

PIECE 3D: Portable Interactive Education for Construction Engineering in 3D

S. Kang^a, H. Cho^b, K. Kang^b, M. Kang^c and C. T. Haas^a

^aDepartment of Civil and Environmental Engineering, University of Waterloo, Canada

^bDepartment of Civil, Environmental and Architectural Engineering, Korea University, Republic of Korea

^cDepartment of Industrial Engineering, Namseoul University, Republic of Korea

Email: s43kang@uwaterloo.ca, hhcho@korea.ac.kr, kikang@korea.ac.kr, mskang@nsu.ac.kr, chaas@uwaterloo.ca

Abstract -

Everything starts from a piece. Bits and pieces are collected to form an entire structure. PIECE 3D is a framework for developing 3D education for the construction engineering field. Construction processes are dynamic and complicated. There are many components, and some processes are hard to understand from 2D pictures or even clips/videos. Thus, to improve the education system, this paper presents a portable interactive 3D education framework. As a case study, we developed rebar work process and measured students' performance and satisfaction. Compared to existing BIM education model, PIECE3D outperformed in portability, conveying educational objectives in 3D, enhancing understanding the processes of rebar, and triggering the interest of students.

Keywords -

3D education; Virtual Reality; BIM; Portable

1 Introduction

Building Information Modeling (BIM) has various features such as integrating and managing the information, illustrating the progress of work and visualizing finished models. Recently, BIM has been used as an educational tool because of its 3D visualization feature. However, education and training are not BIM's main objectives; thus it cannot serve well as an educational tool due to its functional constraints.

Education needs adequate scenarios with objectives and methodologies. For some fields like art and music, creativity should be emphasized without fixed direction. However, when it comes to engineering knowledge transfer, there are terms and processes which are worth remembering. This holds true with construction engineering education. Terms and processes of work need to be taught with objectives and a specific scenario so that students can grasp the concepts quickly,

and those concepts become embedded in long-term memory. The delivery method needs to be intuitive and convenient.

For delivery, we decided to use a smartphone-based platform as most people possess smartphones these days and carry them wherever they go. Thus, we concluded that users can review the learning materials whenever and wherever they want with smartphones. Smartphones also have the advantage of possessing touchscreens rather than mice or keyboards. Touchscreens can aid intuitive understanding of 3D models due to their gestural interfaces.

Considering both software and hardware, this study designed a framework for 'Portable Interactive Education for Construction Engineering in 3D (PIECE 3D).' In order to do so, we first analyzed needs and determined the work types to develop a model. Then, a 3D model was designed, an interactive scenario was constructed, and an interactive scenario-based 3D model was programmed. Once the model was developed, an experiment was conducted to measure students' learning performance and satisfaction with and without PIECE 3D in a controlled experiment. Control material was built on BIM-based learning, and experimental material was built on PIECE 3D. Finally, the difference between the experimental and control groups was evaluated with the t-test.

2 Literature Review

Three dimensional technologies have been used creatively to create different course materials. Ku and Mahabaleshwarkar proposed a new concept of Building interactive Modeling which augments the concept of Building Information Modeling to facilitate interaction [1]. They focused on safety training and equipment operation training. Irizarry et al. introduced layers that bring up exterior walls or even a house in order to execute structural analysis between formwork and loads [2]. They compared 2D and 3D views of rebar and recorded answers from students. Kim

focused on teaching construction details and material quantity take-offs and assessed the effectiveness of BIM [3]. However, these BIM-based studies are not portable nor scenario-based as compared to the approach suggested in our paper.

Virtual Reality (VR) has been applied to general education with positive effects. Construction engineering educators have adopted VR to increase understanding and immersiveness through visualization and interaction. Messner et al. programmed cave-shaped IPD (Immersive Projection Display) to allow students to interactively develop a sequence of arrangements for a room [4]. The room consisted of 'air handling units', 'off-module platform', 'fire protection valve station' and so on. Sampaio and Henriques programmed a 3D exterior wall and bridge [5]. For instance, in rebar work, the components are grouped into 'footing', 'column', 'wall', and 'beam'. Sampaio et al. separated construction engineering education based on life-cycle and provided a 3D VR education model in each section [6]. Sampaio and Martins compared two different construction engineering methods for bridge construction [7]. Park et al. suggested IBAM (Interactive Building Anatomy Modeling) for experiential education [8]. They focused on assembly & disassembly of the building elements in terms of anatomical breakdown. However, as they created the materials based on a finished model, the compositions of building components were limited to components that remain in the finished model. For instance, components that are used temporarily such as forms and scaffolding were not considered.

