The interactive projection mapping as a Spatial Augmented Reality to help collaborative design: case Study in architectural design

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Abstract. This article describes the first implementation of a new SAR, spatial augmented reality, equipped here with a IPM, interactive projection mapping. It presents and analyses it as a new configuration of CSCW, Computer-Supported Cooperative Work. It reveals its success (support encouraging the collective understanding of complex shapes) but also the precautions and limits of this system of graphic interactive projection on a 3D model (delicate calibration, cognitive overload of utilization). It gives details of the adjustments to the status of co-participants (more passive), the status of work space (becoming an extended we-space) and the status of the common artifact (unmovable but polymorphic).

Keywords. Human computer interface for cooperative working, user interfaces for concurrent visualization, spatial augmented reality (SAR), interactive projection mapping (IPM), case studies of cooperative design in architecture and engineering.

1 Introduction

1.1 The stakes in collaborative design

The technical and economic stakes in big construction projects, forces one today to begin the preliminary design work in a multi-disciplinary fashion: architects, engineers, technicians, builders, and managers. Therefore users find themselves involved in dynamic participation already in the "competition" phase [1] : together, they have more or less fifteen weeks of work to imagine, develop and pre-design a large scale architectural object with many functional, structural, formal and economic dimensions. Today, in addition to their technical expertise, the designers must imperatively consider the idea of collaborative design [2]. But how to master the complexity of such a human enterprise?

Modern-day communication and information technologies provide innovative means to achieve this but most of them (BIM systems, building information modeling and PLM (product live management) concern the sharing of detailed but asynchronous information.

Our work focuses rather on the linkage of competence, in real time, for meetings of experts and project reviews [3]. We try to equip co-designer meetings, during which the participants find themselves around the same table and interact, often graphically, on shared documents.

1.2 Spatial augmented reality

We have designed and set up different tools to encourage multi-disciplinary collaboration in the design process, all based on the idea of SAR, spatial augmented reality.

This is defined as a real space onto which virtual information is projected, perceived and, above all, manipulated at the same time by different participants [4]. Our co-design environments allow them to visualize and vote, by a show of hands, to annotate documents shared in real time. Specifically, the co-design environments are composed of a surface for graphic work, real and flat (wall, desk or table) on which all the documents that are useful for the design work (drawing, plans, sketches, texts, photos, perspectives, etc.) are projected. Software, named SketSha (for sketch sharing, figure 1) enables the synchronous manipulation and annotation of the documents with the help of a digital pen. It also enables one to invite another post, with the same characteristics, to join the session and integrate in the same way on the shared documents, in co-presence or remotely (in this case, with the support of a video-conference system [5].

Fig. 1. SketSha, real time sketch sharing software.

1.3 Support to the collaborative design configurations

We have developed and set up several configurations of augmented collaborative space (SAR), in order to respond to the precise collaborative situation conditions. As explained earlier [3, 7], they concern:

- Remote Consulting (RC), to consult remote experts peer to peer (with graphic console and video-conference)
- Collaborative Remote Meeting (CRM), for team work of geographically distant designers (with interactive desk and video conference)

- Group Co-located Review (GCR), to review the collective project in a big group in co-presence (with desk and interactive wall).
- Group Co-located and Remote Evaluation (GCRE), to review the collective project with the co-participants in co-presence and others at a distance (with interactive desk, video-conference and interactive wall).

Each SAR configuration has been validated by being set up in an advanced training project for Architectural Engineers Masters Degree at the University of Liège. The observation and practice of their uses have shown real contributions to the quality of the collaboration, especially by reconsidering several statuses such as the status of the participants, the status of artifacts and the status of work spaces [7, 8].

We have shown that the SAR facilitates sharing of view points, construction of common referential operations and cognitive synchronization; in this way, they participate in the construction of a mutual conscientiousness of the activity and make the participants' status converge, developing the exchanges between them instead of competition.

Likewise, by their capacity to share graphic interaction in real time, the different SAR, assure the immediate "action/perception" coupling. Each co-author can maintain the causality link between the statements and the perception of the line on the shared artifact, giving it an operational status of boundary object shared interactively between the collaborators [9].

Finally the implementation of these SAR led to the revision of the "co-presence/remote" dichotomy in synchronous collaboration proposed by Johansen in 1998 and reused by Ellis [10] revealing the emergence of a "distance in co-presence" situation when an interaction that is based on both a direct modality (conversation in the same physical space) and an indirect modality (the annotation of a virtually shared artifact on differentiated physical supports but situated in the same place) is established.

