A “BOUNDED ADOPTION” STRATEGY AND ITS PERFORMANCE EVALUATION OF VIRTUAL REALITY TECHNOLOGIES APPLIED IN ONLINE ARCHITECTURAL EDUCATION

CHENGYU SUN¹, DIQIONG XU², KRYVKO DARIA³ and PEIHONG TAO⁴
¹²³⁴College of Architecture and Urban Planning, Tongji University, China
¹ibund@126.com ²1530240@tongji.edu.cn ³daria.kryvko@hotmail.it ⁴pehont@163.com

Abstract. Thousands of online virtual experiments are being developed by hundreds of National Virtual Experimental Teaching Demonstration Centers run by top universities in China. According to an analysis on the existing VR technologies accessible in market and the conditions of domestic universities, a “bounded adoption” strategy was raised by Tongji University, when it dealing with a daily teaching context. It puts the manpower and financial resources into the design of virtual experiments, so-called ‘contents building’, rather than equipment purchasing as before. After three new experiments built, an evaluation on their contributions to learning performance is conducted immediately, which tries to understand whether the strategy works and how to move on. As one of these experiments, learning a historic Chinese temple in an online way is compared with other four learning methods from traditional ways to hybrid ways. The result indicates that the VR technologies applied with the “bounded adoption” strategy have a positive coherence to high learning performance, especially in form oriented recognition task, which plays a key role in architectural education. Meanwhile, the current design of virtual task involving building process has to be improved.

Keywords. Architectural education; Online experiment; Virtual reality; Performance evaluation.

1. Background

With the vigorous development worldwide of “MOOC” and other online educational resources in various professional fields, the traditional architectural education also comes to “online” age. “Online virtual experiment” was proposed by scholars at the end of 20th century (Liang & Xia 2016) and it has been initially
developed as “web-based experiments” in many top universities, such as MIT and etc. (Yuan & Wu 2010). It can easily complete various experiments that cannot be carried out in the real world, because of long distance, operational risk, high cost, narrow space, or impossible to be carried out. Obviously, it is an important supplement of traditional experimental teaching in architectural education. In this case, the constructors in architectural background have to keep the balance between construction investment and the real improvement in learning performance, which lies heavily on an understanding of VR technologies and an evaluation of the learning performance.

Since 2013, China Ministry of Education started a systematic establishment of online virtual experimental resources with the construction experiences in mechanical and electrical, aviation, national defense and other online virtual experiment pioneer specialty (Jiang & Jiang 2004), through building hundreds of National Virtual Experimental Teaching Centers. A batch of universities, such as Tongji University, South China University of Technology, Harbin Institute of Technology, Zhejiang University, China Central Academy of Fine Art, Beijing University of Civil Engineering and Architecture and etc. were appointed to setup their centers and to build online virtual experiments in architecture, which are expected to spread in China.

In this study, a “bounded adoption” strategy dealing with VR technology application and a corresponding evaluation on learning performance used by the center of Tongji University are introduced, which reflects the current development of those centers in China.

2. A “Bounded Adoption” Strategy in VR Applications

At present, with the commercialization, miniaturization of various hardware equipment, a large number of virtual technologies have been integrated into the educational vision of universities. Their implementation costs differ nearly a hundred thousand times (from Google cardboard glasses bow with less than 10 RMB to the immersive full-scale virtual environment with several million). Their functions involved shows unprecedented abundant from the audio-visual performance to interactive control, wearing and insertion, which undoubtedly led to difficulty in technical scheme selection for virtual experiment constructors outside VR industry. If twenty years ago, architectural universities tended to pursue “high-grade, precise and advanced” hardware. But now, the actual teaching requirements are placed with more attention. Some factors must be taken into account, such as the number of students who are simultaneously using the VR equipment, the size of the space occupied by equipment, as the number of supporting facilities and so on. Therefore, the online VR experiment construction team of Tongji University proposed a “Bounded Adoption” strategy when selecting and applying VR technologies.

First of all, a gene-like framework describing the capabilities of existing VR technologies in market is established (figure 1), in which 20 factors as genes are summarized under three big groups according to the “3I (Immersion, Interaction, Imagination)” features of VR technology (Portman et al. 2015). In general, op-
A "BOUNDED ADOPTION" STRATEGY AND ITS PERFORMANCE EVALUATION OF VIRTUAL REALITY TECHNOLOGIES APPLIED IN ONLINE ARCHITECTURAL EDUCATION

tions of any factor in the table from left to right, the cost of implementation and expectation on performance are both on the rise, except for the two orderly task options. With such a framework, even a constructor outside VR industry can easily understand the difference between any two technical schemes making a selection under limited budget.

