Using Spatial Augmented Reality in Synchronous Collaborative Design

Applications in Architectural Design Training

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Abstract. This article examines applications of Spatial Augmented Reality (SAR) in architectural and engineering collaboration. These applications can be split into four SAR configurations supported by an innovative software program (SketSha) which enables remote sharing of graphic documents and annotations in real time; remote expert consultation, collaborative design, project review and group evaluation are all implemented in collaborative design training.

Analysis of how SAR affects instrumented training activities is qualitatively conducted on four axes: (1) the status of the object being collaboratively designed; (2) the status of the document as an intermediary object for collaboration; (3) the status of the participants in aiding collective intelligence to emerge and (4) the status of workspace as we question the "co-presence / remote" dichotomy in synchronous relations.

Keywords: Collaborative design, Collaborative learning, Augmented reality, Shared sketches, Awareness, Common ground.

1 Introduction

1.1 Field

The objective of this paper is to discuss the use of Augmented Reality (AR) in collaborative activity. AR is considered here to be the real-time overlay of virtual information on the visual perception of reality (Furth, 2011). In other words, AR supports virtual documents (plan, sketches, blueprints) - created and manipulated by real tools (electronic stylus) - projected on real work surfaces (boards, tables, lecterns). AR is linked here to network sharing capacities and allows real time interactions, both in co-presence and remotely. These devices are implemented in specific spatial configurations; the term SAR - Spatial Augmented Reality - therefore covers the whole spectrum and constitutes a currently little-studied area of research in the CSCW (Computer Systems for Cooperative Work) community (Cardon, 1997; Maher et al., 1993).

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1.2 Context

Our study, rooted in project-based learning, focuses on the application of SAR in advanced training in architectural collaborative design. Training via projects is the result of active learning and aims to position the learners in a problem situation, leaving them the choice of which means to mobilize (both individually and collectively) in order to achieve the objectives they have set for themselves (Hmelo-Silver, 2004). Several authors, including Liu & Hsiao (2002) and Huet & Escribe (2004), have shown how this type of training contributes to the development of the students' general and specific skills. This learning process is well-suited to the integration of knowledge and skills needed to train the learner in mastering the complexity of design activity as it promotes learning through collective reflection on a concrete project. In our study, training is also designed to develop specific skills in annotation and the use of graphic documentation.

1.3 Research Questions

How do these new SAR configurations affect collaborative design? How do the notions of document (shared medium) and artefact (semantic production of collaborative design) evolve? What impact does SAR have on communication between participants? How can the collective workspace be redefined with the use of SAR?

2 Presentation of the Tool: Collaborative Digital Studio (SDC)

The various SAR involved in this study are brought into play via an innovative technological tool - the Collaborative Digital Studio - developed by LUCID at the University of Liege (Safin and Leclercq, 2009). This tool enables the sharing of annotations and graphic documents remotely and in real time. It links two collaborative stations connected by the internet. Each station is made up of a video-conferencing system, a digital surface on which users interact graphically with an electronic stylus, and Sketsha - a graphical interaction software program (Elsen and Leclercq, 2008). The system is based on the metaphor of the traditional meeting with several participants seated around the same table. It enables business meetings in virtual co-presence where discussions can be held via video and any type of document can be exchanged, manipulated and graphically annotated in real time by any participant (Ben Rajeb and Leclercq, 2012). The digital surface can be a large board, a table seating several people or a tablet for a meeting of 2 to 4 geographically separate participants (Figure 1).

Fig. 1. The Collaborative Digital Studio: (1) Projected work surface, manipulated by a physical stylus, (2) SketSha annotation software, (3) Video-conference device

The integration of a system like SDC in SAR requires the redefinition of space and human interactions, as these are brought into play through digital documents made up of graphical information shared both remotely and in co-presence on a real work surface and via a stylus. This pen is used for pointing, drawing strokes, graphical annotations, activating orders (marker selection, eraser, layer creation and other functions offered by the tool) and controlling actions on the various documents (zoom, rotate, move, etc.).

Studies on the indirect manipulation of tools for sharing annotations systematically via a keyboard and a mouse (Beaudouin-Lafon, 1997) have shown that a large number of actions (such as navigation, selection and input of documents) are significantly reduced, while the direct manipulation of graphical documents through a single mediator (here, the stylus) increases human interaction and facilitates appropriation of the technological tool. SDC enables free-hand sketching and constitutes SAR to provide support for project-based design training.

