TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 5467-5476

From 2D Drawings to VR-enabled BIM: Developing a Building Construction Systems Course at the UAEU

[1]Khaled Galal Ahmed, [2]Aysha Al-Sheebani, [3]Fatema Al-Zaabi, [4]Maitha Al-Nuaimi, [5]Mona Megahed
[1],[2],[3],[4],[5]United Arab Emirates University
[1]kgahmed@uaeu.ac.ae,[2]201400297@uaeu.ac.ae, [3]201510038@uaeu.ac.ae, [4]201404691@uaeu.ac.ae, [5]201350368@uaeu.ac.ae

Article Info
Volume 83
Page Number: 5467 - 5476
Publication Issue:
May - June 2020

Abstract

The transformation from traditional 2D drawings into 3D Building Information Modeling (BIM)-enabled Virtual Reality (VR) Interactive Models is gaining momentum in the architectural, structural, and construction industries. On the other hand, the results of related research about improving construction education through the use of virtual reality suggest that students can understand construction projects much better when advanced visualization tools are used. Accordingly, VR tools has been rapidly recognized and implemented in Construction Engineering Education and Training (CEET) especially when combined with BIM. The research, funded under the SURE+ Projects Program by the UAEU, examined the application of VR-enabledBIM techniques, in one of the Building Construction Courses,that is currently traditionally taught at the Abet-Accredited Architectural Engineering (AE) Program at the United Arab Emirates University (UAEU), as a pilot investigation for applying the new tool in all Building Construction Courses. Through a three phases investigative process, the research has defined the potentials and the obstacles that were associated with the pilot implementation of applying the VR-enabledBIM method in teaching the topics of the Arch 316 Building Construction Systems Course. The outcomes of the research proved that this new interactive tool has significantly enhanced the attainment of 2 out of the 4 Course Learning Outcomes (CLOs) of the examined course, namely, 'Explaining construction methods and building construction systems', and 'Expressing graphically and technically building materials and construction systems and methods'. Accordingly, adopting the VR-enabled BIM tool is highly recommended in other Building Construction, Building Design, and Graduation Projects, at the UAEU. This would much better prepare the AE Program graduates to the industry and significantly increase their employability rates.

Keywords: *Architectural Engineering, Building Construction, Building Information Modeling, Education, Virtual Reality.*

Article History
Article Received: *19 November 2019*
Revised: *27 January 2020*
Accepted: *24 February 2020*
Publication: *17 May 2020*

I. INTRODUCTION

All fields of architectural, structural, electro-mechanical and construction industries are currently switching from a relatively analogue-based Victorian-era process to an entirely digitized data powering and informing construction decision-making processes [1], [2], [3]. A leading force in this transformation is the Building Information Modeling (BIM) thatis a computer modeling process which brings together all relevant building information to streamline current and future decision-making processes [4].

In structural and construction design processes, BIM helps engineers, detailers, and fabricators understand the design completely in advance, so they can improve construction design documentation, minimize errors, and streamline collaboration between design professionals [5]. As BIM models contain layers of different building systemsit allows for running virtual tests to make sure that all the building systems are working appropriately and there are no internal or external clashes before construction begins [6], [4].

Locally in the UAE, Dubai Municipality issued a BIM mandate in 2013 and expanded it by another BIM mandate on 2015. The reason for such

mandates is to catch up with the latest construction trends in the world, for all the benefits that these new trends bring to all the stakeholders involved in building industry including project owners, consulting firms, contractors, and government departments.Among these benefits are lowering the cost of construction projects,decreasing the construction time,and increasing the level of coordination between the engineers working on designing and implementing construction projects[7].

On the other hand, as the main target of any successful educational institution is to have its graduates well-prepared to the industry, BIM has been integrated within great numbers of design and building construction schools all over the world to help achieve this goal. The effectiveness of the BIM in enhancing the educational outcomes have been evident. For example, a BIM-based teaching approach has been designed and implemented to teach construction courses offered at California State University, USA. In these courses, BIM models are being developed by students to better understand the buildings in detail and to accurately take off the material quantities. The effectiveness of this approach was evaluated through assessment rubricsand theresults indicated that the approach helped students to effectively learn the construction details and material quantity take-offs [8].

Tyler [9] claims that integrating Virtual Reality (VR) with BIM, to form what might be called 'VR-enabled BIM' or 'VR-powered BIM', is a big step up from just viewing a 3D BIM model on the screen of a student's laptop or tablet. A VR headset allows students to step inside a full-scale 3D virtual environment and interact with the building design and construction components just like they would in the real world. Students will be able to walk through a virtual copy of the building, traverse hallways and open doors and windows. With this virtual reality tool, changes and clashes can easily be detected and corrected before construction begins, thus, avoid making changes once construction is underway which can be costly and can easily extend the construction schedule by weeks or months. Wang [10] adds that VR has been rapidly recognized and implemented in construction engineering education and training (CEET) due to its benefits of providing an engaging and immersive environment. The virtual and augmented reality technologies have really taken off when combined with BIM [11].