2 The research question

Therefore, the SAR configurations implemented provide new means enabling collaborative practices around design artifacts. However, until now, the discussions and interactions were only possible for projected 2D documents (plans, cross-sections, schema, photos, views, etc.) while, in all design works, the use of physical objects is frequently observed to support the reflection process (reduced technical model, industrial prototype, architectural scale-model, etc.). When the shape becomes more complex (for example, organic or non-structured architecture), classical projected 2D presentations are indeed not enough to easily communicate the necessary information. The use of three-dimension artifacts remains in fact an effective means to assure this kind of communication. The first solution that comes to mind in these digital environments would be to simulate the physical object by a 3D digital model. But to use this type of virtual model for the purposes of presentation/creation, it is necessary that the co-designers have at their disposal a CAD software permitting synchronous collaborative work. However, this type of interaction in real time is not obvious on complex digital models because it is subject to numerous technical constraints : very heavy software interface, high-speed 3D information, management of users' interaction contradictions, etc.

Therefore, our research proposes to study the use of a real physical model in augmented design. The principle is to put the model in the Group Co-located Review (GCR) and to project the information on this model, in particular to be able to interact on the 3D surface for annotation in real time.

To encourage exchanges and understanding between designers working on complex volumetric or technical projects, it is necessary to mobilize two ideas that have been little articulated in collaborative design until now : (1) the technology of "projection mapping" with (2) the capacity to integrate synchronous graphic interaction, both in support of the idea of "interactive projection mapping" (IPM) described below.

3 Current uses of "projection mapping"

The projection of images and animations on physical surfaces is a technology that has been available for several years. Without going into a technical description of this kind of augmented reality [8], let us identify 3 principle elements of which it is composed : (1) 3D support, which is the physical element on which the projection is made; (2) the projection system and the video sequences or the images, which are the graphic elements calibrated and adjusted to the object on which they are projected; (3) finally the manual or automatic command system that manages the projection sequence.

Projection on physical objects of different scales (natural elements, water surface, buildings, urban models, furniture, etc.) are broadcast more and more in public spaces. Depending on their use, two categories can be distinguished.

- Projections of shows, which concern “sound and light” exhibitions showed to a large public during special events. This projection shows predefined and synchronized animations, often on existing urban elements, augmented by the projection to represent new visions of space. Arousing artistic emotion, this augmented reality is foremost meant to entertain the spectators but not to interact with it. (see the examples given in the figures 2a, 2b and 3a here below).

Fig. 2. (a) Audio-visual show at Festival of Lights in Lyon (www.fetedeslumieres.lyon.fr), (b) Immersive art experience in the Carrière de lumière (http://carrieres-lumieres.com/en),

- Interactive projection which, beyond the projection of preliminary synchronized images, stand out by the stakes of complementary interaction with the augmented object. The physical element serves therefore as the support for information that can be adapted on command (custom made scenarios). The interaction with the object is then carried through the bias of the command system, in the form of a game of buttons causing this or that projected episode on demand (see the examples given in the figure 3b below).

Fig. 3. (a) Dining experiences with "Le Petit Chef" (www.ilovebelgium.be/dinner-and-show-le-petit-chef), (b) Historical interactive mockup of Nantes city (http://devocite.com/?page_id=1202).

Certainly, both scenarios described here augment the object through projection. However, even if this is announced as interactive, it follows one or another previously defined scenario : it is not possible to get away from scripts that are planned and prerecorded. They are not useful to collaborative design work.

4 Towards a "interactive projection mapping" (IPM)

To enable collaborative interaction around an object in a synchronous way, a new configuration of SAR is proposed. Called "interactive projection mapping" (IPM), it is set up in the university context mentioned above (point 1.3) and is composed of :

- an architectural model, a white-colored reduced model of a building, which makes up the physical support on which interactive information is project, and which is placed on a table in the core of a group of collaborators;
- a series of still images, chosen and organised beforehand to contain the initial digital information, augmenting the model (presentation scenario);
- a high resolution beamer, located above the reduced model, projecting the digital data sent by SketSha software;
- a digital tablet, an Apple iPad® or a Wacom Companion®, on which SketSha works and whose interface permits an actor to interact, with an electronic stylus in real time (collaborative situation).

Together they enable the projection of the initial presentation scenario, composed of the preliminary still images on the physical model and to interact on the information projected at any time with the pen from the tablet.

