Evaluating an Immersive Virtual Learning Environment for Learning How to Design in Human-Scale

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This paper presents a part of a thesis research conducted at METU. It proposes a method for evaluating the effects of an immersive virtual learning environment (IVLE) which is integrated in an architectural design/learning activity. Proposed IVLE application and design/learning activity were designed through a synthesis on constructive learning, problem-based learning, immersive technologies, and intended learning outcomes (ILOs) in learning how to design in human-scale. Immersive experience of bodily interactions and problem solving process are focused. Method of evaluation was also developed over this synthesis, and an evaluation rubric was created based on the SOLO taxonomy. According to the evaluation method, a before-and-after test was conducted within a case study involving a particular scenario of design exercise and interviews. Conclusions are based on the results of this case study.

Keywords: VR in architecture, immersive virtual learning environment, learning modalities, SOLO Taxonomy

INTRODUCTION

Use of virtual reality (VR) technologies in educational research has increased in the last decades. Literature shows a massive knowledge accumulation about potential effects of VR on education in general and in domain-specific terms which stems from various disciplines like in the case of VR use in architectural education (Kalisperis et al. 2002, Angulo 2015). As the most unique and powerful side of VR technologies, immersion factor and particular immersive features gather attention of educational researchers (Bowman and McMahan 2007).

Architectural education is one of the most prominent disciplines whose potential to utilise VR technologies is highly mentioned and popularised. Understanding the space, its generation, its transformation and its interaction is in the core of the discipline. Additionally, based on the discipline’s relation with the notion of representation, architecture has an intense history with all media which communicate the space in novel ways. Indubitably, linking such discipline and the VR technologies gathers a righteous enthusiasm of any associates of this research area. However, one can argue that the research could not satisfy the extent of its aspiration yet.

It is a general consent that VR will contribute in education in all levels in future, and yet the contemporary literature and many researches show that how VR can effect the learning especially in architectural education is not a clear concept. Problem is mostly related with difficulty of assessing the effects on learning when VR is integrated to learning
process. Therefore in this paper, it is concentrated on how VR can be integrated in architectural education, and how the effect of VR on learning can be measured is one of the major issues of this paper. Main contribution of this paper is the novel approach developed for this measurability issue and partial findings on its application within a case study. This approach derives from the tangible links between the potential of specific VR utilities and learning modalities such as constructive learning, problem-based learning, and media interaction model. The overall scenario designed for the case study and the evaluation rubric derived from the SOLO Taxonomy are elaborated further since they are highly prominent in development of this approach. This paper also issues the discovery that moving students out of their comfort zone in terms of the design problem provided in the case study benefits the measurability. It is observed that this criteria played a crucial role in different levels during the case study and the analysis phase.

**EDUCATIONAL APPROACH**

Relation between the domain-specific content and what VR can provide is important. However, alignment between how it can be learned and what VR can provide for such learning process is crucial. Therefore, these concerns should be explored considering basics of them under unifying theories, and a comprehensive integration should be provided as a holistic educational design. It should be designed involving all concerns in its core from the beginning. It should not be an extrinsic addition to the existing educational design.

**What and how students are expected to learn**

Developing an understanding on scale and dimensions is crucial in architectural design education, especially in terms of learning how to design in human-scale. During the entire architectural design education, students are expected to develop this understanding through repetitious practice of creating, observing and analysing representations involving different scales and viewpoints.

Understanding and processing the relation between human body and architectural space is essential. First architectural design assignments in architecture schools involve relatively small scale and less complex architectural spaces, and include multiple smaller design problems of architectural elements (e.g. doors, windows, stairs, various types of furniture, etc.) with which humans bodily interact. Students are expected to study form, scale and dimensions of these spaces in a way to fulfil the spatial needs required by simple use cases and activities. Through such assignments, students can try to understand the spatial needs brought by human body and bodily activities within use cases, and they can try to respond to these needs by making metric decisions in adequate scale. Nonetheless, it is an important phase of education because in this phase, students start to develop an understanding on designing in human-scale beyond their past layman experience and knowledge.