II. Research Problem and Objectives

Building Construction/Construction Management is the main Synthesis (Design) Level at the Abet-Accredited Architectural Engineering (AE) Program,at the United Arab Emirates University (UAEU). but currently, students are mostly relying on 2D drawings or some simple physical models for comprehending different Building Construction Systems in the offered Building Construction Systems courses at the AE Department (Fig. 1). Unfortunately, this made students not fully aware of the Structure/Construction Systems and components due to their 2D 'flat level' comprehension of these systems.

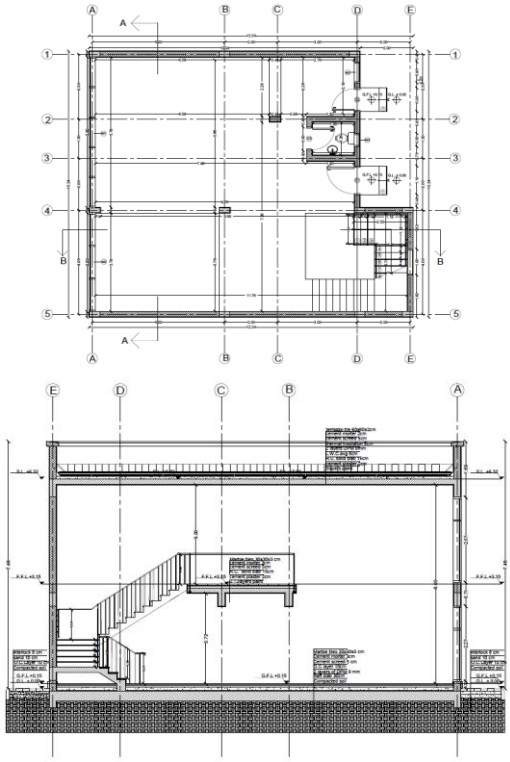


Fig. 1: Conventional CAD 2D drawings for building construction systems and components.

The research, funded under the SURE+ Projects Program by the UAEU, aimed at examining the combination of both BIM and VR techniques, in Arch 316 Building Construction Systems Course,as the basic Building Construction Course in the program.This pilot investigation for applying the VR-enabled BIM as a new tool in all conventionally taught Building Construction

May – June 2020
ISSN: 0193-4120 Page No. 5467-5476

Courses, at the AE Program was undertaken through a three phases investigative process.The objective of this process is to define the potentials and the obstacles that might be associated with the pilot implementation of the VR-enabled BIM method in teaching the topics of the sample course.

III. METHODOLOGY

The three investigation phases are: first, the transformation of the 2D structural/construction systems and materials taught in the Arch 316-Building Construction Systems course into VR-enabled BIM models. Second, is the investigation of the potentials and challengesthat might be associated with integrating these VR-enabled BIM tool in this course. And based on the results of these two phases of investigations, a set of recommendations is suggested forthe gradual integration of theVR-enabledBIM tool into the delivery methods of allBuilding Construction and other courses.

Two main tools were selected for undertaking this research investigations. The Autodesk Revit as a BIM tool and the Enscape 3D Revit-Plug in as a VR tool. The well-known Revit BIM software is a building information modeling tool for architectural, structural construction, electro-mechanical and plumbing design. The robust platform of the software offers an intelligent model-based approach for planning, designing, and constructing infrastructures and buildings [12]. Enscape 3D software (https://enscape3d.com/store/) is a real-time rendering and VR tool for Revit. It is the most favorable Revit visualization plugin for its simplicity and high quality of automatically converting the building materials into visually realistic materials.

The Principal Investigator (PI) of this project had limitedly attempted incorporating BIM in another Building Construction course - Arch 325 (Fig. 2). This experience has given the PI the required BIM knowledge needed in this research project. The selected students participating in the project also have good knowledge about Rivet as the main applied BIM tool.

