Use of Immersive Virtual Environment in the Design Studio

An Assessment Model

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The Architectural Studio is dedicated to teaching students the design process. Students learn by developing an architectural artefact in increasing complexity. They do so through three phases: structuring the problem, developing design proposals and converging decisions into a detailed solution state. This process has been taking place mostly in traditional physical settings. The advent of new technologies, most notably Immersive Virtual Environments (IVEs), introduces a new kind of setting that holds promise to influence the architectural learning process. This paper describes a model we have developed to assess the impact of IVE on this learning process. To do so, we have developed a method for coding learners' design decisions and the way they are developed, accounting for their educational settings - whether a traditional studio classroom or an IVE. The method consists of units we term Knowledge Construction Activities (KCAs) and reveals the relationship between the learning process and the educational setting in which it takes place, through time. The results revealed that the IVE supported extensive design development, especially during the second and third learning phases, calling for an informed integration of IVEs in future Studio syllabi.

Keywords: Design Studio, Knowledge Construction Activities, Immersion, Design process, Design analysis

THE ARCHITECTURAL STUDIO - GOALS AND MEANS OF THE LEARNING PROCESS

The architectural Studio serves as the prime environment for learning the design process. Aided by expert tutors and peers, students learn the process by developing a design problem in increasing complexity throughout one or two semesters. The syllabus is commonly designed to include three main phases: (a) investigation of an existing setting, specification of goals and initiation of preliminary conceptual design decisions; (b) development of an architectural artefact through confronting design conflicts and creating alternatives; (c) convergence of design decisions into a detailed solution state (Jones, 1980). Students often struggle in advancing their projects through these phases, due to design's “wicked” nature. Since neither the problem nor the solution are determined, the choice of defining a problem depends upon previous design decisions and affects subsequent ones (Rittel & Webber, 1973). Studio crits
thus serve as a key setting for confronting these difficulties and acquiring proper design knowledge.

Notably, Architectural design is highly dependent on representation tools. Due to buildings’ size and complexity, the architectural product cannot be prototyped and evaluated until it is fully built. It is therefore evaluated and developed through the utilization of various representation forms at all design stages. These representations contain the designer’s knowledge and lay the groundwork for further design progress (Lawson, 1990; Ferguson, 1994). Each form of representation may serve different purposes. Schematic drawings or diagrams may be useful for early design stages or for specifying design principles, while highly developed drawings and models are beneficial for confronting the complexity that the architectural artefact carries, such as identifying design conflicts between various parts of the design or evaluating the design in context. Highly-developed designs, then, are regularly required in the advanced years of study, and are considered significant educational means for learning the design process. Given that different media deliver different messages (McLuhan, 2006), the choice of using certain media during the design process may stimulate or hamper further design activities.

IMMERSIVE VIRTUAL EDUCATIONAL SETTING

This paper focuses on the affordances offered by Immersive Virtual Environments (IVEs) in support of the Studio’s educational goals. These environments enable users to perform a virtual walk-through and experience a sense of presence in the dynamic display (Slater, Usoh, & Steed, 1995). IVEs were found to support training in dangerous or inaccessible spaces (Freina & Ott, 2015), and to ease cognitive load in several fields, such as chemistry (Limniou, Roberts & Papadopoulos, 2008), geoscience (Billen et al., 2008) and engineering (Messner et al., 2003). Immersive devices were also found effective for supporting communication amongst learners (Bower, Lee, & Dalgarno, 2017), improving learning outcomes (Johnston et al., 2018), and developing and detailing design artefacts (Alatta & Freewan, 2017).

Although still rarely used in Architectural education, IVEs are already acknowledged as able to support the essential pedagogical values of the Studio, such as spatial comprehension (Kalisperis et al., 2002; Paes, Arantes, & Irizarry, 2017), flow of design decisions (Safin et al., 2016), learning experience (Castronovo et al., 2017), productivity (Sopher, Kalay & Fisher-Gewirtzman, 2017) and design reviews (Bassanino et al., 2010).

These studies clearly show the potential IVEs have for Architectural education. Since students rarely realize their projects, and perceive them mostly through static, sequential and scaled representations, we assume that these environments may become a desirable setting for supporting the Studio’s objectives and means.