The history of traditional education based on paper and pencil is far longer than that for any other tools. Paper and pencil allow writing, drawing and modification to be easy and quick. However, paper has some limitations. It is demanding to retrieve paper documents as they take physical space. It is also difficult to manage and classify the large amount of papers when accumulated. The advent of computers overcame the limitations of paper. However, though computers have many advantages, there are limitations to using them in a lecture. First, computers are difficult to configure for each student in each class. Also, they are relatively heavy to carry. Thus, portable devices such as laptop and pocket PC were devised and applied in construction engineering education.

More recently, smart devices such as smartphones and tablets influenced not only the social atmosphere but construction engineering education. Smart devices are handy as they are portable and touch-based. While there are many construction engineering education studies based on computers, there are few based on smart devices. Pedro et al. tried smartphone-based education [9]. However, the content was in 2D rather

than in 3D and was limited to finding safety issues between two similar pictures. Nevertheless, because of the numerous advantages that smartphones have, such as communication, search and entertainment, we developed a smartphone-based platform.

3 The Framework of Portable Interactive Education for Construction Engineering in 3D (PIECE 3D)

3.1 Need Analysis & Work Type Selection

In order to discover the needs of PIECE 3D, a survey of 31 practitioners was conducted. Participants' work experiences and positions varied. Participants consisted of 20 practitioners with less than 5 year experience, 4 practitioners with more than 5 years and less than 10 years, and 7 practitioners with more than 10 years. The participants' main duties varied as well: 11 construction workers, 7 office workers, 4 managers, 4 researchers, and others. Five questions were asked in this survey.

Experienced tools during construction engineering education

Perception towards current education system

Applicability for 3D (VR) learning

Selection of topics to develop in 3D

Possible limitations

The results indicated that educational institutions mainly use textbooks (33.8%), handouts (29.9%), site visits (18.2%) and videos (13.0%). Concerning the current education system, 12 respondents were positive, 13 were neutral, and 6 were negative. This number indicates that the current education system is helpful to many, yet has gaps to be improved. Based on the survey, we concluded that PIECE 3D should neither exclude nor neglect current education paradigms. Rather, the new model should be an additive one that could improve the existing ones.

Although some (22.5%) of the respondents had a negative opinion of VR due to the ambiguity of VR's role and the time and cost it will take to build the model, most (77.4%) of the respondents agreed that virtual reality-based content will be effective when applied to construction engineering education.

3.2 Scenario Setup

A generalized method for learning module development that we also followed for our own module development is described in this section. Based on the survey, needs were identified. A scenario for the contents could be developed either from scratch by receiving advice from practitioners, or it could be excerpted from existing content sources such as

textbooks. For this study, we used both methodologies. We used textbooks for terms and visited experts to learn how the processes work in the site. We created a representative scenario for a typical case for a given topic.

3.3 Model Development

To design the components in 3D, it was reasonable to acquire an existing BIM model. We acquired an existing model from 'Tekla', and imported it to 'Revit' to modify or remove some components. Then, to build a scenario with interactions, 'Unity' was used.

3.4 Model Validation

To validate the suggested model as an integrated learning tool for effective teaching in construction engineering education, a series of assessments were conducted in undergraduate-level courses before actually implementing in traditional lectures.

4 Case Study: Reinforcement Bar Work

4.1 Need Analysis & Work Type Selection

Based on 'Korean Standard Specification for Building Construction (2013),' 20 out of 28 major work types and 51 out of 203 detailed work types were selected. These topics were chosen considering complexity, importance and 3D visualization potential. The survey ranked construction work types that could be visualized in interactive 3D.

According to the survey, steel work should have been selected for the case study (Figure 1). However, after consideration, rebar work was selected, because respondents with less than 5 years experience strongly insisted on the importance of rebar work. As less experienced practitioners tend to rely more on knowledge and experience from the universities or other institutes, their needs were considered to be more critical than the overall needs of the respondents.