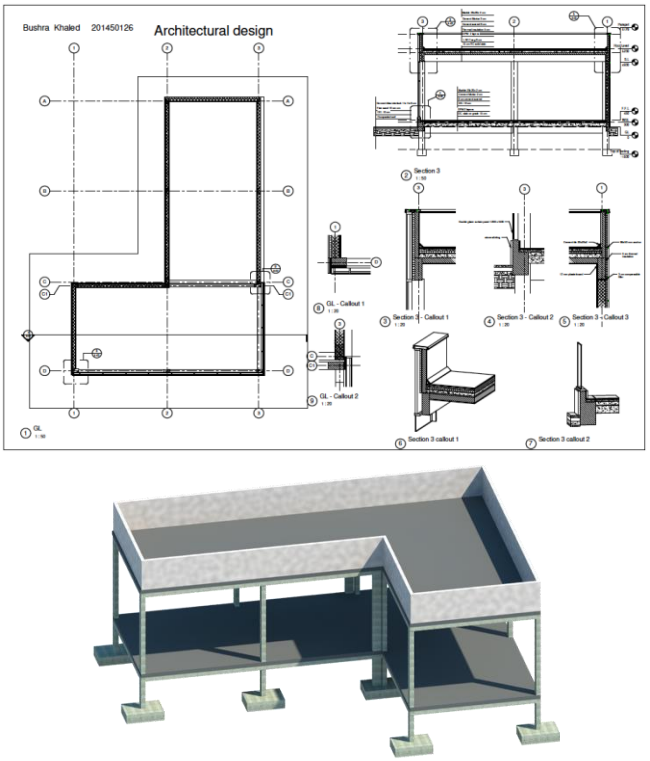


Fig. 2: Samples of the developed Revit BIM models for the Arch 325 - Building Construction Components course.

On the other hand, the PI and some of the participating students acquired the Enscape 3D - VR technical knowledge from a previous SURE+18 project in which they utilized the VR as a tool for community participation in social housing design.

IV. APPLYING THE TRANSFORMATION PROCESS

Phase 1 was applied in two stages: a)transformation of structural systems and b) transformation of building construction systems, as both taught in the course Arch 316.

For stage a, thesimple structure systems were developed into Revit-BIM models with as much accurate materials/details as possible. This included Simple Beam & Column, One and Two-Way Solid Slabs, Flat Slab, Open-Web Joist, etc. For stage b, the simple Building Construction Systems include Walls & Partitions, Roofing, Flooring, etc. Then, the VR tools were prepared, and the researchers used the VR to inspect the different systems to define/fix any perceived problems including clash detections. After the fine adjustment and the corrections revealed form the

May – June 2020
ISSN: 0193-4120 Page No. 5467-5476

VR inspection, the final Revit-BIM Models were uploaded into the Enscape 3D VR Tool and thus the VR-enabled BIM models were ready for all the investigated structure/building construction systems. By the end of this Phase, the needed resources, time consumed in developing the BIM and VR models, and the faced technical difficulties, were identified.

In Phase 2, the application of the VR-enabled BIM tool was piloted with the targeted students andthe potentialsand challenges were defined. As mentioned above, the PI and the team of students piloted the transformation method in one class ofthe course Arch 316. A total of twenty students voluntarily participated in theseinvestigationsessions.Four essential structure/building construction systems were investigated including a. Concrete skeleton structure and building components, b. Concrete skeleton structure: Types of concrete slabs, c.Steel skeleton structure: Open web steel joist framing,and d. Steel skeleton structure: Steel frame structure.

First, the students were asked to read the lecture notes then were asked to draw a simple sketch for the investigated system based on their understanding of it. Afterwards the students investigated the VR-enabled BIM model after wearing the VR headset and used the controllers to navigate the model. Then, the students were asked to redraw the sketch again.To rate the effectiveness of the transformation experience, the participating students were asked after completing their sessionsto answer the following 3 main questions by rating them on a scale of 1 to 5, where 1 is the lowest and 5 is the highest indicator:

- To what extent the VR experience has changedyourbasic knowledge about the investigated structure/construction system?
- To what extenthas your perception about the components of the investigated structure/construction system changed after the VR experience?
- To what extent are you willing to undertake the relevant assignments of your Building Construction Courses in a VR-enabled BIM (Revit) Modeling rather than in CAD?

In addition, the students were given the chance to freely express their opinion about the overall perceived benefits of their VR experience and the technical difficulties they faced during their VR-enabled BIM sessions.

Finally, a final set of recommendations for the transformation process based on the above assessment were developed, as explained later.

V. Results and Discussion

The results of the application of the four main transformed structure/building construction systems came as follows:

A. Concrete skeleton structure and building components

The attached plan and 3D drawings in Figure 3 represent a one-way and two-way solid slabs of a concrete skeleton structure. The figures were given to the participants in the question sheet and they were asked to draw sections A-A and B-B showing the one-way and the two-way solid slabs, the isolated footings, the external Concrete Masonry Unit (CMU) wall with the plasterboard finishing, and a terrazzo floor finishing. After, inspecting the same systems through the VR-enable BIM tool, the students were asked to draw the two sections again.

