Enhancing design representational environment to support design learning in the studios

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Introduction

Students enrolled in architecture school learn how to design as architects in many ways: by experiencing design in the studios, by working as interns in companies, by visiting landmarks and by discussing architectural values with peers. The design studio stands as the hallmark of architectural programs. The studio culture, derived from the Beaux-Arts ateliers, is based on the apprenticeship model of teaching and learning. In traditional studios, students produce various visual design representations to present their project's state of progress. Plans, sections, diagrams, 3D models, mock-ups and sketches create the external design representational environment of the design critique. During the 'crits', students get a feedback from their instructors, most of the time a practicing architect, who guide them in adjusting and refining their design. Both tutors and learners experience designing actions, while handling representations to reflect and act on the project. Design knowledge is embedded in design representations, and its manipulation set the framework for students to shape that knowledge.

This article will question the potential of an alternative representational environment, set for the crits, to support design pedagogy. We will emphasize the importance of the design representational environment as a major feature of the pedagogic setting in the studio. CORAULIS, an immersive platform, will be built in our university by the end of 2017. The device will provide alternative types of design representations, displaying simultaneously an immersive egocentric view and a dynamic exocentric view of the design within a unique physical space. This equipment will be our test-bed to assess the impact of a change in the design crits representational environment on its pedagogic.

In the first part of the article, we will describe the context of our research as well as our hypothesis. The second part will present devices analogous to CORAULIS, that offer dynamic design representations using Virtual Reality (VR), Augmented Reality (AR) or interactive tables, to support design learning. In the third part, we will question the structure of the design learning process during the crits to define its pedagogic characteristics. Finally, we will argue how our proposed critique setting could benefit the learning outcome in the studio by enhancing the pedagogic features underlined.

Context and framework

CORAULIS, an immersive platform designed by a team of researchers in our laboratory, will shortly be installed at our university. It will support visual and

sound immersion with its 360° screen and provide a Spatially Augmented Reality (SAR) table top to augment physical objects (Fig. 01). The size of this high-tech device allows for a table to fit in its center, where users can position their traditional design representations, like mock-ups and 2D printed plans. The 3D model of the same design object will be used to create two virtual views: the top down view, to be mapped onto the mock-up and plan (thanks to SAR techniques) and the first person view, that will be projected on the 360° screen. A user interface is under development to manage interactions (walking, flying) and simulation layer display in both views.