3 Methodology

These various SAR tools were implemented as part of the training for Architectural Engineers at the University of Liege. Our observations are based more precisely on one class (academic year 2012-2013) made up of a dozen students (average age between 21 and 24 years), whose task was to design a large-scale architectural project, both in co-presence and remotely with students from the Nancy School of Architecture (located 300 km from Liege). These students benefited from the support of experts teaching at the Ecole des Mines d'Ales (930 km) to advise them in the design of their project.

Considered as a whole, these situations provided observations that were captured by a video recording device installed in the workshops. From these video data, we observed discussions, annotations, imported documents, appropriation of the tool and how the projects developed over time. Once the data had been gathered, we defined a transcription table for processing and qualitatively analyzing part of the data (the initial corpus was 46 meetings, so approximately 80 hours of video).

This table encompassed various parameters including the spatiality of exchanges (I-space [co-operation], We-space [collaboration] and Space-between [individual or partial collaboration]), action typology (actions made on the project, the tool, the management of human relations, etc.), document typology, the typology of the artefact made (plans, cross-sections, sketches, charts, etc.), and so on. Our results come from our longitudinal observations of different spatial configurations implemented in the context of project-based training and are presented in more detail below (Table 1).

4 Presentation of the SAR Brought into Play

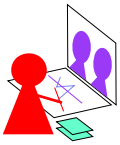
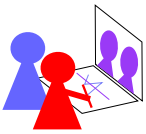
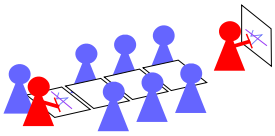
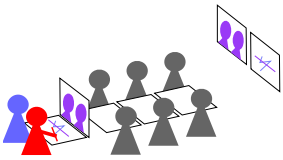
Configuration 1: Remote Expert Consultation. This SAR configuration was established to review the project with remote experts (here, experts in building stability, environment and fire safety) located 930 km from the place of training. In this context, the student using the SDC is alone with the experts, communicating orally with them via the video-conferencing system and sharing annotations via a graphics tablet. In this way, the student can have access to knowledge and expertise from external partners and benefit from direct access to information through real-time interactions, thus facilitating understanding.

Configuration 2: Collaborative Meeting. This SAR configuration brings together two geographically-separate groups of designers to work around a large graphic table seating three people per group for a remote meeting. The participants find themselves in a situation where they can argue and justify their choices via graphical documents they have prepared together before the meeting. The substantial number of participants requires students to take it in turns to speak and handle the stylus in an organised manner. Following their remote meeting, the students retain their annotated files to continue their project design and develop it further.

Configuration 3: Collective Review of the Project. Contrary to traditional project reviews where each student presents his or her project to the supervisor, this SAR is set up so as to gather several students and their trainers to publicly conduct the review of one project. Using a graphic table, the teacher can annotate the document at the same time as it is being presented and sketched by the student on a digital whiteboard facing the other students. Here, both trainers and students can express their views and share their comments, concerns and solutions regarding the project.

Configuration 4: Public Evaluation. Unlike examination juries in traditional training where public presentations take place in co-presence, in front of a display wall and without the possibility of graphic interaction, this SAR configuration enables both co-present examiners and remote experts to evaluate the project. All parties can intervene on graphic productions while respecting the project, given that the annotations produced are sketched and saved on a digital layer specifically created to this end. Students can also complete their plans, explain some of their choices graphically and answer the examiners' questions by sketching additional solutions onto the document shared by all the participants.

Table 1. Presentation of the various SAR configurations

SAR Configuration	Layout	Objectives
1. Remote Expert Consultation 	 Tablet and video-conferencing system	Initiation to the project by integrating other skills; developing knowledge by sharing and accessing expert advice; standardization of representations; prioritizing issues according to the requirements of the project.
2. Collaborative Meeting 	 Table and video-conferencing system	Introduction to coordination: communicating; producing annotations and graphic documents; sharing points of view; generating new ideas collectively.
3. Group review 	 Co-present table and whiteboard	Sharing ideas and generating collective intelligence; reducing competition among students
4. Public evaluation 	 Table and video-conferencing system, co-present whiteboard, remote table.	Reconsideration of the hierarchy between instructors and students via requalification of shared representations: switch from "documents presented" to "working papers".

5 Discussions: New Statuses

Let us now see how the collaborative situations instrumented by SAR change the status of the four key components of collaboration (documents, artefacts, participants and workspaces). The discussion in this paper will enable a qualitative approach for this first evaluation.

