Teaching the process of design is a primary objective of the architectural studio. Due to the complexity of the process, the studio encourages active learning and peer participation during crit sessions. This paper explores the potential of immersive virtual environments (IVEs) for enhancing architectural learning, and proposes a framework for evaluating its educational potential. We have developed a model for coding the three main activities of the architectural design process (analysis, synthesis, and evaluation), along with their physical and social settings. The model comprises of units we call Knowledge Construction Activities (KCAs). We suggest that this model presents a detailed description of the environmental implications of each activity. Applying the KCA model to a studio course that used both a traditional classroom and an IVE revealed that the IVE increased the number of synthesis KCAs, and supported effective criticism. Though limited in scope, the results clearly indicate IVEs potential contribution to architecture pedagogy.

Keywords: Architectural education, Design process, Immersion, Virtual environments, Place

INTRODUCTION

The Pedagogical Aims of the Architectural Studio

Teaching “design knowledge” to architecture students has always been the greatest challenge of the architectural profession, because it has no determined definition (Rittel & Webber 1973). Rather, students must independently construct their knowledge by personally experiencing the design process as it is applied to solving a design problem. They are asked to apply acquired knowledge, concepts, and skills to their design project, guided by a professional tutor and by peer support.

Architectural design encompasses multiple problems, ranging in complexity from the conceptualization of desired goals to the point of attaining a satisfactory solution (Kalay, 2004a) (Figure 1). Goldschmidt highlighted this complexity, revealing the numerous repetitions of different design steps (Goldschmidt et al., 2010; Goldschmidt, 2014). Since learning is based on the learner’s progress, each step must provide stimuli for the production of progres-
sive design decisions, creating learning opportunities that can be discussed in class. Students are often required to use representational objects, such as models and scaled drawings, to communicate their ideas. However, these means only partially convey the complexity and richness involved in the reality they represent, thereby limiting the ability of students to develop their knowledge.

Furthermore, architects learn by sharing knowledge with colleagues and consultants, and through evaluating their own decisions post construction. Students’ projects, on the other hand, are never realized. Hence, learning is highly dependent on precedents and the teacher’s experience.

In order to overcome this obstacle, the studio pedagogy strongly promotes peer participation during design crits. In this respect, architectural knowledge acquisition follows the principles of the constructivist theory of learning, contending that learning is individually and actively constructed by the learner, and strongly bound with its community of practice (Kurt, 2011; Lave, 1991; Lave & Wenger, 1991). Research indicates that peer participation is beneficial, because it enriches the learner’s understanding with multiple opinions and possible solutions, and encourages self-assessment (Farivarsadri, 2001; Oh et al., 2013; Ochsner, 2000; Schön, 1987). Peer support, however, should be viewed in a critical manner, given that it can sometimes be unconstructive or misleading, due to lack of knowledge or competitiveness (Dutton, 1984). However, the fact that exposure to peer projects promotes self-assessment highly emphasizes the advantage of presenting design decisions in group crits.

Changes in the Architectural Learning Environment

Technological developments have affected pedagogy in many fields, including architecture. Since the 1990s, Virtual Environments (VEs) have captured the attention of researchers and educators, prompting them to explore the potential of this technology (Bailenson et al., 2008; Bowman & Hodges 1997; Dede et al., 2005; De Freitas, 2008; De Freitas et al., 2010; Kim, et al., 2013). Survey studies outlining the varied applications of VEs to education (Mikropoulos & Natsis, 2011), emphasize the support that this technology lends to constructivist learning principles and learner engagement (Bronack et al., 2008; Lorenzo et al., 2012; Vosinakis & Koutsabasis, 2013).

Similarly, due to developments in computer aided architectural design (CAAD) tools and information delivery technologies, the studio has rapidly evolved both in terms of its setting and its curricula. New learning environments have emerged, affording virtual, immersive and mixed reality settings (Andia, 2002). Studio courses utilizing VEs have been found to enhance learning behaviors and design thinking processes, indicating the significant role that settings play in the learning process (Clark & Maher 2005; Hollander & Thomas, 2009; Kalay 2004b; Mallan & Foth, 2010).