<table>
<thead>
<tr>
<th>Features</th>
<th>Factors</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immersion</td>
<td>View field</td>
<td>Narrow¹</td>
</tr>
<tr>
<td></td>
<td>Acoustic model</td>
<td>Two-pole linear¹</td>
</tr>
<tr>
<td></td>
<td>AV sync.</td>
<td>Inside view sync.¹</td>
</tr>
<tr>
<td></td>
<td>Tactile sense</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Muscle sense</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Vestibular sense</td>
<td>No</td>
</tr>
</tbody>
</table>

| Interaction   | Delay            | Obvious         | Slight²        | No delay       |
|               | Task             | Passive task²   | Active task    |                |
|               | View orientation | Fixed           | Dynamic³       |                |
|               | Visual information | Fixed         | Switchable     |                |
|               | Object’s parameter | Fixed³        | Adjustable³    |                |
|               | Object’s position | Fixed³         | Free           |                |
|               | Object’s orientation | Fixed³      | Free           |                |
|               | Object’s path    | Fixed³         | Free           |                |
|               | Object’s relation | No³⁺           | Establishable³ |                |
|               | UI               | Proxy Interface³ | Body Interface |                |

| Imagination   | Abstract memory  | No             | Yes            |
|               | Imaginal memory  | No             | Yes            |
|               | Emotional memory | No             | Yes            |
|               | Kineet memory    | No³⁺           | Yes³          |

*Figure 1. A gene-like framework depicting VR technologies in market.*

Next, any proposed online VR experiment has to be depicted in the framework and the options fulfilling the requirements with the lowest hardware investment have be selected according to a real teaching context by an applicant leading an architectural course. A "BOUNDED Adoption" strategy in VR technology application means that the most of limited human and financial resources should be put into the design of experiment itself, especially the interaction process, which does not so heavily rely on hardware. For example, if the location of a component is a piece of key knowledge in a course, highlighting the component in a view of whole building contributes to students’ understanding where it locates, no matter what immersive hardware they use. Only with such a strategy, online VR experiments can run on normal computers in a daily class. For example, the three running on-
line VR experiments in architecture of Tongji University have been planned with yellow options in figure 1, which serve more than 200 students each.

Obviously, it is the applicant in architectural discipline who defines all the knowledge embed in an experiment and makes a proper design supported by VR technologies at an acceptable way for students. As soon as the definition and design are made, commercial software companies will make the development. In a case of affordable hardware upgrade in future, are these companies who upgrade the program to provide a better experience to students. However, it does not change the design of experiment itself, which is so called independence of experiment design for teachers.

Notes: yellow options are adopted by the three experiments in Tongji University. Superscript *: all of them adopt the option; superscript 1: experiment one adopts the option; superscript 2: experiment two adopts the option; superscript 3: experiment three adopts the experiment.

3. Development of Tongji’s Online Virtual Experiments

Following the “Bounded Adoption” strategy, Virtual Experimental Teaching Center of Architecture, Urban planning & Landscape in Tongji University has been running three online VR experiments since early 2016. These experiments act as a start kick of an ambitious plan with more than 30 experiments serving the existing courses. An initial group of 19 interested teachers attended a VR technology demonstration show provided by local companies and three of them got the grants according to their clear experiment design with proper VR technologies selected.

The first experiment is called “Building components recognition and virtual construction for ancient Chinese temple” (figure 2). It is designed by Associate Prof. Tang Zhong and it is used in his course titled “Orders of ancient Chinese architecture”, in which students carried out component recognition and virtual construction experiment in a case of Baoguo Temple in Ningbo. Every one of 407 building components and its historical information will be interactively learnt. Students can observe any construction node, dismantle and assemble it, to achieve a deeper study of traditional wood construction method, which is impossible to achieve in a real conservation building with more than 1000 years old.

The second experiment takes the name “Acoustic parameters of hall space” (figure 3). It is designed by Associate Prof. Mo Fangshuo and it is used in his course titled “Building Physics (Acoustics)”, in which students have to complete an operation of reverberation time survey and experience the acoustic effects with different combinations of hall affective factors. It cannot be easily achieved in real experiments, because of the unavailability of the hall, expensive equipment, material replacement cost and time.

The third experiment is “Traffic control in residential block” (figure 4), designed by Associate Prof. Tang Yuqing and used in his course titled “Urban Road and Traffic”. With on the traffic computing theory of residential area and a set of assumptions, students try to adjust the parameters of traffic system, such as road widths, percentages of different traffic types, peak and valley time periods, to optimize the land use of the area, which is totally impossible in real situation.
A "BOUNDING ADOPTION" STRATEGY AND ITS PERFORMANCE EVALUATION OF VIRTUAL REALITY TECHNOLOGIES APPLIED IN ONLINE ARCHITECTURAL EDUCATION

Figure 2. The recognition of a component.

Figure 3. The virtual stationing of hall reverberation time test.