5.1 The Status of the Documents

The SAR configurations employed here result in each participant being able to assert themselves, express their thoughts and translate their intentions for the project design by annotating in real-time. Whether the project is being reviewed in co-presence, where each individual reacts directly on a shared digital graphic device (SAR 3) or by a jury composed of co-present trainers and remote experts (SAR 4), learners can easily enforce their points of view and translate their choices into sketches. In a traditional jury situation, the projects produced by the students are either sanctified (for fear of distorting the document presented), or downright degraded by modifications from the teacher, the status of the document is reconsidered in the use of SAR. Indeed, these configurations can strengthen the principle roles of the document (as reminded by Carlile, 2004):

- The student's production is respected while he or she may also modify it during the presentation to better explain any comments and even challenge some of these choices (SAR 1); in this case, the tool supports the pragmatic role of the sketch.
- Each project participant (SAR 2) can evaluate and argue their point of view by acknowledging, and distancing, themselves from their own choices; here, the tool supports the semantic role of the sketch.
- Teachers can shape their reviews (SAR 3) without altering the student's work since a layer is created above it on which to generate corrections; in this way, the tool supports the syntactic role of the sketch.
- The documents produced by the student evolves from the status of "document presented" to that of "working paper" whether the review is conducted in co-presence or remotely and regardless of the degree of involvement of the individual agents (evaluators and student examined) and the observers (other students), (SAR 4).

Whether the SAR involve formal (SAR 1 and 4) or informal (SAR 2 and 3) discussions, they all provide the possibility of intervening on pre-prepared, standardised documents. Each participant may insert notes or sketches drawn there and then - so as to quickly explain their points of view and justify their choices - without distorting the personal productions of the other participants.

5.2 The Status of the Design Artefact

By using SAR, the project designed is handled collectively in co-presence and remotely. It is thus an interactive boundary object shared between the collaborators (Star, 1990). This boundary object evolves from a process of negotiating and building consensus among students (SAR 2), experts (SAR 1) and trainers (SAR 3+4). On the one hand, these artefacts reflect the design project and allow students to construct their own discourse and interpretations; on the other hand, they generate different collective reflections on what has been produced, thus contributing to the genesis of new shared representations. The SAR configurations in which these interactive boundary objects are handled reduce spatial and temporal shifts as the tool allows the user to share and interact synchronously and in real-time. The time interval between the change made to the document and information feedback to the various users is invisible to human perception. Unlike other tools for sharing remote annotations

(Webex, for example), where the user loses the causal link between what is being said by the remote collaborator and what is seen on the shared digital graphic document (Beaudouin-Lafon, 1997), here the "action/perception" loop is immediate.

This immediate loop made possible by the SAR presented here even allows the designers to draw by two, at the same time and remotely on the same shared digital workspace. The importance of this coupling to understand the information transmitted has incidentally been emphasized by several authors (such as Cadoz, 1994). It has been observed that there are two types of graphical representation made by two participants to discuss a choice made regarding the design of the artefact.

1- Both geographically separate students draw - simultaneously, independently and on a shared digital document - two different points of view of the project, basing their ideas on a functional drawing created together previously. For example, one participant may sketch on the right-hand side a cross-section of the project while the other draws on the left-hand side a perspective modelling the overall shape of the artefact. Consequently, from a shared reference, two different graphical interpretations of the project are offered simultaneously. Each of these representations carries implicit meanings for each participant and engages a specific line-of-thought and different perspective for the design of the artefact. This juxtaposition of representations created on the same shared digital interface supports cross-interpretation by the two participants who, while drawing their own artefact, can watch the artefact of the other being built, enabling a new form of cross-interpretation.

2- The two geographically separate students draw - simultaneously, together and on a shared digital document – a sole graphical representation. The artefact is thereby designed by two participants by pooling the ideas previously chosen in discussion. In this way, the designers simultaneously proportion, orient, position and transform the project with the help of the synchrony the SDC provides.

The various SAR presented here therefore support action/perception coupling and enable the students to display their project while learning how to synthesize their ideas and expose them to other points of view.

5.3 The Status of the Actors

Collective activities develop from social interactions between the various designers and can be categorized into two types: vertical collective activity and horizontal collective activity. Each type affects the nature of the relationships between the actors differently. In project-based training, which brings together trainers/experts and learners, collective activity is generally vertical with a clearly identified hierarchical relationship between the actors.