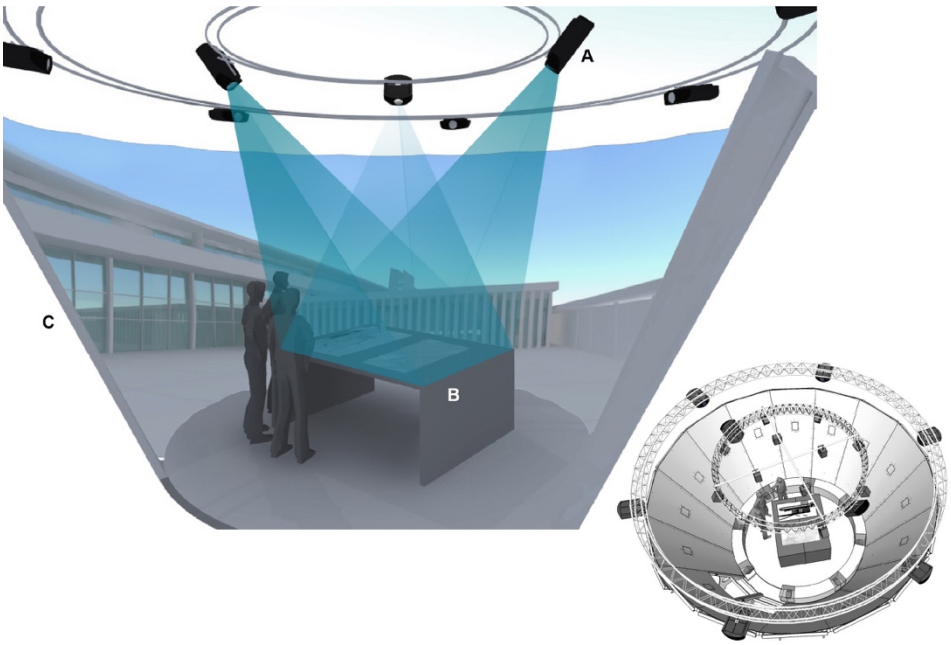

Fig. 01. Possible configuration for CORAULIS (A: 4 beamers for SAR, B: tabletop with augmented plans and mock-up, C: immersive screen)
Source: renderings made by the authors.

Students enhance their skills on spatial representations by handling multiple representations, switching from top-down view, to sections, or to first person sketches. We intend to transfer the traditional desk crit environment of the studio to the CORAULIS environment to test its potential concerning design education. Our hypothesis is that offering a representational environment that supports diverse viewpoints' display, as well as immersive and interactive representations in a unique space, will enhance students' design skills and their learning process. The challenge of the platform's application is to maintain a synchronization between both views. A change in the top down view, as for instance the adjustment of a building envelop, will automatically appear in the first person view representation. The impact of such an application in CORAULIS can be twofold. On one hand, the upraised perception of the project at a scale 1:1 can augment the design quality of the project, due to the feeling of embodiment and presence

offered by VR. And on the other hand, the synchronized 2D/3D environment can assist students to develop their ability to seamlessly switch from one representation to another, and enrich their learning outcome. In the next section we will describe existing devices proposing an alternative type of representational environment to support design education. The potentials and limits of these references gave us insights to develop our own application framework.

Use of VR, AR and hybrid platforms to support design education

Extended research was conducted in order to develop tools providing alternative types of design representations, using Virtual Reality (VR) and Augmented Reality (AR) techniques. The two essential characteristics of VR are immersion and interaction[1]. The user can navigate an artificial environment, that provides a sensitive experience. On the other hand, AR offers a superposition of virtual information in the real environment, that are displayed either with a HMD (Head Mounted Display), a smart tablet or physical surfaces (SAR)[2,3]. Depending on the display setting, these devices propose different uses and aim to support various activities of the design process. We identified six display configurations (HMD VR, Immersive screen VR, HMD AR, Screen based AR, indoor SAR and augmented table top) that we will exemplify to highlight their potential.

The CAP VR environment, an example of HMD VR, was employed for an architectural design studio, by second year students at Ball State University[4]. Students used the HMD to visualize their design during studio sessions. This immersive representational environment upraised students' spatial perception of their design. The analysis of students' design quality showed the positive impact it had on students' design outcome, underlining the educational potential of such a device. Nevertheless, the limit of this tool is that it prevents natural communication between students and tutors, since the student is wearing the HMD. Immersive screen VR is an alternative to the HMD VR. The Hyve-3D proposes an immersive sketching environment, set in a half-hemispherical screen, for students to develop their creativity and experience co-design[5]. Several collaborative design studios, between students based in Montreal, and in France

[1] Fuchs Philippe; Moreau Guillaume; Guitton Pascal, eds. *Virtual Reality: Concepts and Technologies.* London, UK: CRC Press, Taylor & Francis. 2011.
[2] Azuma Ronald. "A Survey of Augmented Reality," *Presence: Teleoperators and Virtual Environments* 6. no. 5. 1997. p.355-85.
[3] Raskar Ramesh; Welch Greg; Fuchs Henry. "Spatially Augmented Reality," in *First IEEE Workshop on Augmented Reality (IWAR'98)*. 1998. p.11-20.
[4] Angulo Antonieta. "Rediscovering Virtual Reality in the Education of Architectural Design: The Immersive Simulation of Spatial Experiences," *Ambiances. Environnement Sensible, Architecture et Espace Urbain*. 2015.
[5] Dorta Tomás; Kinayoglu Gôkçe; Boudhraâ Sana. "A New Representational Ecosystem for Design Teaching in the Studio," *Design Studies.* no. 47. p.164-86.

