

Spatial Augmented Reality in Collaborative Design Training: Articulation between I-Space, We-Space and Space-Between

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Abstract. This paper analyses the use of augmented reality in advanced project-based training in design. Our study considers how augmented environments can contribute to this type of group training: what types of interaction spaces constitute these new learning environments and how are these spaces constructed so as to promote collective reflection ?

Keywords: Project based learning, collaborative design, augmented reality.

1 Context and Hypotheses

We propose to study the use of Augmented Reality (AR) in advanced project-based training. Following the taxonomy proposed by Dubois [1], AR is considered here to be the interactive and non-immersive real-time superposition of virtual information in a real environment. The aim of project-based training in this context is to develop the learners' general and specific skills to devise complex projects in design, architecture and engineering [2]. In the present study, this type of training will be implemented through group activities based on group dynamics.

Indeed, the contemporary designer no longer works alone on projects; rather, he or she collaborates with other experts because projects must evolve in a regulatory framework, integrating progressively more coercive qualitative demands with shorter and shorter deadlines [3]. It is therefore impossible today to speak of initiation at the origin of complex projects in design, architecture and town planning without training students in collective activities. This is why we hypothesise that group activities promote learning through collective reflection on a concrete project, as such activities are well-adapted to the integration of the knowledge and skills required to master complex design.

2 Research Question

The aim of this paper is to understand how augmented reality supports group dynamics in project-based training. In other words, what types of interaction spaces constitute

these new augmented learning environments and how are these interaction spaces constructed so as to promote collective reflection?

3 Scope: Instrumenting Collaborative Practices

Our teaching approach is to develop specific skills in collaborative practices, which are clearly distinguishable from so-called cooperative activities. We consider this distinction to be important because it implies the establishment of a specific pedagogical framework, and it already exists in the definition of collective activities in general (without mentioning the notion of design [3, 4, 5]). Despite the diversity of definitions, all agree on one major characterization: the differences between the tasks assigned to the project participants. As the common goal is the project, the designers are only required to work together because of the need to access shared resources held by individual parties. Bearing these definitions in mind, it is our opinion that design as an activity includes solitary work as much as it includes cooperation or collaboration. The present article will only tackle the moments in which students, teachers and experts work together and share the real-time annotations and graphic documents necessary for design.

4 Integration of Augmented Reality in Training Students in Collaborative Design

The application of augmented reality as it is understood in the present study therefore concerns the real-time projection of virtual documents onto actual work surfaces (tables and boards) and the creation, manipulation and annotation of those documents using electronic pens. Such an application is here linked to how work can be shared via a network and it involves students, trainers and experts working together - remotely and/or in co-presence - on an (architectural) project. It is implemented in specific spatial configurations and the whole is therefore covered under the title SAR - Spatial Augmented Reality.

4.1 Presentation of the Tool used in Collaboration

Our study concerns four different SAR. All four are based on a software solution called SketSha - for "sketch sharing" - developed by LUCID, University of Liège [6]. SketSha is based on the metaphor of a meeting whereby several people are gathered around the same document. In addition to the social exchange between collaborators via videoconferencing, SketSha enables the participants to share annotations and graphical documents both in real-time and remotely. Concretely, this involves the connection, via internet, of several digital surfaces on which users interact graphically with an electronic pen.



Fig. 1. Collaborative system SketSha

4.2 Introduction to the SAR and their Usages

Four SAR were installed as part of the training in collaborative design for students of architectural engineering at the University of Liège. The workshop was attended by about fifteen students and lasted three months during which time the students collaborated in real-time with students from the School of Architecture of Nancy. In these workshops, the students were also able to benefit from consultation and advice from remote experts (architecture, structure, building engineering, fire safety, etc.) thanks to the various SAR which had been installed as part of the course.

SAR 1 Consultation. The first SAR allows individual students to consult various remote experts for help in developing their own project. At this meeting, students are asked to prepare documents and hierarchize the information that they would like to communicate to the expert relative to any questions they have. The pedagogical aim of this SAR is to prepare the students to deal with other expertise and skills while also providing access to other knowledge, references and experiences.



SAR1 Consultation



SAR2 Collaboration



SAR3 Project Review



SAR4 Evaluation

Fig. 2. 4 SAR for collective work

SAR 2 Collaboration. The second SAR brings together two geographically separate groups of students for weekly sessions to work on the same project. At these sessions, two or three students seated around a large graphic table collaborate remotely and in real-time with two or three students from the School of Architecture of Nancy. The pedagogical objective of this SAR is to initiate students in co-ordination (as regards public speaking and joint production of annotations and graphic documents) and in sharing their own opinions in which they explain, negotiate and justify their choices so as to encourage new collective ideas.