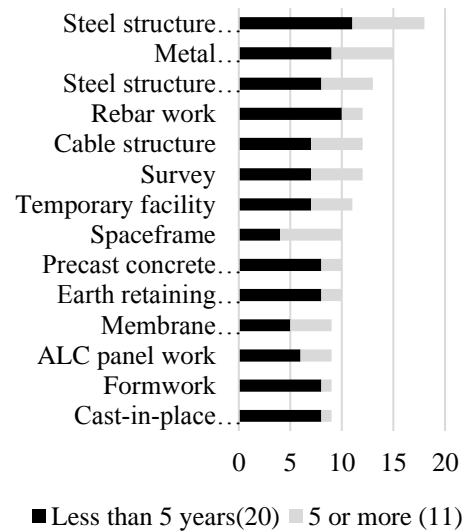


Figure 1. Survey results for work type preferred to be developed in 3D

4.2 Scenario Setup

We set up an example scenario. Actual processes can be flexible. The process sequences from foundation, column, wall, beam to slab were designed. The sequences are illustrated in Figure 2. Before any footing or foundation is built, the elevator pit is constructed in order to dewater the excavation volume. To construct the elevator pit, bottom bars, rebar supports, top bars, vertical bars and horizontal bars are built in that order. Rebar supports exist to support top bars. Vertical bars should be placed before horizontal bars as horizontal bars cannot stand alone in the air. Mostly, internal bars are constructed before external for the convenience.

Once the elevator pit is constructed, types of footings or foundations are selected. Single footings support one column while strip footings support multiple columns in a row. Mat foundations also support multiple columns but in multiple rows. They contain rebar supports between bottom and top bars.

In order to connect footings/foundations and columns, dowel bars are planted. Then, main bars are connected to the dowel bars in the vertical direction followed by tie bars in the horizontal direction. Walls are constructed with the same principle.

Beams have a special process. For beam, top bars are separated into two parts: (1) the edge and (2) the rest. Two top bars on the edge are placed on the wedge to carry the stirrups. The workflow of the beam is top bars (edge), stirrups, bottom bars, top bars (rest) and the cover bars.

Lastly, for the slab, the end parts of the bars go

before bent bars. The middle part goes after bent bars. It is due to the shape of the bent bars, which adds tensile force of the rebar. Main and sub bars refer to the position of the rebar.

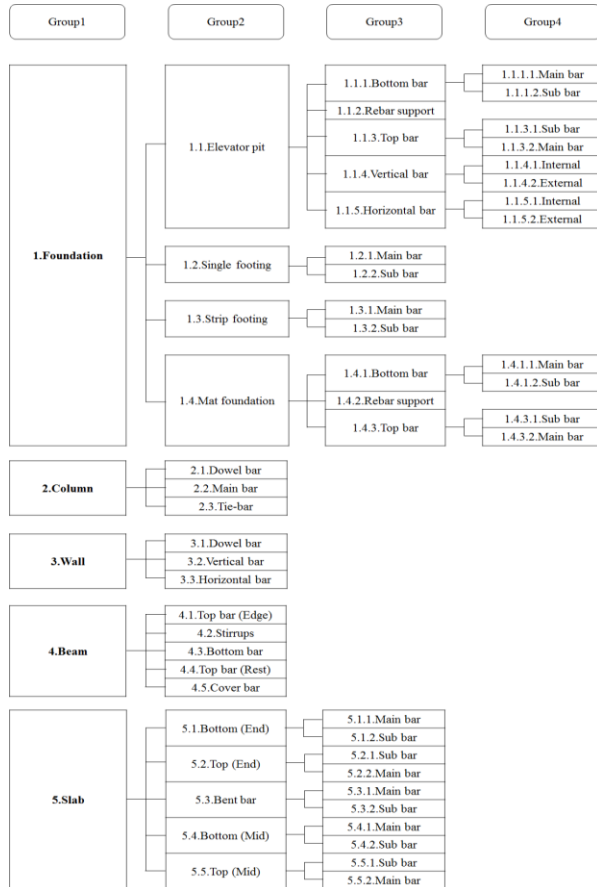


Figure 2. Summary of rebar work processes

4.3 Model Development

PIECE 3D was developed in three steps. The first step was to design the components in 3D. As we acquired an existing building model from 'Tekla', and imported to 'Revit,' (Figure 3) it was not difficult to dissect some components. Once the main components, such as foundation, column, wall and slab were ready (Figure 4), we saved the files respectively. These were used in a "hint" level to demonstrate finished shape as a reference and line silhouette in level 1. Then, components were dissected once again as subcomponents, subsubcomponents and so on. Subcomponents and subsubcomponents were used in level 0, level 1 and level 2.