Starting with this phase, students are fed via various sources of related information during their education. As the scaled representations are main tools of design and design learning, students’ communication with representations provides a multi-layered and interactive source. Human figures, furniture, trees etc. are commonly included in scaled representations in order to easily perceive the scale of a designed space. Students are instructed and encouraged to work with such representations, and they also observe such representations produced by experts. Additionally, guides that provide technical drawings and metric information of architectural elements within a standardised manner (e.g. Neufert et al. 2012) constitute a type of source which provides direct instructions and ready-to-use information.

Another source is students’ ever-growing knowledge and understanding about scale, based on their experience with architectural elements and spaces in real life. Some experiences involve more bodily interactions than others. Students are expected to com-
bine and utilise all these sources in their own way in order to develop their own understanding on relation between architecture and human-scale.

**Synthesis on VR and Learning Theories**

Deriving from the novice architecture students’ difficulties on acquiring an understanding about scale and from the idea that VR can be helpful through immersive experiences on 1:1 scale, this study focuses on the educational objective that students need to learn how to design in human-scale. They need to learn the relation between what is designed, what is represented, and the human in terms of scale. This understanding involves more than just proportions and rote-learning of standards. They need to learn how to approach this relation, how and why to think and work with it while designing. An educational design to be suggested should aim to cover these learning outcomes.

Considering learning about architectural elements with which humans bodily interact, it can be proposed that VR’s immersive utilities, which can provide the awareness of one’s own body and the opportunity to interact via this body in a virtual environment (VE), can be helpful. Students might experience bodily interactions with architectural elements and also might use their body as a reference in an immersive virtual reality (IVR) application which can provide these utilities in addition to 1:1 scale 3D visualisation and head-tracking utility. This might be helpful especially in case of architectural elements, objects, spatial compositions and/or use case scenarios which students are not very familiar with. This can be also aligned with ‘learning by experience’ approach.

Literature displays an emphasis on suitability of constructivist views (Winn 1993) and problem-based learning (Huang et al. 2010) with use of VR in education in general. Deriving from these learning modalities, this study considers the aimed integration in the form of an IVLE to encourage the inquiry of both content and the learning process and to serve in a design/learning activity in which students can experience their own unique design/problem solving process, do self-assessment, and thus construct meaningful knowledge from their new experiences and existing knowledge by actively engaging in authentic and reflective learning activities.

The analogy issued here so far draws a frame to define an adequate IVLE application and an integration method for it. Accordingly, this application should allow an immersive experience by which users can visually explore the environment in 1:1 scale, and directly in true 3D. Even if these utilities alone cannot provide direct benefits for the primary issue of this study, they are fundamental to visual immersion, and most certainly complementary to the other immersive utilities. As the human-scale and understanding the environment in response with human-scale are primary in this issue, this application should also allow users to understand their own scale and to make comparisons between their own body and the environment through visual exploration actualised via natural body movements and interactions.

**METHOD**

Bodily activity is highly crucial in terms of human-scale design. There is a strong and direct relation between these two subjects in many cases. Even if the knowledge about this relationship is not reconstructed from the ground by every designer nor during every design decision, an understanding about it should be acquired by architects for them to be able to comprehend what they are doing, why they are doing, and how they are doing when it comes to making a design decision which is anyhow related to a bodily activity.

Students should learn how to do reasoning and critical thinking in a way examining the aforementioned relation. Deriving from the constructivist learning theory and the problem-based learning, it is believed that adequate learning environment and learning activities, in other words providing a meaningful experience of the act which is to be learned, can lead meaningful learning in this context.
The impact of long-term use of an IVLE on learning should be investigated for sure. However, such investigation should be realised firstly in case of short-term use. Accordingly, case study method is adopted to simulate a kind of design activity which can be realised in a design studio course. Indubitably, such investigation requests a comparison of two situations: one where the application is used and the other where the application is not used. Considering participants’ personal differences and focusing on their individual processes during the design/learning activity, a before-and-after test is conducted to make a comparative analysis. Accordingly, the design/learning activity is designed as it requests respectively a design performance, use of the IVLE application, and then again a design performance.