or in the USA, were organized with critiques lead in the platforms set in each university. Users seamlessly interact with their designs, and can perform collaborative immersive sketching thanks to a 3D cursor interface. Protocol studies, combined with the monitoring of users' design flow, supported that the platform enhances design creativity. Another example of immersive VR is the Immersive Visualization Theatre (IVT), a large screen with stereoscopic visualization, that hosted design critiques as a part of a case study at Technion University[6]. The aim was to compare the type of knowledge construction actions during critique sessions in the IVT and traditional desk crits. The study showed that deeper learning loops were more present in the IVT crits, so it could benefit students' knowledge construction. For both types of VR display, the main feature is the scale 1:1 visualization of the project, that upgrades the design evaluation process as well as the design quality outcome. The limit is that the representational environment is only set in the virtual world, putting aside tangible representations.

The use of AR to accompany design process and education is praised to augment collaboration and communication, merging virtual and physical information. Experimentations with BenchWork showed the potential of the integration of CAD, AR and simulations for design collaboration and desk critiques[7]. Users, wearing a HMD, can interact with the same virtual model with the help of a toolbox, and create new objects or modify existing ones. Screen-based AR became easily accessible with the commercialization of smart tablets. A recent study formalized impacts of the use of SDAR (Smart Device AR) on design communication during a collaborative design activity[8]. Students, teamed by pair, relied on the physical model to work on an urban project. Half of them also used the SDAR application. The analysis of the design conversations showed different behaviours depending on the setting. This study pointed out that with SDAR, the time span of the designing and revising design was longer than in a traditional setting, showing the efficiency of that tool for a design session. At a smaller design scale, the SARDE (Spatially Augmented Reality Design Environment) application provided a suitable setting for an interior design session[9]. The authors emphasize the difficulty for students to represent their design in diverse format (2D and 3D) and to acknowledge design issues. The study

[6] Soffer Hadas. "Immersive Virtual Environment Technology: A New Crit Learning Model," in *Proceedings of Places for Learning Experiences: Think, Make, Change Symposium*. Thessaloniki, Grèce. 2015. p.236-246.
[7] Seichter Hartmut. "Benchwork: Augmented Reality Urban Design," in *Proceedings of the 9th International Conference on Computer Aided Architectural Design Research in Asia*. Seoul, Korea. 2004. p.937-46.
[8] Gül Figen L; Halici Müge S. "Collaborative Design with Mobile Augmented Reality," in *Proceedings of the 34th eCAADe Conference*. Oulu, Finland, 2016. p.493-500.
[9] Chen Chien-Tung; Chang Teng-Wen. "1: 1 Spatially Augmented Reality Design Environment," in *Innovations in Design & Decision Support Systems in Architecture and Urban Planning*. Springer. 2006. p.487-99.

couldn't show the impact on the learning outcome, but students expressed the positive experience they had using the device for an on-site, scale 1:1 refinement of their project. For HMD AR and SDAR, collaboration and interaction with the virtual model through tangible objects is put forward, while on site scale 1:1 design and evaluation is the main quality of SAR applications.

Augmented tabletops provide a suitable environment for collaborative design and decision making. Simulations, like shadows, wind flow or agents are easy to grasp while displayed on the interactive table. The Luminous Planning Table was used for design studios at MIT to support students designs and learning process[10]. Most students asserted a positive feedback on the use of the device for their project. Representing urban simulations, while using an accessible tangible interface, improved the integration of those factors in their design process. The Collaborative Design Platform is also worth mentioning[11]. It offers a similar design environment composed of an interactive table top and a vertical screen for first person view. Urban designers, when they display foam mock-ups on the table, can see how it affects wind flow or shadow cast on the whole urban site. The same 3D scene is displayed on a vertical screen, providing an egocentric representation of the urban proposition.

