Schematic plan of the experimental space

We will proceed by observation as it appears to be the most suitable means to appraise such visual data. It is done through observation grid and camera recording. A few minutes informal interview is carried out immediately after the review session to collect the participants' feelings about their performance. We will not investigate the manipulations carried out on the tablet because we are not testing the software functions.

5.3 Typical procedure

Each experiment takes about 30 minutes: 5’ for experimental space preparation; 5’ for subject installation and discovery of the AR application; maximum 15’ for the review (from this point on, the participant can no longer interact with the observer); 5’ for the debriefing. Before launching the observation, we carry out a preliminary experiment of each type which allows us to test the protocol, validate the time needed per subject, the understanding of the statement, the stability of the software, the experimental space, the structure of the note-taking grid and the video framing plans.

5.4 Collected data

We carried out 3x5 experiments with a review time of 6’ to 15’. The whole corpus constitutes 161 minutes of video, completed by 15 note-grids, 10 annotated plans and sections, 95 screen captures taken with the AR application and the informal interviews synthesized into 15x5 keywords. Based on these data and after coding, each temporal unit of each experiment can be characterized according to a series of parameters deriving from protocols of design processes analysis (Ben Rajeb & Leclercq, 2015). Theses analyzed data concern:

- The subject's actions trace his review activity (measure, draw, explore 3D, take a screenshot, comment).
- The the spatial scale of the reviewing activity (1. whole, 2. building, 3. interior or exterior, 4. room, 5. detail). An average level can be calculated.
- The focus of attention (implantation, program, structure, function, layout, light, aesthetics).
- The types of errors found (programmatic, functional, site, representational, informative).
- The additional tools used for the review (fine-liners, ruler, visualization software, screen capture).

6. RESULTS

6.1 2D Experiment

We start the analysis of the collected data with the comparative basis experiment: the 2D review. The general representation below summarizes the course of the 5 2D experiments. We can read the duration of each review, the moments when errors are detected and the cumulative error curve.

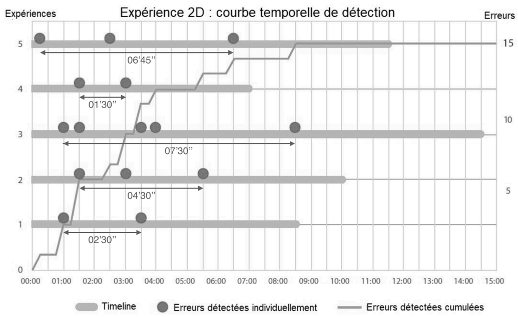

Figure 5: Graph of the timeline of the 2D experiment

We can notice that these reviews present the three usual phases of an architecture review: a project discovery phase, before the detection of the first error, an error detection phase and a verification phase. This segmentation is logical since the subjects take time to get acquainted with the situation before doing the review and then checking their work. The discovery phase lasts on average one minute for the 2D review (Table 1). It should be noted that the subjects are experts in reviewing projects such as this one.

We also investigate the link between review time and number of errors found. Note that no time limit was given to the participants and that none of them exceeded the 15-minute review time. Table 1 illustrates that the longest reviews are also the ones where the highest number of detected errors. Furthermore, we see from Fig. 5 that the longer the detection phase, the more errors are detected. As the other phases do not vary much, we can conclude that as the total review time increases, the detection time increases and more errors are detected.

Table 1. Summary table of the temporal analysis

Experiment Number	**Exp. duration**	**Nb of errors**	**Time to 1st err. detect.**
Exp 4	07’00’’	2	01’30’’
Exp 1	08’30’’	2	01’00
Exp 2	10’00’’	3	01’30''
Exp 5	11’30’’	3	00’15’’
Exp 3	14’30’’	5	01’00’’
TOTAL	**51’30’’**	**15**	

Table 2. Table of spatial scale (level of abstraction)

Experiment Number	**Average spatial scale level**
Exp 1	1,71
Exp 2	2,20
Exp 3	3,14
Exp 4	3,29
Exp 5	2,30
Moyenne	**2,52**

Is the spatial scale level also related to the number of errors found? Our qualitative analyses do not allow us to establish a correlation, but they do advance some initial trends. Indeed, tables 1 and 2 evidence a relationship between these two parameters: except for experiment 4, the experiments characterized by the highest level of spatial scale are also those with the highest number of errors found. Nevertheless, an error may be detected, not because the subject analyses a plan in greater depth, but because he has been attracted by an element of representation different from what he is used to. We have observed this phenomenon several times: while a participant is evaluating a room, he suddenly detects an error elsewhere.