Figure 4. The simulation with a set of traffic parameters.
4. Evaluation of Learning Performances

Although there are enough researches indicating that interaction improves learning performance upon objects involved (Gantt 2001), and it is almost affirmed that applying VR technologies in form-oriented learning plays a positive role (Huang 2005; Chen & Wang 2008; D'Souza et al. 2008), investors and constructors are still curious about the different performance among various VR technologies they select under the “Bounded Adoption” strategy. Thus, a systematic evaluation on the first experiment is conducted according to both objective and subjective methods (Gill et al. 2013; Ayer et al. 2016).

4.1. CHARACTERISTICS OF STUDENTS INVOLVED

There are 150 first year students (66 males and 84 females) in architecture involved in the evaluation. The average age is 19 and they haven’t any knowledge about the ancient Chinese temple. Most males (61.9% boys and 17.2% girls) have experiences on 3D computer games and all of them have experiences on online shopping. Thus, they understand how to use the online virtual experiment naturally.

4.2. OBJECTIVE EVALUATION

The proposed objective evaluation tries to compare the students’ knowledge gained by five different learning methods in the same learning time. In other words, the percentage of correct answers after learning indicates the learning performance of the corresponding learning method.

The subjects are randomly divided into five (A-E) groups each with 30 students. There are three steps in the evaluation:

Step I, every group learns the same knowledge (names of wood components and building steps of Baoguo Temple) through a specific method (table 1) in one hour: Group A is taught by a teacher (figure 5, left), who uses the traditional plans and sections in 2D drawings. Group B studies the books by themselves; Group C plays the online virtual experiment designed by the same teacher (figure 5, middle); Group D is taught by the teacher with virtual experiment demonstration (they do not operate by themselves); Group E listens to the teacher’s brief explanation in 15 minutes and plays the online virtual experiment in 45 minutes.

Step II, every group answers the same 30 questions in 10 minutes just after the learning process (figure 5, right). The questions cover components recognition and building process understanding.

Step III, the learning performances, namely the percentages of correct answers of five groups are analyzed to indicate the contribution of VR technologies used in the current online virtual experiment developed with the “bounded adoption” strategy.

According to the performances indicated by average number of correct answers (figure 6), it finds out that the learning methods, involving interactive operation on online virtual experiment (Group C and E), get significantly higher scores of component recognition questions than others, which suggests the current development improves the learning performance indeed at least in this specific kind of knowledge. Obviously, it plays an important role in the discipline of architecture.
Furthermore, the performances on two kinds of knowledge, namely “component recognition” and “building process”, are analyzed against three main factors (the duration of virtual interaction, whether there is teacher’s oral explanation on orders among components, whether the temple is visualized in 3D). It indicates that longer duration of virtual interaction and 3D visualization obviously contribute to high performance if the knowledge of component recognition is concerned (figure 7). While it is not so evident in the case of building process (figure 8). Because VR technologies support the both contributing factors. It can explain why online virtual experiment has better performance than the others as found above.

In short, the learning methods with bounded VR technologies adopted have already shown advantages beyond the traditional methods at least facing with the knowledge of component recognition.
Figure 6. General performance of the five groups.

Figure 7. Influences of factors on component recognition learning.

Figure 8. Influences of factors on building process learning.
4.3. SUBJECTIVE EVALUATION

Following the reply to the questions, the students in all groups submit feedbacks on their learning experiences, which cover the extent of pleasure from learning and the extent of interest inspired (figure 9). It is easy to find out that the three groups (C, D, E) using VR technologies are ranked top and Group B with support of books had the worst experiences as expected. In short, the bounded VR technologies adopted in the experiment have already enough improvement on subjective experiences for the students taking the traditional methods as competitors.

5. Conclusions

Facing with the “online” age, the discipline of architectural is seeking an upgrade with the support from VR technologies. However, the balance between huge investment on cutting edge hardware and real teaching context with a large number of students is a conflict in front of universities in China. In this way, a “bounded adoption” strategy focusing on design of experiment rather than purchasing expensive hardware was raised by a team of Tongji University. Following this strategy, a gene-like framework is provided to help normal architectural teachers to understand the technologies and they can play central roles in the design of their own course-based online virtual experiment with cheapest technologies applied. Is the software company who helps them to turn their designs into final deliveries taking care for the various hardware. The result under the strategy is evaluated both in an objective and a subjective way, which indicates that the bounded VR technologies adopted in the experiment have an obvious contribution to the architectural education upgrade at least in the learning of component recognition knowledge.

Meanwhile, in this first round of construction, there is still many issues to improve, such as the design of interaction for the learning of building process knowledge. The current design with passive building task does not show any contribution to the upgrade. More complex active task (sequential task and parallel task) will be tested in the following construction.
Acknowledgements

This study is supported by a National Project of Upgrading Educational Method (2016-ZX-171), Key Laboratory of Ecology and Energy Saving Study of Dense Habitat (Tongji University) Ministry of Education, National Center for Simulation-based Pedagogy in Architecture, Urban Planning and Landscape Architecture.

References


Portman, M.E. and Fisher-Gewirtzman, D.: 2015, To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning, Computers, Environment and urban systems, 34, 376-384.