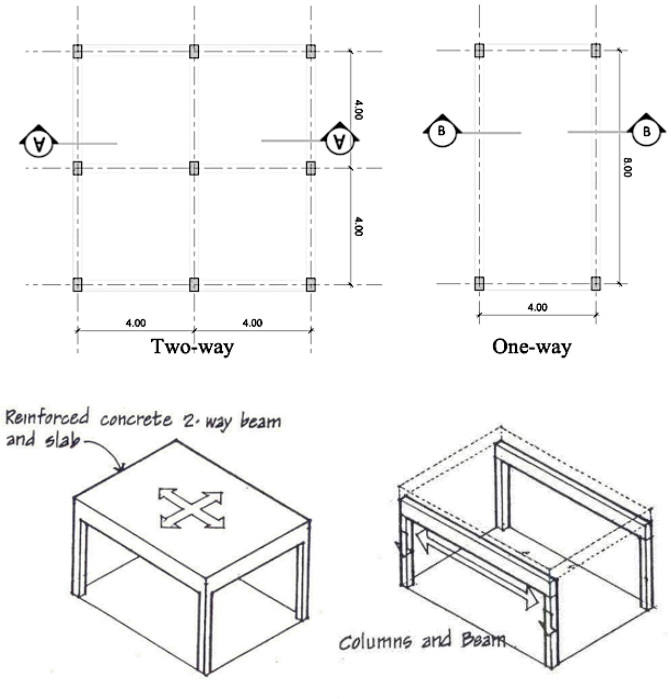


Fig. 3:Structural plan and 3D presentation of one-way and two-way slab[13].

Figure 4below shows an example of a student's sketches for the sections before and after utilizing the VR-enable BIM tool and Table 1 summarizes

May – June 2020
ISSN: 0193-4120 Page No. 5467-5476

the results of the questionnaire administered with the 5 students after completing the session.

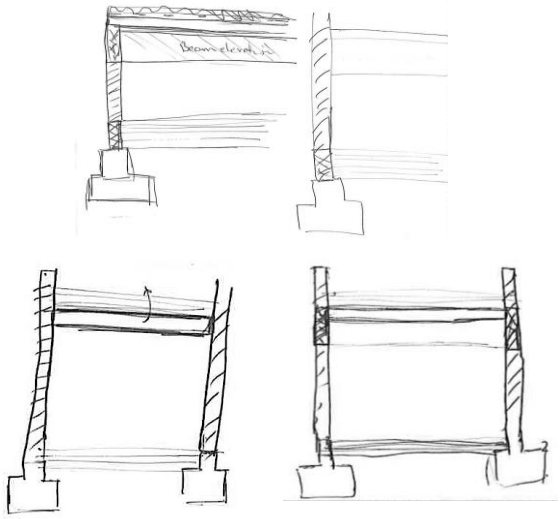


Fig. 4:A student's sketches example for the sections of the concrete skeleton structure and building components before (above) and after (below) using the VR-enabled BIM tool.

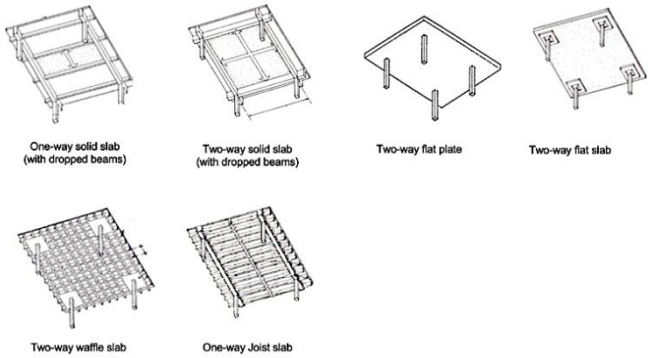
Table 1: The questionnaire results aboutthe Concrete Skeleton Structure and Building Components.

Student	Q1	Q2	Q3
Student #1	4	4	4
Student #2	5	5	4
Student #3	5	5	5
Student #4	4	3	2
Student #5	5	5	5
Total	**4.6**	**4.4**	**4**
%	**92**	**88**	**80**

The questionnaire shows that all the participants believe that the VR experience made significant changes(92%) to their basic knowledge about the investigated structure/building construction systems. The majority of them believe that theirperception about the components of the investigated structure/building construction systems have significantly changedas well (88%) after experiencing the VR tool. And, the majority of them are willing to producethe relevant assignments of their Building Construction courses in a VR-enabled BIM (Revit) Modeling rather than in CAD (80%).