Those examples draw the outlines of our research references' context. The advantages brought by those devices are either the embodiment of the user in the virtual environment, projects' representation at a scale 1:1, design collaboration or the contribution to the design quality supported by the display of interactive simulations. The potential of those devices for design pedagogy unveils but is not yet clear. It seems necessary to question the structure of the design learning process, in order to develop a suitable representational environment framework that can support design pedagogy in the studio. In the following section, we will highlight specific features of design learning in the studio.

Learning how to design in the studios

The design studio is the cornerstone of architectural degree programs. Students and tutors meet once to twice a week, in the studio for a design critique session. Each student presents his/her work in progress, which is followed by a discussion on the design quality. During that moment, design propositions are evaluated, issues are discussed and potential solutions are formulated. Students develop design skills in a process of trial and error, by practicing design.

[10] Underkoffler John; Ishii Hiroshi. "Urp: A Luminous-Tangible Workbench for Urban Planning and Design," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM. 1999. p.386-93.

[11] Schubert Gerhard et al., "Bridging the Gap: A (Collaborative) Design Platform for Early Design Stages," in *Proceedings of the 29th eCAADe Conference*. Ljubljana, Slovenia. 2011. p.187-193.

Instructors act as a source of design expertise and guide students in their designing process. The studio setting benefits the social constructivist approach of learning and can be mapped onto the "community of practice" concept[12,13].

Schön[14] considered design studio as an educational model to support the development of tacit knowledge or reflection-in-action, that are specific to professional knowledge. Constructed design critiques are essential to provide an efficient learning setting[15]. Design knowledge are shared during the critique, between the instructor and the students. Tutors have a knowledge-in-action about design, which means that they know how to design in practice. Most of the time, they highly struggle to describe how they design, because they are not fully aware of the design processes they exploit. Indeed, Curry[16] underlines that depending on the level of expertise designers have, they call different types of knowledge to solve design issues. While experts rely on procedural and strategic knowledge (knowledge-in-action), novices and advanced beginners (students) depend on their factual, conceptual and a few procedural knowledge. Experts developed their design knowledge through years of practice, where they assimilated design strategies, or what Schön's refers to as "design repertoires"[15]. During the critique, instructors challenge students' designs, and if design issues are pointed out, get involved in design demonstration or a collaborative design activity with the student. This mode of teaching is necessary since the learning objective is design itself which cannot be only described as factual knowledge and procedural activities. Students learn during the critique, either by observing their tutor performing a design activity or by engaging in a co-design activity.

Design conversations between students and tutors, that follows students' presentation of their project, is an important moment of the crit session. Fertile and constructive communication between the learner and the tutor will support a suitable learning framework. Nonetheless, the asymmetry of design knowledge between the expert (tutor) and the novice (student) can hinder mutual understanding on design issues. As explained before, experts possess procedural and strategic design knowledge that they seamlessly recall to solve design issues. Students will need some years of practice to acquire that type of knowledge. This

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[12] Vygotsky Lev. *Mind in Society: The Development of Higher Psychological Processes*. Cambridge Massachussets. Harvard University Press. 1978.

[13] Lave Jean. "Teaching, as Learning, in Practice.," *Mind, Culture, and Activity* 3(3). 1996. p.149-64.

[14] Schön Donald. *The Design Studio*. London. RIBA. 1985; Donald Schön, "The Architectural Studio as an Exemplar of Education for Reflection-in-Action," *Journal of Architectural Education*. 1988.

[15] Dinham Sarah M. "Teaching as Design: Theory, Research and Implications for Design Teaching," *Design Studies* 10, no. 2. 1989. p.80-88.

[16] Curry Terrence. "A Theoretical Basis for Recommending the Use of Design Methodologies as Teaching Strategies in the Design Studio," *Design Studies* 35, no. 6. p.632–46.

asymmetry of knowledge favors a student/instructor relationship based on the dependency of the student upon his/her instructor. Oschner[17] underlined the vulnerability of students during the studios and the importance of maintaining a constructive bond in the student/instructor relationship.