ASSESSING DIFFERENT LEARNING ENVIRONMENTS IN TERMS OF STUDIO EFFECTIVENESS

The possibility of choosing between different educational settings raises a fundamental question: which environment better supports the Studio’s changing needs throughout the semester? Until now most Studios have exclusively used the traditional classroom space, therefore researchers lacked the ability to account for multi-environment syllabi. They focused, instead, on modes of communication (Oh et al., 2013; Schön, 1987), learner and teacher profiles (Goldschmidt, Hochman, & Dafni, 2010), educational content (van Dooren, et al., 2013), design methods (Cross, 2006; Lawson & Dorst, 2009), and supportive design tools (Andia, 2002). Consequently, while students are often encouraged by their tutors to use a certain design tool to promote their progress, the spatial setting is usually absent from the conversation. This keeps tutors from improving support for their students through this important channel.

We argue that due to prevailing technological developments, the impact of space on the learning process can no longer be disregarded. To assess this
impact, we developed a method for evaluating the learning environments’ effectiveness for learning the design process (Sopher et al., 2017). The method was applied to an Architecture Studio course at the Faculty of Architecture and Town Planning, Technion, Israel. The course, taught by Professor Dafna Fisher-Gewirtzman, used both a traditional studio classroom and an IVE as educational settings. Analysis of the learners’ design decisions that were presented in the two environments showed that the IVE was more supportive of productive learning. The current study further investigates these issues and proposes a detailed view of the way the IVE was used along the Studio’s learning phases.

MEASURING LEARNING PATTERNS OVER TIME

The objective of the reported study is to evaluate the affordance of different learning environments with respect to the Architectural Studio learning phases. To achieve this goal, we made use of the theory of Place (Canter, 1977; Lefebvre, 1991). Place emerges from the interaction between users and their social and environmental settings. The environment is considered an active component that supports or restricts certain interactions that may cause the appearance of behaviours.

In keeping with the above notion, we consider learning activities performed in the studio as situated patterns that emerge from interaction of students with the teacher, with each other and with the educational settings. Each learning pattern represents a learner’s design decision that is presented and discussed in class. These patterns then serve as the basis for further knowledge construction. We refer to these patterns as units of Knowledge Construction Activities (KCAs) (Sopher et al., 2017). Each KCA pattern consists of a design activity and the spatial and social settings it emerged from. Spatial setting comprises the physical and virtual elements that were utilized during the crit, such as the classroom, drawings, models and the virtual display. Social setting includes all crit participants and the form of discussion, such as personal crit, group crit, or formal reviews. Design activities include all learners’ design-process decisions; commonly known as Analysis, Synthesis, Evaluation (Lawson, 1990) as presented during the crit. KCAs are coded and mapped onto a graph that describes their emergence throughout the course; allowing an analysis in reference to the Studio phases (Figure 1).

![Figure 1](image_url)

**Design development analysis**

Architects and students utilize representations to evaluate and further develop their designs (Lawson, 1990). It can be said that design knowledge is embedded in and constructed upon these representations at different levels of detail, serving different purposes. Suwa & Tversky (1997) depict the kinds of design topics that students perceived in their drawings and the way these led to further design advancement. It may be further stated that the more a project is developed, more design topics that co-influence one another enter the crit discussion thereby enhance learning. This paper demonstrates the way different settings are utilized during the learning process to develop the architectural artefact.

A design’s level of development is determined by the form of representation, its purpose, and content. A low level of development signifies a preliminary thought, that is usually out of scale or context. Highly developed diagrams that are precise and show a relation to other diagrams (e.g., circulation and structure) signify a high level of design development.
circulation and structure). Floor plans, sections and models are means to describe and reflect upon the artefact’s complexity, materials and context. Their degree of development is determined according to this desired complexity. Poorly developed drawing and models might be scale-less or ignore context and materials, while advanced ones would express these properties. Figure 2 demonstrates diagrams and models in increasing level of development. Table 1 depicts the grading principles of the level of development. The KCA model provides a flexible platform for evaluation, which can obtain more properties or detail them as needed.

CASE STUDY
In order to answer the research question, we followed two Studio courses. Both courses took place at the Faculty of Architecture and Town Planning, Technion. The first course (ARCH02) was taught by Professor Dafna Fisher-Gewirtzman, during spring semester, 2016. It used a traditional studio classroom and an IVE, at different intervals. The second course (ARCH03) was taught by the Architect Ruth Liberty-Shalev, during fall semester, 2017. It used only a traditional studio classroom, thereby serving as a control group for the experiment. The research sample included four undergraduate students from each course. All students were in their third year of study. Figures 3 and 4 show the Studio crits. Figure 3 is an IVE crit and figure 4 is a personal desk crit performed at the traditional studio space.