B. Concrete skeleton structure: Types of concrete slabs

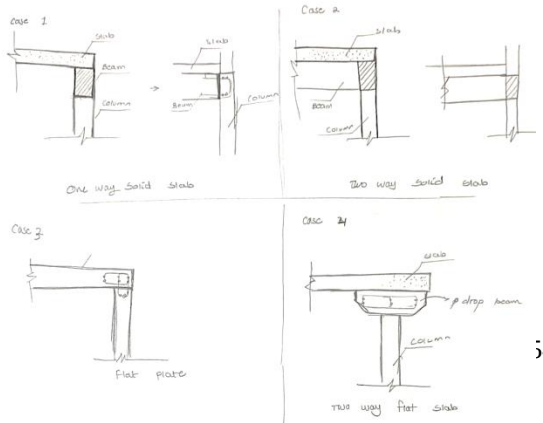
To investigate their understanding of the different types of concrete slabs including solid slabs, flat slabs, flat plates, joist slab and waffle slab, before and after the transformation process, the participant studentswere given the illustrations of



these systems in a 3D format (Fig. 5) and were then asked to draw sketches in sections for these different types.

Fig. 5: Types of concrete slabs[13].

Figure 6 shows an example of a student's sketches for the types of concrete slabs of a concrete skeleton structure before and after utilizing the VR-enabled BIM tool.Through the sketches and the outcomes of the questionnaire (Table 2) it became clear that all the participants believe that the VR experience made a slight change (64%) to their basic knowledge about the investigated types of concrete slabs. The majority of them also think that theirperception about the components of the investigated types of concrete slabs have slightly changed as well (64%) after experiencing the VR tool. But despite that,the majority of them showed willingness to produce the relevant assignments of their Building Construction courses in a VR-enabled BIM (Revit) Modeling rather than in CAD (80%).



TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 5467-5476

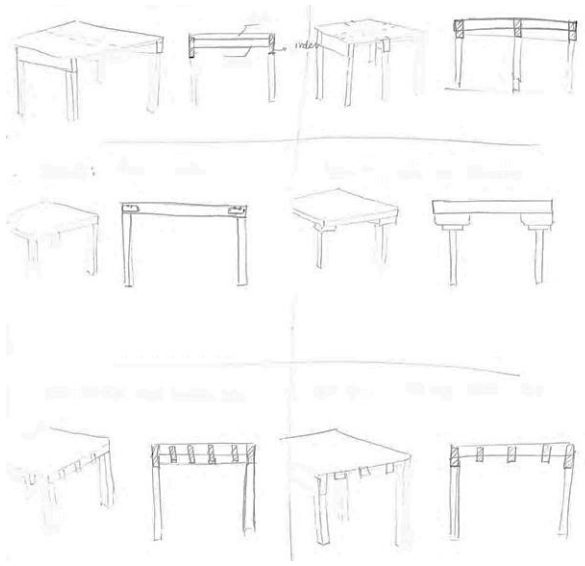
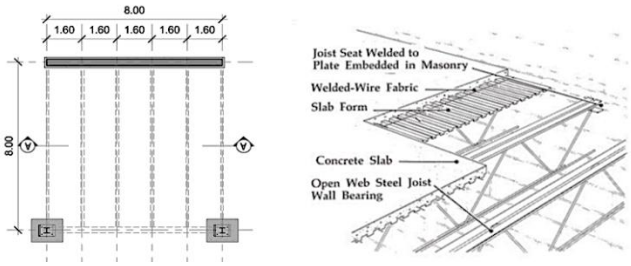


Fig. 6: A student'ssketches example for the types of concrete slabs before (above) and after (below) using the VR-enabled BIM tool.

Table 2: The questionnaire results about the Concrete skeleton structure: Types of concrete slabs

C. Steel skeleton structure: Open web steel joist framing

Similarly,to explore theparticipants'understanding of the open web steel joist framing system,they were given the shown drawings about this system (Fig. 7) and as usual were then asked to draw sketches fortwo sectionsbefore and after conducting the VR-enabled BIM session, showing the connections between the open web joist and the wall in the first section, andthe connections between the open web joist and the beams in the second. They were also asked to add a metal decking roofing system over the open web joist framing.



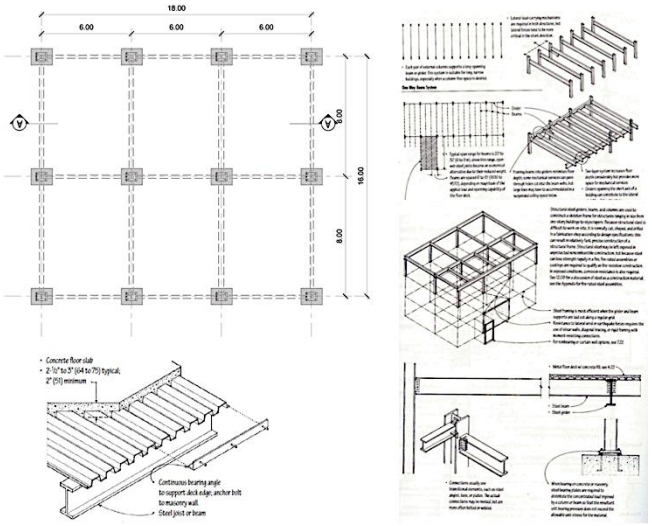


Fig. 7:Open web steel joist framing[13].