In this point, there are some questions to be answered. What is the quality of students’ process of problem solving and making design decisions during such design activity? Furthermore, to what extent do they utilise the related immersive features of the application into the problem solving process? To what extent do those utilisations enhance the quality of problem solving process? Accordingly, the focus moves from evaluation of the end-product to evaluation of the process of problem solving and evaluation of how students build their final solutions against the problem.

In order to collect this kind of information, interview method is chosen. How the analysis and evaluation will be done also plays an important role in preparation of the interview. Such systematic evaluation method can be derived from the SOLO taxonomy developed by Biggs and Collis (1982), where SOLO stands for the Structure of the Observed Learning Outcome. Biggs and Collis derive from Piaget’s theory of cognitive development and particularly the developmental stages in thinking. They argue that there are also stages within a hierarchical order, which realise in process of learning. According to their argument, these stages are not identical with, but derive from those developmental stages; so thus their hierarchical order. Accordingly, in terms of evaluation, they focus on the structure of the actual responses that students give to particular learning tasks, rather than any concept of cognitive structure of the individual. Biggs and Collis investigate this idea through direct research on student learning, in which they study the organisation of responses from a large number of students from various educational levels, in various subjects. SOLO taxonomy involves five levels to describe the structural complexity of a student response. These levels are respectively; (1) prestructural, (2) unistructural, (3) multistructural, (4) relational, and (5) extended abstract among which the last one corresponds to the highest level of structural complexity. These levels also differ in terms of required capacity of working memory; and relating operations, consistency and closure involved in the performance.

As a method for investigating the quality of learning through a design/learning activity, considering the learning as an iterative process which is always influenced by internal and external variables, and thus evaluating it by the level of its complexity and sophistication highly coheres with the nature of design. In this case, this coherence becomes more prominent, considering that this study aims to investigate the involvement of certain components of the learning environment in students’ proceeding in complexity of implementing a response to an open-ended design task along the process. One of most advantageous features of the SOLO taxonomy is that it is applicable to open-ended tasks because it focuses on the structural complexity of any response given by the student. Under these circumstances, the SOLO taxonomy preserves a great guidance for the evaluation intended in this study. Therefore, an evaluation rubric is prepared by deriving from the SOLO taxonomy and by concentrating on the educational objectives.

CASE STUDY
A design/learning activity was composed as an exemplifying design exercise which can be executed in a design studio course. Accordingly, an appropriate
design problem was prepared to ask students to design an architectural space including architectural elements which are related to bodily activities in terms of size and form. Additionally, an appropriate IVLE application was built in order to provide for students to utilise during the design exercise.

**Participants**

The experiment was conducted via voluntary participation of students who are in their first month of second year architectural education at universities in the city of Ankara in Turkey, since they are in the phase that they start getting familiar with how to design in human-scale.

**Design Problem**

Design decisions to be analysed should be addressed in a suitably larger design problem. Therefore, it was aimed to keep the problem simple and focused, and to keep the required architectural elements relevant to bodily activities and human scale as much as possible. Accordingly, participants were asked to design a 20 m² kitchen area including kitchen fittings and furniture as a part of a single-floor family house for a wheelchair user.

The user type was added as a criterion in order to move students out of their comfort zone. Reason behind this was to increase the active engagement of students during the overall learning activity and during the use of IVLE as a source. In preliminary studies of authors, it was observed that such active engagement was lower and that students tend to improvise and rely on their past knowledge about measurements since they have a life-long familiarity in a sense.

**The IVLE Application**

An IVLE application was designed, providing stereoscopic 3D vision and head-tracking technologies. It also allows the users to see the skeletal representation of their both hands in a realistic scale (Figure 1), to control them in real-time, and to interact with the virtual environment via real-time hand motion controlling.

The application was conceptually designed as a virtual learning environment which holds a library of models of various architectural spaces, environments, objects, etc. The partial software prepared and used for this case study provides a single virtual model which constitutes a kitchen area with fittings and furniture (Figure 1). This environment was designed and modelled as a simple example of an ordinary kitchen with applicable measurements which correspond to the Neufert et al.’s “Architect’s Data” (2012). It was not designed with the criterion of being usable by a wheelchair user, and does not cover 20 m² nor include every type of fittings and furniture. An interactive model was prepared to the extent that participants can open and close the door, cabinets and drawers by using their own hands in an intuitive way.