SAR 3 Project Review. The third SAR is used to review the project in co-presence between students, trainers and experts. At these meetings, the students are asked to display their project on an interactive board and interact with the rest of the class throughout the presentation. The expert and the teacher share the same annotated document, but theirs is projected onto a graphic table. The aim of this SAR is for the teachers, experts and students to share opinions in real-time and to enable each party to interact either orally or through drawing. Each individual's project thereby evolves through collective reflection which, in our opinion, helps to reduce competition between students.

SAR 4 Evaluation. The fourth SAR enables collective evaluation of student projects by various co-present and remote experts interacting in real-time. Here, the student is asked to present his or her project to the class but also to the remote experts whom they have already met on two previous occasions in the context of SAR 1. SAR 4 enables all participants to intervene on the final graphic documents of the student's project. The major objective of this SAR is to transform the documents presented – supposedly frozen images at a final jury – into working documents to stimulate collective reflection and the emergence of new ideas.

5 Methodology

5.1 Collection of Data

Longitudinal observations were conducted for each SAR; in other words, observations made over the course of several sessions on how students appropriate the tool and prepare the design project. Only the teachers were aware of the objectives of the observations: to define the involvement and contributions of the various SAR in the student's learning process in design collaboration.

In the definition of our protocol, we considered it vital to vary the parameter of number of actors as several publications focusing on collective activities (like [7]) show that the performances of the interactions between the designers as well as the decisions made can be influenced by the number of actors taking part (directly or indirectly) in the design. This is why the experimental protocol was defined in such a way as to use the same augmented system in the same class of students for collaboration over the same lapse of time while varying spatial configuration and the number of participants. All our observations were recorded using an audio/video recording device.

Table 1. Total of data accumulated in the four SAR

	SAR 1	SAR 2	SAR 3	SAR 4
Configuration	Remote	Remote	Co-presence	Remote
Participants	1 student 1 teacher 4 experts - Alès	3 students 3 remote students 2 experts/teachers	1 student 3 experts/teacher 16 students (public)	1 student 7 experts/teachers 16 students (public)
Students	17	5 groups x 6	17	17
Sessions	2 x 0:30	7 x 0:30	2 x 0:30	1 x 0:30
Durations	17:00	17:30	17:00	8:30

5.2 Data Analysis

Collaborative design can be analyzed from various points of view: (1) physical working conditions, (2) the emotional or psychological aspect and (3) cognitive. This final point of view - analysis of the design process relative to the situation, actors and the subject being dealt with - is the one we will be focusing on in this study by considering group awareness, intermediary objects and the common referential used to study these situations.

This is why the discussions, annotations, imported documents, use of the tool and use of the different SAR by all participants are observed and analysed qualitatively using a specific coding scheme (fig. 3). This scheme distinguishes between three types of interaction spaces according to how the actors use them:

1. We-Space: in which remote participants annotate and modify a shared real-time document using the electronic pen;
2. I-Space: in which the actor works on his or her document alone;
3. Space-between: a private conversation in which certain members of the group isolate themselves to work together independently of the We-Space in which they are participating.

These spatial interactions are first of all described as actions relative to various parameters which are mainly:

- active actors: this group is made up of all the participants of the SAR under analysis and they are coded as being active when they explicitly intervene in the observed situation;
- documents: these are categorized according to how they are shared. If it is shared, is it with the participants as a whole or solely with one collaborator in a private conversation?
- action typology: these define the objective of actions such as isolating oneself, pooling information, challenging, acting on a decision or giving instructions, evaluating, producing together, negotiating or formulating group's rules, and so on.

These spatial interactions are then studied and analyzed by regrouping them into sequences to illustrate conversational dynamic between collaborators. We believe that the sequence designates a series of successive choices which form a narrative unit in

which are created as a function of the needs, aims, negotiation process, justification and consensus building in project design. These co-spaces vary, change and evolve between the actors' personal spaces (I-Space), co-work spaces which bring the actors together (We-Space) and the junction between the two (Space-Between). These changes enable students, teachers and experts to participate in building joint reflections so that all the actors may evolve together towards the same objective.

The collaborators/learners who are working together on the same project and sharing a We-Space (SAR 2) show a tendency towards working as a unit to assure coherent choices and interdependence between the different elements making up each individual's reflections. The learner, showing his or her project to the other students, experts and teachers and thereby making the transition from I-Space to We-Space (SAR 3), has a new perspective on his or her own production while benefiting from the collective reflections of the other participants. Learners, in appealing to experts from other domains to nurture and answer their queries (SAR 1), enrich the pool with opinions, knowledge and references linked to the project. At the final jury (SAR 4), private conversations develop between the learner and the students, and occasionally even the expert in co-presence (Space-Between), thereby creating a situation where the project as an end-product is discussed and challenged.