The faculty’s IVE corresponds to the definition for immersion provided by Slater et al (Slater et al., 1995). It is equipped with a 2.4 x 7.0 meter screen with a 75° field of view and three synchronized projectors enabling a dynamic 3D display (with the aid of 3D glasses). The space provides shared display for up to twenty people. Immersive experience is enabled when one participant moves through the model in what is termed a virtual “walk-through”. The lab supports a large-scale display of static images and walkthroughs of Sketchup, Rhinoceros and Revit models.

The experiment’s tools included non-interfering observations, documentation of learners’ design products, and recordings at each crit during the en-
<table>
<thead>
<tr>
<th>Form of representations</th>
<th>1- Schematic</th>
<th>2- Moderate development</th>
<th>3-Highly developed design</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diagrams</strong></td>
<td>Form (E.g., Morphology)</td>
<td>No constraints: No scale; no context</td>
<td>Preliminary constraints: Scale; Structure; context</td>
</tr>
<tr>
<td><strong>Function</strong></td>
<td>Primary functions; Relations between functions</td>
<td>Sub-functions: Areas; Relations between sub-functions</td>
<td>Primary functions and sub-functions: Scaled areas in form; Scaled relations in form</td>
</tr>
<tr>
<td><strong>Use (E.g., circulation, viewpoints)</strong></td>
<td>No constraints: No scale or context</td>
<td>Preliminary constraints: Scale; different users, heights</td>
<td>Under constraints: Scale; Implementation onto the designed form</td>
</tr>
<tr>
<td><strong>Drawing</strong></td>
<td>Plans and sections</td>
<td>Scale is optional; No materials, interior or exterior content</td>
<td>Scale; Preliminary materials; preliminary interior or exterior content</td>
</tr>
<tr>
<td><strong>Architectural Details</strong></td>
<td>Scale is optional; No joints</td>
<td>Scale Preliminary materials and joints</td>
<td>Scale Developed materials; and joints</td>
</tr>
<tr>
<td><strong>Models</strong></td>
<td>Physical and virtual</td>
<td>Scale is optional; Primary volumes; No materials; no interior or exterior content</td>
<td>Scale Preliminary materials; Preliminary interior or exterior content</td>
</tr>
</tbody>
</table>

Additionally, course Arch03 had a preliminary team exercise that took part from the beginning of the semester and was completed by the first interim crit - thus leading the individual design process to be spread over a shorter learning period than course.
ARCH02. These differences limit the ability to compare the two syllabi, but nonetheless provide significant information regarding the way different settings were used during the learning process.

RESULTS
Analysis retrieved 351 KCAs in course ARCH02, and 300 KCAs in course ARCH03. Intending to reveal the way learning spaces affect learning through time, the authors followed the syllabi, and utilized interim crits as points of transformation to the following learning phase (e.g., stage two starts at the first interim crit).

Analysis of the level of design development
In order to illustrate progress in the design learning during a course, the analysis shows the average levels of design-development that was achieved by all students per crit (Figure 5). Results reveal a significant difference between the two courses throughout the semester. Students in course ARCH02 developed their projects to a higher level than students in ARCH03 as the course went on. Additionally, the rise in the level of design-development of ARCH02 shows greater consistency than course ARCH03; this may imply that a stronger stimulus for the students was present during the course’s crits.

Students in course ARCH02 developed digital models during the early learning phase, allowing them to experience a virtual walkthrough at the IVE. These digital models were the main source of communication during the crits. Physical models were produced during the first learning stage, but were
scale-less or partially complete and served as conceptual entities. Students in course ARCH03 had a different narrative. Extensive design activities were performed over plans, sections and architectural details. Broad use was made of physical models during all learning phases, with attention to scale and materials. Although all students had access to a digital model of the existing site (due to previous teamwork), most control group students chose to prepare physical models that ignored the context. Digital models were prepared during the late second learning phase. These were developed before the final review, enabling them to present tangible images and animated films.

Figure 6
The average level of design-development of KCAs in course ARCH02 through the semester, along with the learning environments in use.