Immersive Virtual Environments (IVEs) are of particular interest to the current paper. They facilitate overcoming the “barrier” between the user and the visual display by creating a sense of “presence” for participants (Slater et al., 1995). Originally designed as a “Virtual Reality theater”, CAVE (Cave Automatic Virtual Environment) type of IVEs were developed with the intention of supporting the discovery process (Cruz-Neira, et al., 1993). Special attention was given to architects’ need for a “walk-through” experience of a proposed design (Cruz-Neira et al., 1993). IVEs provide a shared visual display for all the attendees; thereby support the architectural learning need for peer participation.

The advantages of IVEs have been proven in fields that demand the analysis of complex infor-
formation, such as spatial cognition (Natapov & Fisher-Gewirtzman, 2016; Billen et al., 2008), geosciences (Magali et al., 2008), chemistry (Limniou et al., 2008) and engineering (Messner et al., 2003). In the field of architectural and urban design, research has highlighted the benefits of IVEs in supporting the design process (Okeil, 2010), collaborative design between remote users (Dorta et al., 2011; Dorta et al., 2016), spatial comprehension (Maftei & Harty, 2012; Sopher, 2015; Sopher & Kalay, 2015) and providing a tangible display (Kalisperis et al., 2002; Portman, et al., 2015; Otto et al., 2009; Zikic, 2007). Although IVEs are still very expensive compared to other available VEs, these studies show their potential for achieving the objectives outlined earlier. Through the collective, dynamic experience created by an IVE, students can share knowledge and experience a richer learning process. This is especially important when aiming for an in-depth appreciation of the design's different levels of complexity, a process that would warrant extensive design decisions.

In light of these recent developments, architectural education is now at a critical junction: how may one discern which learning environment is more beneficial, or what degree of fit it has for different students? Historically, the studio space has served as the sole learning environment. Therefore, most existing research has neglected to consider this component. While this omission may not have made a significant difference when assessing other design tools, it now bears substantial impact, given the transformation of educational environments. Addressing these shortcomings, this paper proposes a framework with which to evaluate the educational potential of IVEs, assuming that they can indeed enhance the architectural learning process.

CONSTRUCTING A SITUATED LEARNING MODEL

We propose addressing the questions listed above by using place theory as a methodological tool for examining the relationship between the environment and its users. “Place” is defined as an emergent phenomenon, constantly shaped according to situated surroundings through time. It is derived from the activities whose performance is enabled by both physical and social settings (Alexander, 1979; Canter, 1977; Lefebvre, 1991; Malpas, 2006; Norberg-Schulz, 1988; Tuan, 1978). This theory is also used in other disciplines, such as in computer science, promoting human computer interaction (Harrison & Dourish, 1996; Dourish, 2004); and in environmental psychology, investigating personal attitudes towards settings such as place-identity (Proshansky et al., 1983) or place-attachment (Lewicka, 2011). In recent years the design field has experienced a revival of “place” theory as a setting for inquiry (Aravot, 2002; Clark & Maher, 2005; El Antably, 2011; Rieuf & Bouchard, 2017; Schneekloth & Shibley, 2000).

Examining learning through the lens of place proposes considering learning behaviors as situated acts, bound and constructed upon their environmental components. Hence, a learning space would be the physical and virtual settings that afford learning, while a learning place would refer to the act of learning performed in particular settings. In accordance with this approach, each design decision that is presented and discussed during the crit is considered a “Knowledge Construction Activity” (KCA) unit. Each KCA consists of a situated pattern derived from three domains (Figure 2): the spatial setting, which includes all physical and virtual components utilized during the crit; the social setting, which includes all crit attendees (e.g. tutor, peer, learner); and the design activities, which consist of the learning behaviors involved in developing the design product, such as verbal and visual communication.

Forms of Design Knowledge

Linking the construction of design knowledge with its social and spatial settings suggests evaluating the environment through the learners’ performances. Learners’ assessment in the studio frequently involves, however, additional components, such as the quality of outcomes, or creativity (de la Harpe et al., 2009). These aspects may obscure the objective of
investigating how the environment affects the learning process: a high-quality project may be produced by a few design activities, as much as a low-quality project.

Focusing on the process of design creates a premise with which to overcome this ambiguity. The design process is considered to comprise of the activities of analysis, synthesis and evaluation (Cross, 2006; Goel & Pirolli 1992; Jones, 1980; Kalay, 2004; Lawson, 1990; Rowe, 1998). Framing it as a set of well-defined skills creates an opportunity to assess learners’ expertise and to develop instructional design strategies (Christenson, 2016; Öztürk & Türkkan, 2006).