All these intermediary spaces therefore involve the mechanisms implicit in mutualizing knowledge, sharing comprehension and the cognitive synchronization relative to building mutual awareness of the working environment (social awareness), the design (activity awareness) and the tasks and contributions of each person within a group (action awareness) [11]. These mechanisms and their links to the intermediary spaces - We-Space, I-Space and Space-Between - are detailed in the following paragraphs.

6.1 We-Space

The SAR as a whole principally encourage this intermediary space: the co-work space. This space was analyzed using the coding table and more specifically, the actions, the documents brought into play, and the relationships maintained between the actors. It is nevertheless important to highlight the fact that the project evolves principally through speech, even though these words are often put into drawings to explain and justify these choices and find a consensus between the actors as a whole. These drawings are collectively manipulated in presence and remotely. They constitute a shared interactive boundary object that evolves from a negotiation process and consensus building between students (SAR 2), experts (SAR 1) and trainers (SAR 3&4). These artefacts promote collective reflection on the productions which generate new shared representations (especially in SAR 2). Moreover, they translate the student's individual design project, thereby enabling him or her to view the project from a different perspective (I-Space) and construct his or her own speech as well as new interpretations and reflections between the other learners (Space-Between) who are present at the public evaluation (SAR 3) and the jury (SAR 4). The SAR in which these interactive intermediary objects are manipulated therefore reduce the spatiotemporal gaps brought into play because the interval of time between the action made on the document and the information feedback to the various users is immediate.

The We-Space is particularly encouraged because it does not involve any loss in the causality links between what is said and the annotations created by the actor – in either augmented presence or virtual co-presence – and what the other actors receive as regards information.

Consider the case of remote collaboration between ULg students and students from the School of Architecture of Nancy (SAR 2). New modes of exchange were observed in this scenario: one which brings out the need to create one's own I-Space from a We-Space and one which shows the possibility of creating a joint drawing with two people, thereby emphasizing the We-Space. In both situations, graphic representations created by two people were brought into play to work on the object being designed. In the first case, the students individually propose different points of view of the project under discussion by dividing the We-Space into two and thereby creating two I-Spaces. One student draws an interior view of the project while the second draws a cross-section; both are able to see the plan they have previously discussed. As all participants see what the others are doing, the student drawing the interior view can, without speaking, readjust his or her sketch while looking at the cross-section being simultaneously constructed by the remote collaborator. This juxtaposition of representations developing on the same shared digital interface encourages cross-interpretation from both actors, even if their initial intention was for each to have his or her personal working space. In the second scenario, the students both draw the same perspective of the plan that has been discussed and collaboratively worked on beforehand. In this way, they pool the choices previously made without even having to speak to one another.

6.2 I-Space

The SAR were implemented so as to promote the We-Space. They were not particularly designed so as to enable independence. Independent work is synonymous with isolating oneself and designing independently while taking into account the work done by the others [9]. Visser also introduces this notion when she speaks about “parallel activities” and their importance in collective work. In her opinion, these parallel activities are marked by interruptions and recoveries throughout the process. They “constitute an indication of the place 'individual conception' can occupy in a co-design meeting between architects” [2, p.152].

In our opinion, independence marks the time spent working in isolation; these are the moments when the project is thought out independently while still taking the opinions of the others into account. Thus, the need to “create one's own I-Space” emerges, because work involving several people does not systematically lead to continuous interaction. Even if the students, trainers and experts tend to reflect together on how the project will evolve, our analyses show that each individual thinks independently and constructs their own isolated reflection at given moments. Even the students/audience take note during the presentation at the jury because they are strategically readjusting what they are planning to say and their answers relative to the remarks made by the experts and teachers. Often, this I-Space is marked by:

- moments of silence during which the actors isolate themselves, either to produce notes and/or personal graphic sketches, or simply to read data or look for a reference to illustrate an idea. In this situation, certain I-Spaces enable continued joint reflection while others interrupt it so as to enable the actors to reflect upon a new point of view;
- personal spoken comments, made in an undertone and not intended to be shared but which result nevertheless from collaborative situations. The I-Space becomes, in this case, a Space-Between which allows certain actors to create private conversations in a collaborative activity (*cf.* 6.3).