Participants experienced (e.g. moved around, observed, interacted with, etc.) the environment through an avatar which represents a person on a wheelchair in terms of size and eye level, and they sat on a chair with similar height during the experience (Figure 2).

An Oculus Rift DK2 head-mounted display and a Leap Motion Controller hand-tracking device were integrated and used for the application. Application software was built via Unity 3D Game Engine 5.3.4f1, Leap Motion Orion 3.2.0, Oculus Configuration Utility 1.10 and Rhinoceros 5 3D modelling software. During the case study, the application software was run...
on a computer with Intel(R) Xeon(R) CPU E5-1620 v4 (3.50ghz) processor, 16 GB memory and NVIDIA GeForce GTX 1070 graphics processor.

**Procedures**

A scenario was created involving a design exercise with three major sessions and the interview session following the exercise. In the first session (S-1), participant is asked to design by using pen and paper, and to make measurement decisions as much as possible, and to represent them on proposals within 15 minutes. In the second session (S-2), the IVLE application, its content and capabilities are introduced to participant for the first time. Additionally in this point, it is announced that there will be another session similar to the first one, involving identical design problem and requirements. Then, participant uses the application; and meanwhile observer takes notes for the participant in participant’s own words, when participant demands. This session is video-recorded from participant’s viewpoint. In the third session (S-3), participant is again asked to propose a design within same conditions of first session. Participant is allowed to utilise the notes from previous session and the representations proposed at the end of first session as sources. Two interviews are conducted with participant right after the final design session, involving the two design sessions respectively. Participants are allowed to use their notes, submissions and video-records during the interviews, and the interviews are audio-recorded.

**DATA COLLECTION AND ANALYSIS METHOD**

This study aims to analyse reasoning behind measurement decisions in terms of thought contents and thought relations between those contents in relation with particular designed volume and the notion of human-scale. Accordingly, an evaluation rubric was prepared based on these contents, relations and the SOLO Taxonomy. This rubric helped to ask proper questions during the interviews, such as; “What kind of thoughts, ideas, or criteria did you have and/or consider while making this decision about this measurement?”; “What was your reasoning and/or story behind this decision?” These questions helped to collect the kind of data involving various criteria and references thought and considered by the participant for a specific measurement decision. Participants provided a story involving how they connected these ideas, where they acquired these ideas, what was their reasoning, and eventually how they utilised any of their specific immersive experiences from the IVLE session.

Based on the verbal reports, each participant’s two responses addressing the same dimension of a volume from two design sessions are evaluated and compared. Observed advancements are attributed to use of immersive features, only if two conditions are provided. First, the participant mentions a specific moment when they use an immersive feature and mentions it as a reason or a source of a thought. Second, that thought is mentioned as at least a part of a specific content (of the response) which causes that response to be evaluated as advanced.

Corresponding the SOLO taxonomy, the evaluation rubric consists of five levels respectively (from lowest to highest): Prestructural (P), Unistructural (U), Multistructural (M), Relational (R), and Extended Abstract (EA).

A prestructural response involves no adequate
knowledge, but incompetence. Sometimes it can be observed that it involves an attempt to create a link between response and the given cue (i.e. question) by using an irrelevant information or tautology. In this case, some examples of contents encountered in prestructural responses are: “neglecting”, “irrelevant reasoning”, etc.

A unistructural response provides a link between response and the given cue through one relevant aspect, information, or datum. On the other hand, a multistructural response provides a link between response and the given cue through multiple relevant aspects, information, or data. These aspects are not necessarily independent from each other, but the response does not employ a linking concept or any interrelation over those aspects to create a consistent conclusion. In this case, some examples of contents encountered in unistructural and multistructural responses are: “wheelchair size”, “body size”, “wheelchair size and body size (any measurement belonging to a body on a wheelchair)”, “activity/movement (a, b, etc.) involved in a use case (a, b, etc.)”, “recalling an example from daily life”, “correlating scale/measurement with another volume/dimension”, etc.