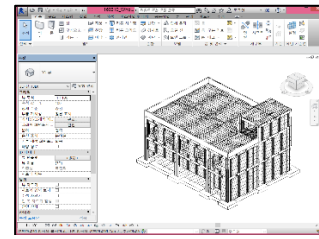


Figure 3. Entire BIM model

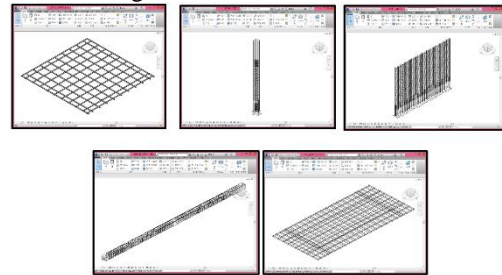


Figure 4. BIM model components (Foundation, Column, Wall, Beam, Slab)

The second step was to create a scenario (Figure 5). From level 0, students can learn the terms of rebar components not only top or bottom rebar but specific terms such as support rebar, stirrup and dowel bar. Students can zoom, move and rotate the components in any direction. In this level, students can also learn the process of rebar work as it is arranged in sequences. From hint level, students can view the finished design before moving on to next level. Level 1 shows line silhouette in green. Students can zoom, move and rotate the given components in order. From level 1, students can review the process and learn the right positions of rebar components. Finally in level 2, students are required to perform their learning experience from previous levels. A black space is given, and students can assemble the components in the right sequence at the right position. The labeling is not in order but is in random to check student's understanding of the processes. Screenshots of each level are illustrated in Figure 6.

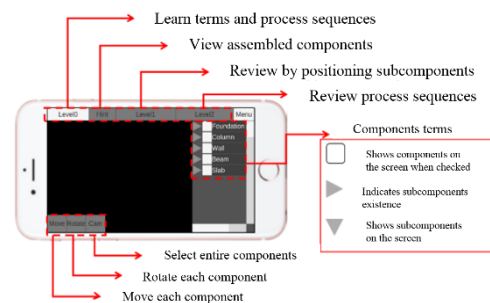


Figure 5. Roles of different levels and buttons

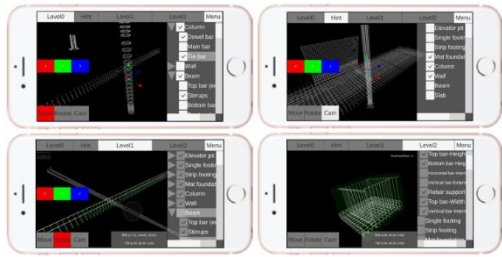


Figure 6. Screenshots of each level

The third step was to create interactions. There are unique features in PIECE 3D. Because the model is based on smartphone, it is touchscreen-based. In this case, it is complicated to move or rotate in 3D as the smartphone can only recognize two fingerprints at once. To overcome such barrier, we decided to integrate a feature called ‘Gizmo,’ which allows user to view in 3D directions.

4.4 Model Validation

To evaluate the usefulness of PIECE 3D as an integrated learning tool for an effective teaching approach in construction engineering education, we conducted a series of assessments in an undergraduate-level course, ‘Building Systems’ in the Department of Civil, Environmental and Architectural Engineering at Korea University. The experiments compared the effectiveness of PIECE 3D for learning with that of a tabletop computer. The course is a three-credit course for second year or higher grade students. Every year, 50-80 students take this course as a prerequisite for ‘Building Construction’ so that consistency in prior knowledge is maintained. ‘Building System’ introduces various kinds of wooden, reinforced concrete and/or steel buildings. ‘Building Construction’ investigates deeper the processes and methods of building construction.

The experiment was designed to meet two objectives: 1) learn the terms of rebar and 2) learn rebar fabrication processes. We believed students taking ‘Building System’ were suitable for this experiment, as they have learned the basic concepts and characteristics of rebar. This experiment would facilitate overall and detailed understanding of rebar work before taking ‘Building Construction’ and would also engage the students’ interest in learning by doing.

Out of 29 students who participated this experiment, 26 students were taking Building Systems in Spring 2016. All 29 students were in department of Civil, Environmental and Architecture Engineering. Participants consisted of 11 second year students, 16 third year students and 2 fourth year students. Students were asked to come to the office (Engineering Building 351) individually or in pairs. A laptop and a

smartphone were prepared in the office.

The operating system of the laptop was Microsoft® Windows® 8.1K (64 bit version) and it contained 8GB RAM. The BIM program used for the experiment was Autodesk Revit 2015.