We propose applying the KCA model to design activities, assuming that the number of activities produced in a certain environment may indicate its capacity to enhance learning. The KCA model affords a detailed description of the environmental implications of each activity, as well as of the design process as a whole. Each design decision is analyzed according to its pattern of activity. Analysis, in this context, consists of recognizing and defining existing problems and their conditions. These include site description, identifying commonalities or anomalies, and formalizing design goals and principles. Synthesis consists of changes to the design regarding its form, function and use. Evaluation consists of various queries made by the learner regarding the artifact’s ability to achieve desired goals. These goals include acoustics, energy or structural tests; comparison between design alternatives; and verifying limitations, such as height, ergonomics or density, to fit the desired performance.

**Coding KCA Settings Through Time**

Seeking to identify how settings affect particular KCA patterns, we now consider their contribution to knowledge construction through time. Although students are expected to make progress from one crit to the next, learning does not necessarily ensue. A learner may receive comments regarding a design issue during one crit, yet only respond to them a few crits later. In addition, reflecting on an artifact can induce comments on various design issues (e.g. size, scale, or concept) that cannot be encoded in a particular KCA. Thus, comments are recorded at crit time, including their subject of interest, commenter and learning environment. Subsequent KCAs, carry the information of the social settings, and where they were conceived (Figure 3).

Table 1 demonstrates KCA encoding methodology. Each design decision presented at the crit is encoded, along with its environmental setting and related comments.

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**Table 1**

Data encoded in student’s KCAs
CASE STUDY
We followed a novel studio course, taught in the Fall of 2013 by Prof. Dafna Fisher-Gewirtzman at the Faculty of Architecture and Town Planning, Technion. The course alternated between a traditional studio classroom (Figure 4a) and an IVE (Figure 4b) as its educational setting. Our IVE has an advanced computer graphics system, compatible with most 3D modeling software programs. The room is equipped with a 2.4 x 7.0 meter screen with a 75° field of view, and three high-definition, synchronized projectors that can project a uniform and continuous display. The IVE can host up to twenty people for a simultaneous shared immersive experience (through the use of 3D glasses): one participant leads the tour through the model in a variety of scales, while the audience follows and actively shares this dynamic virtual walk-through.

The research sample consisted of four design projects, produced by six undergraduate students (two pairs and two individuals) in their third and fourth year of studies. The expected learning outcomes were similar to those of a traditional studio course at this level, requiring the design of a small-scale public building. In order to perform a virtual walk-through, the students were all obliged to develop detailed digital models.

The students were followed by means of observations, crit recordings, and design product documentation, over the course of one semester. Design analysis was used to determine KCA patterns. Protocol analysis was used to encode the participants’ comments. Figures 5-7 demonstrate the students’ work in the IVE, showing the detailed models achieved during the course (Figure 5), and critiquing activities during a virtual walk-through by the teacher (Figure 6) and a peer student (Figure 7).

KCA ANALYSIS
Students’ KCAs were coded through the analysis of four projects. Figure 8 exemplifies this process. The analyses, shown in this section, demonstrate the environmental implications on the emergence of KCA with each project.

Design Process KCAs
Analysis of the design process KCA pattern revealed that most KCAs, especially synthesis activities, emerged in IVE crits (Figure 9); allowing further communication and project development. Synthesis activity encompasses the learner’s knowledge, applied and expressed in the proposed form; thereby it is highly significant for further progress. Figure 10 shows the number of synthesis KCAs that were prepared for IVE crits, in accordance to their mode of display. As opposed to other representation for-
mats such as sections or animation, the walk-through mode is not preplanned. This factor encouraged students to thoroughly develop and detail their models, thus creating the opportunity for them to enrich their design knowledge and to improve their modeling skills. The results that are shown in figures 9 and 10 indicate, hence, the IVE’s support in experiencing a richer learning process.