A relational response goes further than a multistructural one. It provides multiple relevant aspects, information, or data and issues them in a conceptual scheme. Through employing a linking concept or interrelations over those, it constructs a consistent conclusion within given context. In this case, contents encountered in relational responses constitute what participant employs as a linking concept or as an interrelation over several other contents corresponding to multistructural level. An example of this is considering separate bodily movements involved in a use case scenario to modify the same measurement.

An extended abstract response provides what a relational response can, but further conceptualise all the relevant aspects, information, or data, and their interrelations at a higher level of abstraction. It introduces an abstract principle, deductions, and/or analogies which were not present as any kind of cue; yet it explores their compatibility with another and with the integrity of whole response. Considering the scope of given design problem, any extended abstract response was not expected and not found in this design/learning activity.

To exemplify the evaluation process, evaluation of Participant-10's decision on cooktop width can be examined. Since she reported that she has identified the width of the cooktop according to overall width of the big storage unit which includes the cooktop in a drawer form in the first session, this decision was evaluated as unistructural. She also designed a small unit including a regular drawer at the same level with cooktop. In the third session, she reduced the size of big storage unit. She elaborated on a modular design which allows wheelchair user to open the cooktop and the drawer by pulling them towards each other to meet at the mid and to use them as a single plane. She reported that she considered wheelchair user's capability to manoeuvre between units when drawers are closed and difficulty to use the drawer and the cooktop simultaneously. She also mentioned her experience of interaction with base cabinets in IVLE and the difficulty that she realised by this experience as her reasoning behind this process. Therefore, this decision is evaluated as relational, and advancement is attributed to her utilising the immersive features of IVLE.

RESULTS

Results show that among 14 participants, 13 participants displayed advancement in at least two of their pairs of responses between two design sessions. Among 14 participants, 4 participants displayed 1, 7 participants displayed 2, 2 participants displayed 3 advancements where they mentioned their immersive experience in a causal relation to the particular content of their responses which indicates the advancement. Table 1 shows these results including situations where immersive features were used but no causal relation was reported (NC), and situations where immersive features were used and a causal relation was reported (CR).
CONCLUSION
Participants experience an actual design process, and their thoughts during the design process are asked. Structure of these thoughts and their contents are analysed in detail. Accordingly, if a participant effectively utilises any immersive experience in any decision making process, the questions like “What did you think while making that decision?” also requests the information about such utilisation. It is crucial to assess the causal relations between the observed advancements and the use of particular immersive features. The approach followed in this study provides the opportunity to explore such causal relations. With this approach, this study’s contribution to the field differs among others in terms of two aspects. First is how the evaluation rubric is created and employed. Second is the scenario which moves participants out of their comfort zone in terms of their familiarity with the design requirements at hand and with the provided type of experience of an environment. These two aspects allow elaborating on measurable facts and introduce new ways of working with and of evaluating the VR in architectural design education. This approach might guide future research on integration of VR into architectural design education.

REFERENCES
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Winn, W 1993, A conceptual basis for educational applications of virtual reality, University of Washington

Table 1
Evaluation of Observed Advancements

<table>
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<tr>
<th>ID</th>
<th>Type of Measurement Decision</th>
<th>Level</th>
<th>Immersion</th>
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<tbody>
<tr>
<td>1</td>
<td>countertop (depth)</td>
<td>M</td>
<td>R</td>
</tr>
<tr>
<td>2</td>
<td>window (height from ground)</td>
<td>P</td>
<td>M</td>
</tr>
<tr>
<td>3</td>
<td>countertop (depth)</td>
<td>M</td>
<td>R</td>
</tr>
<tr>
<td>4</td>
<td>countertop (height)</td>
<td>M</td>
<td>R</td>
</tr>
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<td>5</td>
<td>door (width)</td>
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<td>U</td>
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<td>countertop (height)</td>
<td>U</td>
<td>M</td>
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<td>door handle (height)</td>
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