Figure 8 shows a student's sketchesexample for these twosections before and after utilizing the VR-enable BIM tool, while Table 3 shows the results of the administered questionnaire with 5 students.

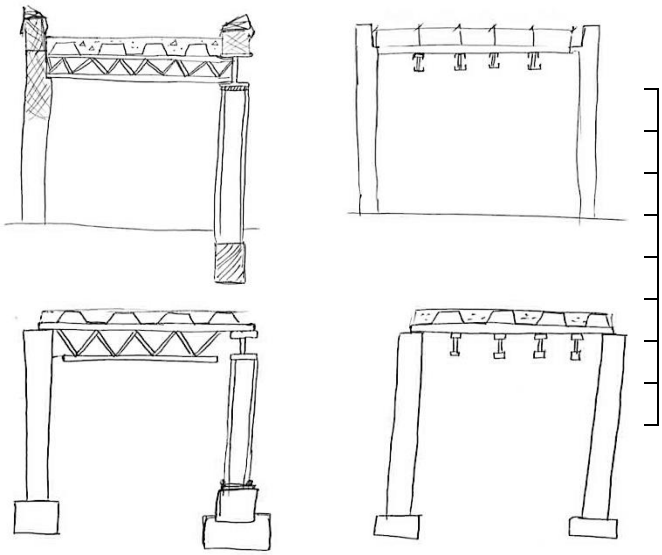


Fig. 8: A student sketch example for the Open web steel joist framing, before (above) and after (below) using the VR-enable BIM tool.

Table 3:The questionnaire results about the Open web steel joist framing.

Student	Q1	Q2	Q3
Student #1	5	5	5
Student #2	5	5	5
Student #3	5	5	4
Student #4	3	3	4
Student #5	3	3	5
Total	**4.2**	**4.2**	**4.6**
%	**84**	**84**	**92**

Student	Q1	Q2	Q3
Student #1	5	4	5
Student #2	5	4	4
Student #3	5	5	4
Student #4	5	5	5
Student #5	5	5	5
Total	**5**	**4.6**	**4.6**
%	**100**	**92**	**92**

According to thequestionnaire'sresults,the majority of the participants believe that the VR experience made significant change (84%) to their basic knowledge about the open web steel joist framing. The majority of them also believe that theirperception about the components of the investigated system have significantly changed (84%) after experiencing the tool. Moreover, all of them affirmed their willingness to produce the relevant assignments of their Building Construction courses in a VR-enabled BIM (Revit) Modeling rather than in CAD (92%).

D. Steel skeleton structure: Steel frame structure

Finally,after given the illustrations of the steel frame structure (Fig. 9), the participants were asked to draw sketches for the section direction A-A showing the connection between the steel column and the footing, the connection between the column and the beam, and to add a metal decking concrete slab over the steel framing.

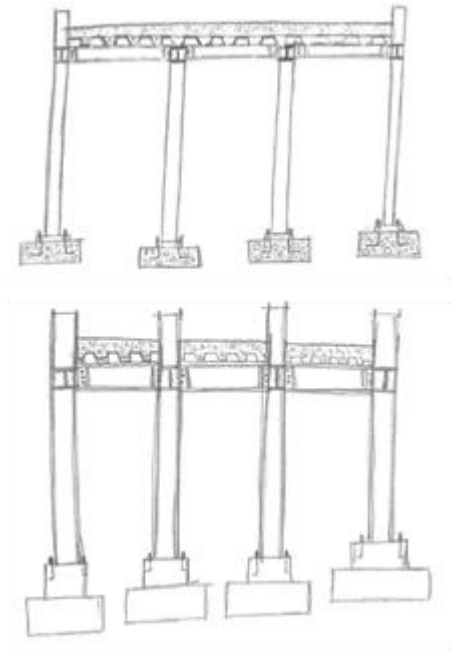


Fig. 9:Steel frame structure[13].

Figure 10 shows an example of the students' sketches for the steel frame structure section before and after utilizing the VR-enabled BIM tool.

Fig. 10: A student'ssketches example for the steel frame structure, before (above) and after (below) using the VR-enabled BIM tool.