But because the tool allows the user to draw synchronously and remotely, participants can intervene with both hands peer-to-peer (SAR 1 and 2). So in the SAR 1, 3 and 4, we observe a change in the status of the examiner as any other actor attending the project review can also draw over his or her corrections. By giving the opportunity to all to modify the document, the changes made by the teacher are less sanctified, which encourages a questioning of the choices made, regardless of the actor: expert, teacher or student. Whereas in classic project reviews the learner is alone with the teacher without possible interaction with other colleagues, in the SAR 3 and 4 it is clear that the relationship between the students changes, thereby enhancing discussion

between them rather than competition. SAR thus enhances the sharing of views, the emergence of common ground and cognitive synchronization; this contributes to building a mutual awareness of the activity.

5.4 The Status of the Co-workspaces

Different classifications have been proposed to index CSCW groupware. One of the most common classifications for spatio-temporal positioning is the matrix proposed by Johansen (1988, taken by Ellis, 1991) which is constructed on two axes: "synchronous/asynchronous" and "co-presence/remote". Observation of the SAR configurations implemented in training sessions requires the "co-presence/remote" dichotomy in synchronous collaboration to be reviewed. Indeed, we have seen a situation of "distance in co-presence" emerge; for example, use of the whiteboard and the digital table in public correction (SAR 3) establishes an interaction that is based both on direct modality (conversation in the same physical space) and indirect modality (annotating a virtually shared document on physical media situated in the same room but differentiated). SAR therefore nuances Johansen's notion of spatiality. Hence, in synchronicity it is necessary to distinguish between real presence and augmented presence, in addition to virtual co-presence.

Table 2. Johansen's spatio-temporal matrix and its evolution in SAR

	Same place	**Diff. places**
Same time	Real presence	Virtual co-presence
Diff. time	Asynchro-nicity	Remote Asynchronicity

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	Same place		**Diff. places**
Same time	*Real presence*	*Augmented presence*	Virtual co-presence
Diff. time	Asynchro-nicity		Remote asynchronicity

This nuance imposed by the SAR also requires questioning of the relationship the actors have with these co-working spaces, simultaneously brought into play in both physical and virtual environments. This relationship forms alongside the transformations brought about between the personal spaces of the actors, the co-working spaces that bring them together and the link between the two (Suchman, 1996). These different areas are therefore distinct relative to how the actors use them:

- I-Space: the personal work that each actor annotates individually.
- We-Space: the workspace that is virtually shared and that the actors annotate and modify collaboratively.
- The Space Between: the workspace that is isolated from We-Space and which requires the actors to work idependently from the rest of the group.

Distinguishing between the various workspaces that make up the SAR is especially important in situations of co-presence and virtual co-presence where teachers and learners alike are involved in constructing common reflections. These types of workspaces are ephemeral and are brought about according to the needs, goals and choices relative to the negotiation, discussion and consensus building that occurs amongst the actors as the project is being designed. The collaborators/students working on a project form a unit, ensuring coherence between choices and interdependence between the different parts that make up each individual's reflections. These areas therefore

involve mechanisms to share knowledge, share understanding and synchronize the cognitive processes necessary to construct a mutual understanding of the context of the work, the project, the tasks and the individual contributions of each member of the group.

Adjusting to these different workspaces brought into play in the SAR requires a flexibility that should provide the tool for each individual to handle his or her workspace and organise the interface easily. This flexibility between We-Space, I-Space and Space-Between is only partially managed by the system currently used in the SAR presented here. The graphical annotation synchronous sharing software requires the pooling of all documents created. Video-conferencing does not allow certain actors on either side of the screen to isolate themselves from the group and create their own Space-Between. The system does not offer the opportunity for passive learners in the context of SAR 4 to intervene at any time or to interact with the jury. Generally speaking, these SAR contribute fully to group cohesion by creating these intermediate workspaces between co-presence and virtual co-presence. But they support peer-to-peer sharing between collaborators rather than empowerment of each individual, a result that is well-adapted to project-based training.

6 Conclusion

We have presented here four cases of collaborative design implemented in SAR (Spatial Augmented Reality) configurations based on a remote synchronous collaborative graphical tool (SketSha). These situations, observed in a context of training in a studio for architecture and engineering, have enabled a qualitative description of changes in the main components of instrumented collaboration: the changing status of the activity's artefact; requalification of the notion of shared documents; reconsideration of the hierarchy of agents; and questioning the notion of presence. The latter challenges the spatio-temporal communication of the collaborators and encourages detailed study of the concept of space to better characterize participant cognitive synchronization. The next step of this experimentation will involve a quantitative study of these concepts of I-space (co-operation), We-space (collaboration) and Space-between (individual or partial collaboration) in the new concept of augmented presence hereby presented.

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