5 Context of the implementation

This new configuration of IPM-SAR was implemented in 2016 in the context of an architecture workshop at the 1 Master architecture civil engineers level at the University of Liège in which one of the developed projects presented strong formal particularities : conceived to accommodate two auditoriums in the heart of the city of Nîmes (France), this ambitious architectural project was characterized by a complex exterior shape (organic architecture) to accommodate cultural functions such as complex organizational limits on interior spaces linked to the spectacle (figure 4).

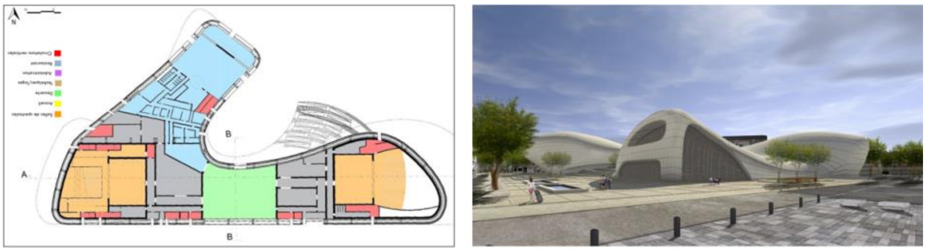

Fig. 4. Architectural plan (ground floor) and perspective drawing.

A group of two student-designers tried at first to master this double complexity, by means of a parametric digital 3D model developed by Rhino® and Grasshoppers® [11] but the realization of this sophisticated virtual model ran up against the limits of manipulation of the model, which was very complicated to permit efficient evolution of its multi-constraint shape. So they chose to work on their real model with a 1.5 meter-long physical model made in clay. This malleable matter permitted the development of their concept and to adapt it in a fluid and rapid manner throughout the three months of their design work.

However, we observed, during different reviews of the intermediary projects, all carried out on the configurations presented in point 1.3, a clear difficulty to communicate their complex project based on the traditional 2D elements.

This case study answers the hypotheses raised in the problem (point 1.2) : in fact, the physical model was at the heart of the design considerations, but lacked a means to communicate the under-lying intentions of the complex formal renderings. Therefore the new IPM-SAR configuration was adopted to support the trial of the final presentation of this architectural product. To meet the pedagogical demands, two concerns needed to be mastered : (1) present the result of the design from still images calibrated on the white model and (2) assure the defense by permitting a graphic interaction in real time on the augmented model in answer to the questions and remarks of the jury. The scaling and the rotation / translation of the images on the white model were supported through the basic functions of Sketsha, the mapping between the images and the model was realized with some landmarks common to both supports (as it is necessary to guarantee the matching of the model to the projected images).

6 Observations and discussion

The implementation of the situation was held in December 2016 (figure 5). It concerned the 2 student-designers, who sat at either end of the 1,80 m x 1,20 m projection table, and several evaluating experts who sat on a 3rd side of the table (E). One of the students (S1) assured the presentation by drawing with SketSha on a tablet (T). The clay model, painted white (M), was augmented by different images and by his interactively projected drawings. The other student (S2) commented on the interaction by hand (figure 6). A camera recorded (C) the whole presentation sequence to enable the analysis which follows.

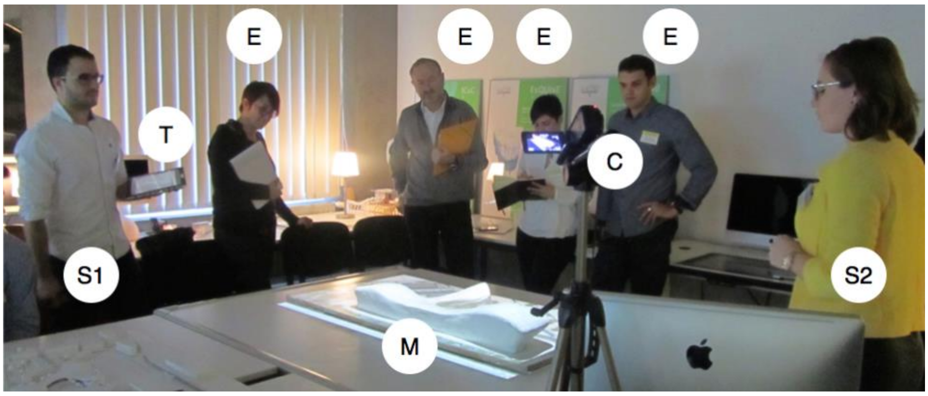

Fig. 5. Interactive Projection Mapping implementation.

Fig. 6. Interactive Projection Mapping in action: the first student is drawing lines on the mobile tablet, whereas the second student is commenting on the augmented white model while these lines are appearing simultaneously for the whole jury.