Yet this I-Space is not supported by the SAR installed in our training programs. Here, participants in the various sessions do not have the possibility to create their own individual graphic space (I-Space) unless they use the tool differently, or create a personal space which is independent of the SAR concerned, by use of a personal notebook, for example. As previously seen in the SAR 2 We-Space, certain collaborators find a solution by geometrically dividing the space into two parts. This juxtaposition of I-Space within a We-Space encourages cross-interpretation followed by a pooling of this information and the confrontation of the two proposals, thus leading to new cross-interpretations. Once these independent actions are completed, new reflections emerge which are often then pooled to be shared with other participants. An example of this is when an expert takes notes during a student's presentation and then shares the comments with said student so that they may work together to develop a joint reflection on the project.

Today, we believe that it is important to develop the SAR so that I-Spaces can be formed. Indeed, even if the SAR do not prevent the participant from creating his or her own private notebook by using a pen and paper outside the shared interface for example, the SAR nevertheless oblige said participant to change the tool's function by installing a private work methodology so as to construct a personal work space. This I-Space is all the more important in collaboration because it allows the participant, the student in particular, to refocus on his or her own perceptions and individual interpretations. These choices and personal interests are more often than not defined by dividing the tasks according to the needs and/or interests of each individual in the group (particularly in the case of SAR 2).

6.3 Space-Between

The Space-Between is a private conversation that is created between two or several participants independently from the rest of the group. Like the I-Space, the Space-Between is not managed by the SAR, especially not between remote actors. It is all the more problematic because the Space-Between is principally based on oral exchange. In SAR 2 and SAR 4, the creation of a Space-Between actually disturbs the collaborative process rather than nurturing it, as in group communications and via video-conferencing, all sounds emitted from one place (near, far, low voice, high voice) are heard with the same tonality by the geographically remote participants.

Yet collective activities develop from social interactions, amongst other things, whether they are collective or private. Private interactions gain particular importance in the case of collective activities which present a well-identified hierarchical

relationship between actors. As the tool enables the participant to draw synchronously and remotely, remote actors can intervene peer-to-peer (SAR 1&2). All other players attending the project review may also modify their drawings on the basis of the examiner's corrections (be the examiner an expert or a teacher).

In giving this possibility to all participants to make adjustments to the document, the modifications made by the teacher become less sacrosanct, and this encourages the challenging of choices made, regardless of the participant involved. Where a classic review of a project places learners alone with the teacher with no possible interaction with their classmates, the SAR encourages exchange between students and limits competition. Sharing points of view, building common operative referentials, finding common ground and cognitive synchronization are thereby encouraged by the SAR, enabling the We-Space, but also managing the Space-Between. These SAR contribute to building common ground relative to the project, and perfectly managing activity awareness. In contrast, they do not allow social awareness (because it is difficult to know what is happening behind the screen and where such and such a background noise is coming from) and action awareness (because the SAR do not hint at the specific characteristics of each participant and their tasks in the collaborative activity). This is principally due to the impossibility of creating a Space-Between, particularly in the case of SAR 2 and 4.

7 Conclusion : Towards Articulation between Intermediary Spaces

As observed in the previous paragraphs, it is impossible to separate the intermediary spaces. The We-Space, I-Space and Space-Between as a whole define the co-work space between the actors. Nevertheless, adjusting between these diverse intermediary spaces involves flexibility that should be provided by the tool, so that each individual may easily manipulate and structure his or her interface. This flexibility is currently only partially managed by the system used in the SAR presented here. SketSha, a piece of software enabling synchronous sharing of graphic annotations, was initially designed for the pooling of synchronous work on documents, but video-conferencing does not enable the actors either side of the screen to isolate themselves and create their own private conversations. Our qualitative analysis also confirms our former results [10] : the SAR participate perfectly in group cohesion by creating intermediary spatialities between augmented presence and virtual co-presence. They aid and equip the student in learning how to collaborate. They encourage peer-to-peer sharing between learners, trainers and experts, but at the expense of independent work and the creation of private conversations. Moments of isolation enable interlocutors to express their ideas using their own knowledge, references and contexts and they tend to bring together a certain number of singularities, those of: the student, the other participants, the project to be designed and the tool being used. The designer/student must therefore juggle between these singularities by personal interpretations constructed in the I-Space and the Space-Between that he or she gradually appropriates as the collaboration process progresses.

In this way, the next generation SAR will also have to enable users to easily move between the shared work space (the We-Space as it stands today) and a personal or private space according to the needs and contexts of the collaborators. Articulation of these intermediary spaces within the SAR is currently at the pre-test stage, using technical solutions based on the use of individual graphics tablets placed upon the shared table. This will better support cognitive synchronization in the co-actors as it will be promoted by the flexibility of access to the other intermediary augmented spaces. In turn, this will promote comprehension of the complex activity that is design.

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