The operating system of the PIECE 3D was Microsoft® Windows® 10Pro. The virtual reality engine used for this smartphone-based program was Unity 5.3.1f, and the IDE (Integrated Development Environment) was Visual Studio 2015. The language was C# and the test phone was a Samsung Galaxy Alpha.

It took 40 min to an hour for students to complete the experiment. Students were first asked to keep the objectives in mind. Then, the instructor explained how to view 3D models from a BIM program embedded in the laptop. By using keyboard (shift) and mouse (scroll wheel), students were able to zoom, move and rotate each and overall components. With the ‘view cube’ that assists visualization in Revit, students were able to view from the direction they wanted. Students could see eight components: elevator pit, single footing, strip footing, mat foundation, column, wall, beam and slab. Students were asked to pay attention to terms and processes. Students were allowed to ask questions to the instructor freely so that interactive atmosphere could be created. The instructor kindly explained basic principles of processes so that students can infer the sequences. For instance, the instructor gave hints such as ‘top bar’ is built after ‘bottom bar,’ ‘internal bar’ is built before ‘External bar,’ and as horizontal bar cannot stand alone in the air, ‘vertical bar’ is placed before ‘horizontal bar’. After viewing all eight components, students were asked to answer three questions in a quiz including terms and processes of rebar work. Question 1 was to recognize ‘column’ components terms, and questions 2 and 3 were asked to measure the understanding of the sequences of ‘mat foundation’ and ‘beam.’

Then, students were told to control smartphone-based model. The instructor showed how to check/uncheck the checkbox, how to zoom and move and rotate the components. Students went through all four levels (level 0, hint level, level 1, level 2) and were asked in another quiz to answer three different questions. Question 1 was recognizing ‘elevator pit’ components terms, question 2 and 3 were asked to measure the understanding of the sequences of ‘wall’ and ‘slab.’

Finally, based on students’ experiences, they were asked to evaluate BIM model and PIECE 3D. The survey included 15 criteria and they are assorted into four groups: 1) device suitability, 2) scenario quality, 3) device convenience and 4) user interest.

Based on the quiz and satisfaction evaluation

results from 29 students, we conducted the t-test to find the significance of the satisfaction difference between the BIM-based model and the PIECE 3D model. SPSS 12.0 K was used to analyze the data.

Since the sample size is small (N=29), the normality of data need to be examined before proceeding to the t-test. As the results of the quizzes do not follow a normal distribution, because they are scored either right or wrong, we decided to evaluate them separately. Figure 7 represents the results of the quiz. While BIM-based excelled in questions about terminology slightly, for processes, PIECE 3D outperformed considerably.

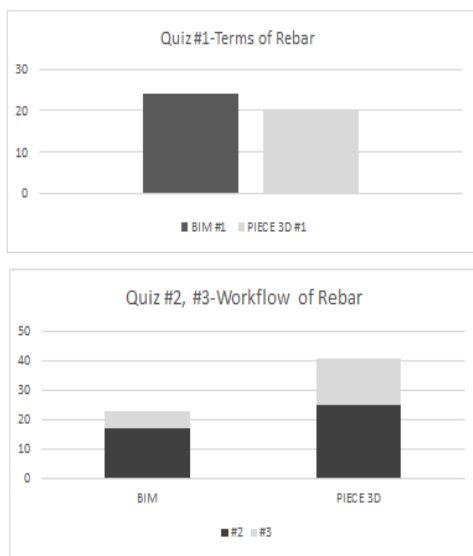


Figure 7. Result of quiz (Total: 29)

Once the students finished the quiz, they were asked to fill out the survey questionnaire to measure PIECE 3D satisfaction. Results are presented in Figure 8 and criteria are explained in Table 1.

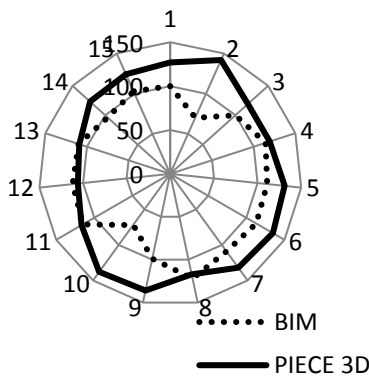


Figure 8. Results of satisfaction survey

Table 1. Criteria of satisfaction survey

Criteria (1: Strongly disagree, 5: Strongly agree)
1) Easy to access
2) Easy to carry
3) Adequate during the lecture
4) Complements traditional materials (e.g. textbook)
5) Successfully achieves objective
6) Increases understanding in 3D
7) Logical contents included
8) Detailed contents included
9) Easy to learn the terms
10) Easy to learn the processes
11) Adequate device speed
12) Easy to use
13) Convenient to use
14) Immersive
15) Interesting

Before conducting paired t-test, normality test of difference between paired data was carried out. As criteria 3, 12, 13, 14 have p-value higher than 0.05, it can be said that they follow normal distributions. Thus, a paired t-test can be conducted. For the other criteria that had p-value lower than 0.05, a Wilcoxon test was conducted.