Figures 10, 11a and 11b reveal the manner in which different learners used the educational settings. Students O&L and A rapidly 3D-modeled their design, producing synthesis KCAs to be reflected upon during a virtual walk-through. Students N&D, however, presented design alternatives for shared evaluation. The Evaluation pattern was rarely used independently by the students. The analysis of this activity, hence, does not depict significant results. Observations depicted different Evaluation patterns performed at the IVE. These ranged from the comparison of design alternatives to a prolonged evaluation of one design alternative, conducted through multiple viewpoints during walk-through mode.

**Social Setting Analysis**

The analyses in this section show KCAs that emerged in response to comments made in previous crits, demonstrating the comments’ effectiveness.

Table 2 quantifies the comments that were followed by KCAs according to their setting, and indicates that the IVE significantly contributed to the emergence of further KCAs. Students N&D an A used the IVE as their main stimulator, reacting with subsequent KCAs. Although students N&D had difficulty using the immersive technology, being too embarrassed to walk-through their project, their learning pattern reflects extensive stimuli by the IVE. Students O&L were assessed as highly skilled students. As such, they produced many new decisions (shown in “Other” cate-

<table>
<thead>
<tr>
<th>KCAs</th>
<th>Decision</th>
<th>Social Setting</th>
<th>Spatial Setting</th>
<th>Design Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>KCA-6</td>
<td>Identifying circulation, entrance, relations in context</td>
<td>Environment</td>
<td>Commenter</td>
<td>IVE</td>
</tr>
<tr>
<td>KCA-7</td>
<td>Shape definition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KCA-8</td>
<td>New roof</td>
<td></td>
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<tr>
<td>KCA-9</td>
<td>Section development: Setting functions</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 8**

Coding KCAs from the data
category, table 2), reflecting self-assessment abilities and an independent learning profile. Student B, who rarely used the IVE, used the studio as his main learning source and hence mostly relied on the teacher as a learning resource.

Figures 12a-12d show effective comments in accordance to different commenters. The “Teacher-Peer” comments category describes a discussion over a certain subject. The results indicate this activity was effective solely in the IVE, indicating the communicative qualities afforded by this environment. Consequently, the charts reflect the IVE’s dominant efficacy in the “Peer” category. Peer participation occurred mostly in the IVE, leaving the studio environment to be used for personal crits. Students N&D and A made significant use of shared knowledge, presenting design alternatives that had been deliberately prepared for peer evaluation. The “Teacher” category shows that more KCAs emerged due to the teacher’s comments in the IVE than due to comments in the studio. This indicates the environment’s role in the interaction. The “Learner” category indicates some evidence of self-assessment activities. Despite their low frequency, they mostly occurred due to IVE crits, highlighting the need for further work on this topic.

Figures 12a-12d warrant close observation. Although they indicate social and environmental influences on the learning process, the students’ own learning capacities need to be considered as well. Findings show that highly skilled students easily adapted to the technological challenges, and profited from independent learning. On the other hand, weaker students, with low modeling skills, or ones who were ashamed to use the technology, profited mostly from the IVE’s social advantages, by utilizing group discussions and peer comments. Since students O&L were both in their fourth year of studies and had well-developed skills, they were able to participate and contribute to their peers’ learning during crits. This led to the presence of more peer-related KCAs for students A and N&D, who were in their third year of studies.

Social setting analysis reveals that despite the teacher’s dominance in emergence of subsequent KCA, group discussions and peer commentary facilitated by the IVE stimulated further KCA emergence, emphasizing this environment’s capabilities of sup-
supporting a diverse learning model. However, the studio’s social settings are highly dependent on the group’s dynamics. Since this study was performed on a small scale, these results need further inquiry.

CONCLUSIONS
This paper set out to describe the impact of the use of IVEs on architectural education. Although the case study was performed on a limited research sample, the results clearly demonstrate the pedagogical role played by IVEs in enhancing design activities and supporting peer participation.

The research results underscore this environment’s substantial capacity for encouraging the emergence of synthesis learning activities. This is a highly significant factor, given that the crit’s social interaction strongly relies on learning outcomes. The findings show that the IVE supports different use patterns according to personal skills and learning profiles. Future research should examine IVEs impact on learner expertise.

The research findings suggest that the studio space was dissolved from its original role as a shared learning environment, and mainly served as a setting for intimate, informal desk crits. Additional observations conducted with similar studio courses using both IVE and traditional space support this understanding, raising the question of studio design principles in view of current and future technological changes.

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