6.1 Qualitative observations

First, let us emphasize the success of the experiment: and the jury declared that it was filled with enthusiasm by the formula and assured us that they had well understood the speech and the complexity of the presented model. The trainers confirmed that the understanding of the project proved to be better than that noticed during earlier reviews which had only used projected 2D documents.

Indeed, several members of the jury attended intermediate presentations of the same project without the IPM and they were able to compare both types of the presentation. Specific project information (like users' access, pluvial flow, structure principles, etc. - notions difficult to develop and to argue in complex architecture), were all understood by the whole jury (even the members who discovered the project for the first time). This fact comforts us about the interest that the use of the IPM in the SAR can have. This first test was promising, so, during its next use, other means will be used to develop validation criteria around this notion of communication efficiency.

The implementation of this configuration led us to realize the importance of good calibration of the projection with the physical object. Of course, this calibration concerns the position and the scale of the projected images whose characteristic points must correspond to those of the model, but also the position of the model in relation to the projector, in order to reduce the inevitable impact of self-caused shadows on the model itself.

The experimentation of the new IPM-SAR then enabled us to observe that an important cognitive load had to be put into play by the drawing participant. Even though he knew perfectly well his presentation speech, the video shows that the drawn actions slowed down or even temporarily suspended his oral expression. The causes of this difficulty, noticed more in this configuration than in the other SAR, can be explained by (1) the necessity of permanent mental reorientation of the annotated drawing, taking into account that the tablet is mobile compared to the model which is stable and (2) the necessity to assure that the drawing, shown in 2D on the tablet, is correctly reflected on the 3D surface of the model. Drawing while looking only at the model proved to be impractical because of the relief of the object and the lateral position of the participant. Finally the project presentation by its augmented 3D model was not sufficient : if it proved to be a powerful means of communication to explain complex shapes, it had to be be completed by a presentation of classic projected views (plans, intersections, interior views of the model, etc.) that were put into play here in another SAR, in this case on the interactive whiteboard (GCRE SAR).

6.2 Adjustment of the statuses in the IPM-SAR

How does the status characterizing the earlier SAR evolve? Referring to those recalled in point 1.3, we can notice that the new IPM-SAR configuration brings the following adjustments.

The status of the participants has temporarily returned to a classical one : the posture has remained that of students and evaluators. This is due to the conditions of the first experiment that gave the means of interaction to one lone participant (the student drawer), the others could only remain passive in relation to the augmented object.

The work space has kept its status of we-space, bringing together all the participants in co-presence in the same collaborative space. However, this could be qualified as “extended we-space” because it integrates all the persons in the projection space (concept of "collaborative bubble") around the augmented artifact that is the catalyst.

The status of the artifact is very special in the IPM-SAR. Due to its size and weight (1.5 m one side and 30 kg.), it is evidently unique and unmovable during the interaction, in contrast to other documents put into play in the earlier SAR, whose projection enabled the alternation in the work space. However, this uniqueness is enriched by the polymorphic quality of the physical support : the object can include interactive projections of multiple subjects, as do the flat surfaces of the other SAR. Here, the model of the building is augmented, for example, by the 3D graphic representations of the supporting structures, by the flux of internal circulation, by the position of vertical circulation (elevators) or even by the sides of the roof to collect rainwater. Let us also notice that, in any case, the flat surface of the table remains accessible around the 3D model and enables annotations and interactive drawings like the other SAR (the idea of second drawings [12].

7 Conclusions and perspectives

This article describes the first implementation of a new SAR, spatial augmented reality, equipped with a IPM, interactive projection mapping. It presents it and analyses it as a complementary configuration to the 4 configurations already known in the heart of CSCW, Computer-Supported Cooperative Work. It points out its success (support encouraging the understanding of complex shapes) but also the precautions and limits of this system of graphic interactive projection on a 3D model (delicate calibration, cognitive overload of utilization). It gives details of the adjustments to the status of co-participants (more passive), the work space (becoming here an extended we-space) and the common artifact (unmovable but polymorphic). To go beyond the observed limits in this first experiment we plan two main actions :

- to make the participants active by putting at their disposal a personal tablet that will enable them to take control in their turn of the interaction with the shared 3D artifact;
- to complete the interface of the SketSha software which establishes the graphic link between the collaborators and the artifact, by an auto-orientation function of the 2D drawing shown as graphic support on individual iPads, in relation to the fixed orientation of the augmented model.

This last action will enable us to reduce the cognitive load that is necessary for the graphic interaction on the tablet : no matter what position and orientation of each participant, he can draw an image that corresponds to his point of view on the shared model.

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