Though there are differences in amount, for all eight pairs, PIECE 3D scored higher when it came to comparing means. Considering p-value, the author concluded that criteria 14 had significant differences between BIM and PIECE 3D. In other words, when it comes immersiveness, PIECE 3D surpassed the previous tabletop based BIM model. We also executed Wilcoxon test for the rest of the criteria.

The results reveal that for criteria 1, 2, 5, 6, 7, 9, 10 and 15 the alternatives are statistically different, and PIECE 3D outperforms the existing BIM model. Not only was PIECE 3D portable, but as it conveyed the educational objectives successfully in 3D, it was effective for students to understand the materials especially the terms and processes of rebar. It also triggered the interest of students.

5 Conclusion

This study proposed an effective education system using BIM and VR technologies. From needs analysis to model validation, four steps were taken to build ‘Portable Interactive Education for Construction Engineering (PIECE 3D).’ First, we discovered the needs from industry to find which topic would be preferred to be taught in 3D. Then, we set up a standard or a common process for the topic we want to develop. Next, we developed smartphone-based content. Finally, we compared PIECE 3D with an existing BIM-based

tabletop model in two perspectives: hardware and software.

From the quiz results and satisfaction survey, it became evident that PIECE 3D outperforms the tabletop model overall. PIECE 3D not only successfully helped deliver course objectives, but it facilitated understanding in 3D. Reviewing processes from 'Level 0' to 'Level 2' enabled students to learn the terms and processes of rebar work easily.

The case study of rebar work is only a part of the whole of construction works. For the future studies, more models can be developed from earthwork to demolition. Also, this model could be extended to different types of construction such as infrastructure or plants. Although we had some technical limitations due to the small screen and touchscreen system because of our smartphone-based platform, it was intuitive and immersive.

Lastly, we would like to emphasize the importance of current education systems. The suggested framework should not replace the current systems but complement them, so that students can interact better and effectively learn in class.

Acknowledgement

We would like to record our appreciation to Jujin Kim, for developing the application, Myungdo Lee for providing BIM data and Jihong Koo for guiding us to learn the terms and processes of the rebar work. Special thanks to Professor Hunhee Cho and Kyung-In Kang for supervising Master's thesis.

References

- [1] Ku K. and Mahabaleshwarkar P. S. Building interactive modelling for construction education in virtual worlds. *Journal of Information Technology in Construction*, 16: 189-208, 2011
- [2] Irizarry J. et al. Exploring applications of Building Information Modeling for enhancing visualization and information access in engineering and construction education environments. *International Journal of Construction Education and Research*, 8(2): 119-145, 2012
- [3] Kim J. Use of BIM for effective visualization teaching approach in construction education. *Journal of Professional Issues in Engineering Education and Practice*, 138(3): 214-223, 2012
- [4] Messner J. I. et al. Using Virtual Reality to improve Construction Engineering education. In *Proceedings of the 2003 American Society for*

Engineering Education Annual Conference & Exposition, 2003

- [5] Sampaio A. Z. and Henriques P. G. Virtual Reality technology applied in Civil Engineering education. *Proceedings of Current Developments in Technology-Assisted Education*, 1351-1355, 2006
- [6] Sampaio A. Z. et al. Virtual Reality technology used in Civil Engineering education. *The Open Virtual Reality Journal*, 2: 18-25, 2010
- [7] Sampaio A. Z. and Martins O. P. The application of Virtual Reality technology in the construction of bridge: The cantilever and incremental launching methods. *Automation in Construction*, 37: 58-67, 2014
- [8] Park C. S. et al. Interactive Building Anatomy Modeling for experimental building construction education. *Journal of Professional Issues in Engineering Education and Practice*, 142(3): 04015019-1-12, 2016
- [9] Pedro A. et al. Framework for integrating safety into construction methods education through interactive virtual reality. *Journal of Professional Issues in Engineering Education and Practice*, 142(2): 04015011-1-10, 2016