6.2 AR Experiment

For the review with AR, we can summarize the process in the following figure.

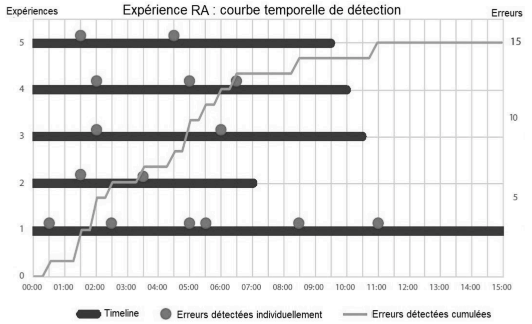

Figure 6: Graph of the timeline of the AR experiment

As before, we can divide the process into three phases: discovery, error detection and verification. The average time of discovery is 1'30", thus longer than in 2D. This additional time can be explained by a short learning stage. This stage being short, it is not a sign of a need for a preliminary tablet training phase. This loss of time being quite negligible on the scale of the review and not very disturbing for the user, we can interpret it as a positive sign regarding the usage of new tools.

In an intriguing way, the « implantation » error was detected in 100% of the cases. However, the implantation of the building is only the third or fourth focus on which the participants were looking and it only occurs a minor part of the time. Therefore, does the employment of an augmented reality model influence the focus? Does it help to focus attention on other elements than in a traditional review? First of all, the main focus of the subjects was similar in both experiments and concerned the layout and functionality (tables 3 and 4). Thus, AR does not seem to influence the focus. Nevertheless, we note that participants spend more time on the « implantation » focus in 2D than in AR while, at the same time, the proportion of implantation errors detected is higher in AR than in 2D. AR therefore seems to highlight certain errors associated with the characteristics of this technology. By doing so, it allows attention to be drawn to other elements than in a classic review.

Table 3. Main focus in 2D

Experiment Number	**Average spatial scale level**	**Main focus**
Exp 1	1,71	Functional
Exp 2	2,20	Lighting and implantation
Exp 3	3,14	Layout
Exp 4	3,29	Layout
Exp 5	2,30	Functional

Table 4. Main focus in AR

Expe Number	**Average spatial scale level**	**Main focus**
Exp 1	3,63	Functional > Layout
Exp 2	2,07	Layout > Implantation
Exp 3	2,62	Functional
Exp 4	2,90	Layout
Exp 5	2,68	Layout

Furthermore, none of the informative errors, in our case the absence of a graphic scale, were found. This lack of detection can be explained by the habit of being able to zoom in and out on a digital platform such as a computer or smartphone screen, which puts the notion of scale into perspective. We wonder then whether this lack of scale could constitute a handicap when it comes to error detection. It should be noted that the number and type of errors detected do not seem to differ in 2D or AR. In both types of review, participants make assumptions about the dimensions of the elements, due to the lack of scale. It should also be noted that the intention to measure was never mentioned. This can lead to damaging consequences, as uncertain approximations can lead to serious errors in the subsequent design. However, this is not related to the specific usage of AR.

6.3 Mixed experiment

The mixed experiment presents the process illustrated in Fig. 7. In terms of protocol, each participant reviews according to his affinity with the two proposed modalities, 2D or AR. Thus, some of them keep a single modality while others alternate between the two. We are therefore more vigilant in analyzing the data and basing our reasoning on a qualitative analysis of the elements observed.

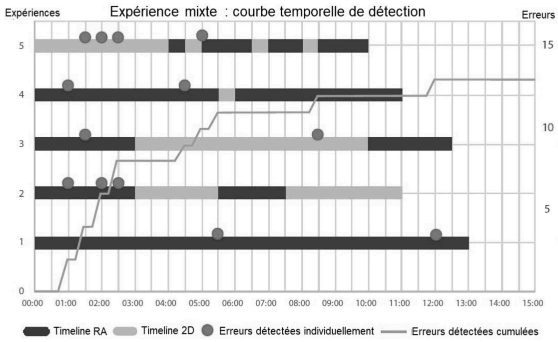

Figure 7: Graph of the timeline of the mixed experiment

We observe a detection phase with two different slopes: a strong slope with high density error detection (1'00-2'30), and a lower slope (4'30-12'00). This reflects a two-speed activity: a first modality is chosen and kept for 4 minutes on average, after which the number of errors decreases. This is due to the time lost in changing modality, which includes a media change, an adaptation and a new discovery phase. The 1'30" plateau seems to confirm our interpretation. Moreover, it is logical that the second detection phase has a lower slope than the first one: the subject having already found some errors, has statistically fewer chances to detect others.