The design discussion during the critique is set in the representational environment. Visual design representations form a communication space for the participants to express and share their mental models of the architectural project, and engage in designing[18]. Goel[19] proposed a model to link design phases, design representations and their transformations' types: lateral transformation, a change in the concept and vertical transformation, a detailing of a concept. For Schön[15] and Goldschmidt[20] design representations influence the direction taken during design activities. Oxman[21], on the other hand, argued how re-representing designs can be a key element of design education. Design activities imply a modification of the design representations which give a feedback to the designer on its own design. Design knowledge is embedded in external design representations which supports that they act as a major factor in the pedagogic setting of the critique. While discussing design issues, representations' manipulation situates design activities in a specific representational environment.

Based on literature references, we pointed out pedagogic characteristics of design critiques in the studios: 1) Design learning is based on an observation of a design activity or collaborative designing during the crit; 2) The asymmetry of design knowledge between tutors and students accentuates the importance of tutor/student relationship; 3) Design knowledge is embedded in the design representational environment.

Supporting design learning by offering a suitable critique setting

The design representational environment set the space for discussing design issues and constructing design knowledge during critique sessions in the studios. VR and AR techniques offer alternative types of representations that are immersive, interactive and promote users' collaboration. CORAULIS, merging both technologies, sets a crit space that will address the pedagogic characteristics underlined above. First of all, it will offer an intelligible design representational environment to favor communication and collaboration between instructors and

[17] Ochsner Jeffrey K. "Behind the Mask: A Psychoanalytic Perspective on Interaction in the Design Studio," *Journal of Architectural Education* 53, no. 4. 2000. p.194-206.
[18] Goldschmidt Gabriela. "The Black-Curtained Studio: Eulogy to a Dead Pencil," in *SCAD Symposium Proceedings*. Bremen. 2011.
[19] Goel Vinod. *Sketches of Thought*, MIT Press, 1995.
[20] Goldschmidt Gabriela. "On Visual Design Thinking: The Vis Kids of Architecture," *Design Studies* 15, no. 2. 1994. p.158-74.
[21] Oxman Rivka. "Educating the Designerly Thinker," *Design Studies* 20, no. 2. 1999. p.105-22.

students. The display of simulations can accelerate the evaluation process and lead to fertile discussion on design issues. That upgrade of the representational environment lays the space for knowledge sharing and co-construction. While co-designing, students experience a higher level of active participation, constructing their designing skills in a sustainable way. Moreover, the sense of presence provided by immersive representations can support a better understanding of the design being reviewed. The display of multiple and synchronized views on the architectural project can entail a better understanding of both student and tutors' mental model of the project to avoid misunderstanding on the design's concepts. Finally, students can upgrade their skills to switch from diverse representations format, within the same representational environment. The features proposed in our framework will impact students' way of constructing their knowledge and can be beneficial for their learning outcome.

Our future work will consist of running an experiment to verify our hypothesis. We intend to compare critiques' design learning potential in a traditional setting and in the CORAULIS setting. Our evaluation will be based on the critique conversation analysis, using the protocol analysis method[22]. Commonly, this method is exploited to study designers' behaviour, so it will be adapted to analyze design learners' behaviour. The method aims to assess the type of design actions happening during the crit, students' engagement in these design or co-design activities and the way they manipulate design knowledge embedded in the representational environment. The information deducted by our critique conversation analysis method will give us insights on the students' behaviour during the critique as well as an indication of its pedagogic quality. A short interview with both tutor and student, after the crit session, will complement that first approach, and include learners' and tutors' perceptions in the overall analysis. The stake of our work is to test the performance of a device like CORAULIS in a pedagogic situation, considering a single crit session as a unit of analysis. Our approach can provide foundations for future interventions in the studio pedagogy to improve student learning.

[22] Ericsson Anders; Simon Herbert. *Protocol Analysis: Verbal Reports as Data*. MIT Press. 1984.; Gero John; Mc Neill Thomas. "An Approach to the Analysis of Design Protocols," *Design Studies* 19, no. 1. 1998. p.21-61.