Meanwhile, Table 4 concludes the results of the administered questionnaire after conducting the experiment. According to the results, all the participants believe that the VR-enabled BIM experience made overwhelming change (100%) to their basic knowledge about the steel frame structure. All of them also believe that their perception about the components of the investigated system have significantly changed (92%) after experiencing the tool. Furthermore, all of them affirmed their willingness to produce the relevant assignments of their Building Construction courses in a VR-enabled BIM (Revit) Modeling rather than in CAD (92%).

Table 4: The questionnaire results about the steel frame structure.

So, out of the four investigated structural/construction systems, the students' understanding of only the "types of concrete slabs"

May – June 2020
ISSN: 0193-4120 Page No. 5467-5476

were not highly affected by the utilized tool. This might be referred to the obvious simplicity of the system itself.When calculating the overall average ofthe questionnaire's resultspertaining to the fourinvestigated structure/building construction systems, it becomes evident that, overall, the majority of the participantshavea very positive opinionabout their experience of theVR-enabled BIM tool. Combining these results together shows that the majority of participants believe that the VR-enabled BIM experience made significant change (85%) to their basic knowledge about the 4 investigated systems. The majority of them also believe that their perception about the components of the investigated systems have significantly changed (82%) after experiencing the tool. Furthermore, the majority of them affirmed their willingness to produce the relevant assignments of their Building Construction courses in a VR-enabled BIM (Revit) Modeling rather than in CAD (86%) (Table 5).

Table 5:The overall questionnaire results about all the investigated structure/construction systems.

Structure/Building Construction System	**Q1**	**Q2**	**Q3**
Concrete skeleton structure and building components	4.6	4.4	4
Concrete skeleton structure: Types of concrete solid slab	3.2	3.2	4
Steel skeleton structure: Open web steel joist framing	4.2	4.2	4.6
Steel skeleton structure: Steel frame structure	5	4.6	4.6
Total	**4.25**	**4.1**	**4.3**
%	**85**	**82**	**86**

Some additional narratives were collected from the participants after answering the short questionnaire. These narratives gavefurther feedbacks regarding the students' experienceof utilizing the VR-enabled BIM tool through subsuming them in three categories as follows:

First, for the benefits the students gained form the VR-enabled BIM experience, one of them stated that, "*It is a great and helpful experience for me to learn more about structural systems. In specific, I liked the quality and visuals that showed the difference between one-way and two-way slabs*". A second student mentioned that, "*It was a great experience and I actually understood the structure systemsin detail. That's the first time I feel like I can imagine the structural elements*." A third one added, "*It was a very informative and interesting experience.*"Actually, during the sessions, most of the students asked the research team to do a number of workshops to teach them how to create 3D models in Revit and how to convert these models into VR, because they believed that this tool will help them to avoid doing many mistakes in their assignments and will save the time wasted in drawing Building Construction details on CAD.

Second,for the faced difficulties, one of the students commented that, "*the only disadvantage for this experience is that it is time consuming and may need long hours for each class. However, it helped me a lot in understanding all the building components.*" Another problem was related to the usage of the VR headsets. A student commented that "*My head is in pain!*" and a second one mentioned that, "*It is a great tool that let us imagine the 3D of the building, but it gave me a little headache!*"

Third, for the students' recommendations, several studentssuggested that, "*this tool should be generalizedfor educating the AE students because it is very useful in understanding the construction systems and details.*" A student concluded, "*I think the VR-enabled BIM tool would be very helpful in terms of understanding structural and construction systems, especially for the junior students who lack the knowledge about these systems. Therefore, I suggest that the AE department use this tool for teaching students in architecture and building construction courses because many students learn easier through visual tools like this one.*"Some students suggested to present their design studio models by the VR-enabled BIM method instead of the conventional way of printed posters, because they believe that this can help them explain their ideas much more clearly.

As most of the participant students were interested in the experiment and the tool, they asked to see more VR-enabled BIM models other than what they already saw during the sessions. Moreover, some of them said that this tool would help them significantly in their future career as they will keep up with the advanced technologies in the market.

Despite this evident success, but the transformation process encountered some difficulties as well. First, there are some technical difficultiesexperienced during converting the 2D

May – June 2020
ISSN: 0193-4120 Page No. 5467-5476

drawings into BIM models using Revit software. These include the need for high proficiency in Revit to be able to satisfy the need for a clear and comprehensive modellingof the transformed systems and components.This is mainly because many of the ready-made Revit families are simpler than needed and/or not showing the exact required levelof detailing. Increasing the level of proficiency in Revit required form the research team of students watching lengthy tutorial videos that used for self-paced training for them. This took a lot of time and effort. Some specificadvanced Revit tutorials were not even free to access.

Other difficulties were encountered during conducting the VR-enabled BIM sessions. These include findings matching time slots for the sessions that are suitable for both the participants and the research team. This has increased the total time for conducting the sessions. Dizziness of some participant students during the sessions also increased the allocated time of some of them.