Figure 7
The level of design-development of Synthesis KCAs, produced by course ARCH02, within the traditional studio classroom and the Immersive virtual environment.

Development ratios within the learning environment
Course ARCH02, as a multi-environment Studio, deserves a deeper examination. Figures 6 and 7 depict the impact of the learning environments on learners’ progress. Figure 6 provides the average level of design-development during crits and their utilized space. Results reveal significant increases in activity before IVE crits, showing the IVE’s competence in encouraging the use of this learning medium. Most importantly, this pattern occurs before informal crits as well as before formal presentations. Since students tend to provide detailed presentations during formal crits, these results emphasize the IVE’s capabilities during informal crits, thus significantly strengthening the research hypothesis.

As seen in figure 6, the use of the learning environments was not spread equally throughout the course. The first learning phase had a sole introductory IVE crit, ending with a formal interim crit at the IVE. Therefore, the learning process was mainly studio based. Lessons 1-6 show a mild increase in design evolution, and a steeper one in the last two crits (lessons 7 and 8), before the interim review. The second learning phase had three IVE crits that formed 27% of the section. The phase contains increased detailing performance in both learning environments. The third learning phase mainly utilized the IVE. By then, most digital models were highly developed and were explored through virtual walkthrough. The traditional studio crits during this phase served for discussing plans and sections that were less detailed, what explains the decrease of development in this learning environment.

Figure 7 shows the ratios of Synthesis KCAs, within the learning environment. In Architectural pedagogy, Synthesis decisions are especially important. In this type of design process activity, learners construct their knowledge by formalizing solutions on the architectural artefact. Findings show correlation between IVE crits and highly developed synthesis KCAs. Notably, during the first phase of the course, the students mainly utilized the traditional studio, leading this environment to serve as the main support for structuring the design problem through raw and schematic design decisions. Further investigation is thus needed for clarifying the competence.
of IVEs for early learning phases.

**Individual students’ learning progress**

The KCA model provides analyses of each individual’s performance. Figure 8 demonstrates the learning performance of each student during the course. The chart shows each learner’s trend-line of design-development and demonstrates the students’ varied pace as the semester progressed. Students S03 and S04 from course ARCH03 clearly benefitted from the course’s formal social setting. Both students showed a steep rise from the mid second phase, performing intense design activities before formal reviews. Student S02, on the other hand, invested her time in adjusting the project’s morphology, performing fewer development decisions. The emergence of new ideas during the last learning phase led student S02 to a decrease in the development rate. Awareness to these kinds of knowledge construction patterns allows the attending tutors to personally support their students’ needs. Student S02 may need more encouragement to detail her design, in order to cope with additional levels of complexity. A student that designs a specified and detailed artefact quite early may need to experience some conceptual design exercises, in order to experience and apply different design principles onto the artefact. The KCA model, then, is a suitable framework for taking pedagogical decisions that promote individual capabilities.

**CONCLUSIONS**

The Architectural Studio has long served as a model for pedagogical innovation, by affording flexible setting for teaching models, accommodating different tools and personal evolvement (Schön, 1985). However, due to prevailing developments in technology leading to fundamental changes in the educational settings, it lacks a suitable answer for maintaining this advantage for the years to come. To cope with this shortcoming, the authors developed a framework for
evaluating the different settings’ effectiveness for the Studio’s objectives and for needs changing through time.

KCA analysis revealed that different learning environments affected learners’ performance. The IVE was found to encourage intensive development of Architectural artefacts, particularly in Synthesis design decisions. Use of the traditional studio space was correlated with raw material and schematic design decisions. A difference was also found in the treatment of the artefacts. Intense development of digital models was recorded in the multi-environment course, whereas the traditional course presented highly developed plans and sections.

Analyzing the courses’ learning intervals reveals major differences between them, in terms of pace and degree of performance. Results identified the IVE’s competence for supporting advanced learning phases, which concern the evaluation of relatively detailed forms. Further investigation is needed to identify this setting’s capabilities during early design stages. These results provide a significant basis for the hypothesis that there is a relationship between learning environment types and learning. Studio learning is a process that evolves through changing settings and time. As such, the Studio syllabus ought to address these needs. The current study casts light on the high competence of the KCA model in integrating educational components into measurable units that can support multi-criteria evaluation and future syllabus design.

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