This experiment leads to another outcome: 80% of the participants decide to start with AR and 80% finished with it. 65% of the review time was spent on AR compared to 35% on 2D. We investigate the causes that lead the subjects to prefer AR. We can see two factors: the desire to try out new tools with subjects describing AR as « fun » and « playful »; and the interest of subjects in using AR to understand the site and to check plans.

7. GENERAL DISCUSSION

The previous results and discussions enabled us to identify the interesting points of each type of experiment. This general discussion aims to extend our investigations by cross-referencing the results obtained and thus provide a concrete answer to the research questions formulated in section 3.

Does augmented reality provide a better level of understanding and analysis of the architectural project compared to « traditional » methods? In our experiment, AR does not provide added value in these aspects. Indeed, the 2D experiment seems to remain the most efficient review format. As the following table evidences, for the same number of errors found, the total review takes less time in 2D than in AR. The average effective time and the average duration of the active phase also confirm this conclusion. However, the time difference is relatively small. The number of errors detected is also identical, so we could consider AR and 2D on an equivalent level. This advances the idea that AR does not stand out positively from 2D.

Table 5. Summary table of temporal data for the three experiments

Exp. Type	Total duration	Av. duration	Nb detected err.	Spatial scale level	Av. effective time
2D	51’30’’	10’18’’	15	2,52	4’32’’
AR	52’00’’	10’24’’	15	2,78	4’42’’
AR + 2D	57’30’’	11’30’’	15	2,40	4’24’’

Does augmented reality provide an analysis of additional factors that do not usually appear? In other words, does the focus vary according to the reviewing media? Informative errors were more often detected in 2D than in AR, while the implantation error was more easily detected in the 3D AR model. Lack of scale was only detected once when moving from the 3D model to the 2D documents. These few facts suggest that the focus varies between review media. This is also seen by Cheng et al. (2001) and Kirsh (2010) who highlighted the use and benefits of multiple representations, typically in real contexts. However, more experiments are required to affirm this with certainty.

Is augmented reality a relevant tool for the preliminary design review? For all the above reasons, we believe that it is indeed a relevant tool. However, it is not a better tool than the existing solutions. We have seen that it influences the qualitative parameter rather than the quantitative one, the focus remaining different. Thus, it would be advisable to choose a modality according to the parameters that wish to be observed.

8. CONCLUSION

This study allowed us to explore augmented reality and its employment in architectural project reviews. Through 15 project evaluations, we tried to evaluate this technology's contributions. The subjects had to identify a maximum of errors, deliberately included in the project, by use of 2D documents, augmented reality model, or a combination of these two. Thus, we found that this technology's contributions are limited. Similar to a traditional solution, it does not seem to provide significant added value in error detection. However, we found that AR did influence the designer's focus. The experiments also highlighted the existence of three phases during a review: a discovery phase, an active phase and a verification phase. We found that the discovery and verification phases tend to be constant. This allowed us to notice a link between the time spent in active mode on a project review task and the final quality of this work characterized by a high number of errors detected.

The first limitation encountered is that AR system is yet fully mature. The second limitation is related to the sample, which is composed of 15 subjects with a similar profile. This already allows some results to be drawn, but the sample could be increased and diversified so that the conclusions can be more extensive and nuanced. Moreover, there is a possible effect of the participant's background knowledge, them being novices in AR usage while experts in traditional 2D documents usage. Nevertheless, the observed AR learning stage was short and didn't bias the results. Finally, the last limitation is linked to our analysis angle. The augmented reality review involves multiple notions including the notion of error, the design process, human behavior, human-machine interactions and real-time interaction. We have chosen to focus only on the notion of error.

As the field of study is currently in full expansion, we do not doubt that the possibilities for research will continue to grow. We are currently carrying out experiments under real conditions of review by professionals on large-scale integrated design projects to explore the use of AR on tablets, its added value in terms of communication and the handling of this new tool. Furthermore, the data collected allows us to go beyond the parameter of the notion of error and to analyze complementary factors such as the impact of interfaces or architectural project components. We could thus see if this confirms or refutes our statements.

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