Despite these faced difficulties and limitations, the VR-enabled BIM tool showed its efficiency as an essential educational tool in the field of Building Construction at the AE Department, UAEU, especially in the more complicated structural and building construction systems. So, all in all and based on the participants' opinions and comments, the VR-enabledBIM tool was significantly successful. It helped visualize the structure and construction systems components in a way that made the students able to recognize and differentiate between various types of thesesystems and components. Moreover, the tool managed to add more knowledge about the investigated systems to the students, and it even made many of them looking for using the tool in other courses.

VI. CONCLUSION

In this research the VR-enabled BIM tool was assessed in one of the Building Construction courses at the AE Department, UAEU.The aim was to define the potentials and the challenges that might face the application of the tool as a contributor in improving the teaching and learning process of building construction courses.In the investigated course (Arch 316), the VR-enabled BIM tool allowed the students to comprehendmore efficiently the components of the complicated structural and building construction systems, ifcompared to the conventional 2D/3D drawings method as it is currently the case for the Building Construction courses. The outcomes of the research show that this innovative and interactive tool is evidently effective and could really enhance the attainment of the Course Learning Outcomes of the investigated course and actually those of other Building Construction and Design courses, as well. Besides the evident opportunities, there are some challenges associated with this transformation process that were revealed while conducting the VR-enable BIM sessions. These challenges are mostly relevant to the availability of Revit Families, consumed time and effort in preparing BIM Revit Models, and the dizziness associated with wearing the VR Headsets. Those obstacles should be overcome through more preparation and funding before generalizing the transformation experience in other Building Construction and Design courses. All in all, combining the BIM and VR in the Building Construction Education through applying the VR-enabled BIM tool as a future trend in learning and teaching processes, would prepare the AE graduates to the industry and would also significantly increase their prospectus employability levels.

REFERENCES

[1] Qoura (2018) Why are BIM & Revit the future of digital building construction industry?, Available online: https://www.quora.com/Why-are-BIM-Revit-the-future-of-digital-building-construction-industry, First accessed 23 Feb. 2019

[2] Royal Institution of Chartered Surveyors (RICS) (2014) International BIM implementation guide RICS guidance note, global, 1st edition,London: Royal Institution of Chartered Surveyors (RICS).

[3] Green, Erin (2016) BIM 101: What is Building Information Modeling?, Available online: https://www.engineering.com/BIM/ArticleID/11436/BIM-101-What-is-Building-Information-Modeling.aspx, first accessed 14 Dec. 2018.

[4] Trivedi, G (2018) Why BIM Consulting Model is Advantageous to Construction Firms? Available online: https://archinect.com/true.cadd/release/why-bim-consulting-model-is-advantageous-to-construction-firms, first accessed 13 Feb. 2019.

May – June 2020
ISSN: 0193-4120 Page No. 5467-5476

[5] Autodesk (2019) Building Information Modeling, Available online; https://www.autodesk.ca/en/solutions/bim, first accessed 24 Jan 2019.
[6] Hall, John (2018) Top 10 Benefits of BIM in Construction, Available online: https://connect.bim360.autodesk.com/benefits-of-bim-in-construction, first accessed, 11 Dec. 2018.
[7] ConstructionWeek (2015) Revealed: Dubai Municipality's updated BIM mandate. Available online; https://www.constructionweekonline.com/article-34893-revealed-dubai-municipalitys-updated-bim-mandate , First accessed on 30 Dec 2018.
[8] Jin-Lee, Kim (2012) Use of BIM for Effective Visualization Teaching Approach in Construction Education, Journal of Professional Issues in Engineering Education and Practice,Vol. 138, Issue 3.
[9] Riddell, Tyler (2016) Virtual Reality in Construction, Available online, https://esub.com/virtual-reality-in-construction/, first accessed on 22 Dec 2018.
[10] Peng Wang, Peng Wu, Jun Wang, Xiangyu Wang (2018) A Critical Review of the Use of Virtual Reality in Construction Engineering Education and Training, International Journal of Environmental Research and Public Health 15(6):1204
[11] Premier Stoneworks (2018) Augmented Reality and Virtual Reality in construction 2018, Available online; https://premier-stoneworks.com/augmented-reality-and-virtual-reality-in-construction-2018/, First accessed on 16 Feb. 2019
[12] Finances online (2019) Best 20 Building Information Modeling (BIM) Software in 2019, Available online: https://financesonline.com/building-information-modeling/#revit, first accessed: 10 Feb 2019.
[13] Ching, Francis D.K. (2008), Building ConstructionIllustrated, Fourth Edition, John Wiley & Sons, Inc: NJ.