

IMPLEMENTING VIRTUAL REALITY - BUILDING INFORMATION MODELING IN THE CONSTRUCTION MANAGEMENT CURRICULUM

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SUMMARY: *As the industry transitions towards incorporating BIM in construction projects, adequately qualified students and specialists are essential to this transition. It became apparent that construction management programs required integrating Building Information Modeling (BIM) into the curriculum. By bringing Virtual Reality (VR) technology to BIM, VR-BIM would transform the architectural, engineering, and construction (AEC) industry, and three-dimensional (3D) immersive learning can be a valuable platform to enhance students' ability to recognize a variety of building principles. The study carries out a methodology for implementing the VR-BIM in the construction management undergraduate program. Based on the previous literature review, in-depth analysis of the program, and accreditation requirements, VR-BIM will be implemented throughout the curriculum by combining stand-alone class and integration in the existing courses method. The challenges that may face the program planning to implement VR-BIM are discussed, and few solutions are proposed. The lab classroom layout appropriate for the applications is designed to be adjusted for several layouts to accommodate all learning styles and objectives. A comparison between different Head-Mounted Display (HMD) headsets is carried out to choose the appropriate equipment for the lab.*

KEYWORDS: *BIM; VR; Construction Management; Curriculum*

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1. INTRODUCTION

The standard paper drawings and two-dimensional (2D) computer-aided design (CAD) drawings have been the standard for a long time in the Architecture, Engineering, and Construction (AEC) industry. Building information modeling (BIM) changed the way the construction industry functions, which became one of the most promising AEC technology advancements. As defined by the National BIM Standard, Building Information Modeling (BIM) is "a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward" (The National Institute of Building Sciences, 2020).

The current form of BIM term was pioneered in the work of Professor Charles Eastman (Nassar, 2010). Eastman et al. (2008) define BIM as "a modeling technology and associated set of processes to produce, communicate, and analyze building models." BIM Models are made of smart objects representing a physical element like doors and columns that hold a set of data. It can virtually build a structure before physically constructing it, allowing the project participants to explore and analyze a project digitally and make changes. That is less expensive than making changes during the construction phase (Hardin & McCool, 2015). The use of BIM in the Industry has surged from 28% in 2007 to 71% in 2012, and contractors' adoption of it is the highest at 74%, when compared to architects and engineers (McGraw-Hill, 2012).

BIM facilitates virtual Reality (VR) as a tool in the construction industry. It supports a smoother and more natural integration of VR during the design process. VR-BIM is an interactive multimedia technology that enables users to connect with digital objects, offering users a simulated physical presence in an enhanced virtual world (Biocca & Levy, 1995).

VR developed from flight simulation research in the 1960s. Ivan Sutherland was one of the first scientists to describe VR in his paper "The Ultimate Display" (Sutherland, 1965). The idea was to simulate a virtual reality that can't be differentiated from physical reality. Dioniso et al. 2013 defined VR as computer-generated simulations of three-dimensional objects that look real and need physical user interaction.

Immersive VR is useful because it immerses the user into an environment and gives them a sense of presence in a location where they are not physically present.

VR technology has a wide range of applications that can help a project with accelerated site training and protection, design progress, and coordination with all parties involved, and lower project costs (Behzadi, 2016).

As they are used in different important sections of projects, BIM and VR are the future of the building industry. In the modern construction process, BIM and VR technologies are used to perform worker safety preparation, defect management, quality management, project scheduling, knowledge collection, safety management, logistics management, and project progress assessment (Ahmed, et al., 2017).

Adding the virtual interface technologies to BIM will continue to revolutionize the instructional methods used in construction education and enhance students' learning experience (Messner & Horman, 2003). The 3D immersive experience can be a valuable resource for strengthening students' ability to build their sense of space (Paes, et al., 2017).

While BIM has become the trending technology, its applications and benefits in the AEC industry have not been maximized primarily due to a lack of trained BIM professionals (Gu & London, 2010; Lee & Hollar, 2013). This demand is followed by a necessity to implement BIM in AEC education. Therefore, many institutions adjusted their program curricula to integrate BIM (Chen & Gehrig, 2011).

2. LITERATURE REVIEW

2.1 VR-BIM In the Industry

BIM is used in the construction industry in many applications. Generating three dimensions (3D) visualization of the project (Azhar, 2011) is not the only use of BIM. It can be implemented in all phases of the project life cycle (Ahn, et al., 2016). As the construction projects are getting more sophisticated, the need for closer collaboration, more effective communication, and documentation is required (Eastman, et al., 2008). BIM improved the traditional paper-based tools in construction to a virtual environment, which increased efficiency, communication,

and collaboration (Lee, 2008). It is viewed as the ultimate solution to the problems of coordination across the building supply chain (Howard, et al., 2017).

When the schedule is added to the 3D model, time is introduced as the 4th dimension (4D). 4D models are essential in illustrating workflow and in creating a sequencing simulation that shows in 3D the building being built from start to finish. It will also provide early clash detection and identifying spatial conflicts in construction. (Azhar, 2011; Eastman, et al., 2008; Hardin & McCool, 2015). Clash detection is defined as an overlapping between components in the same space that occurs in 2D drawings, which can be easily identified in BIM. (Memon, et al., 2014).

Sampaio, et al., 2012 created a project using virtual reality technology for construction planning. A 4D model is created by linking the geometrical AutoCAD 3D model of distinct construction activity steps to the construction planning schedule. This application shows the construction process, eliminates inaccuracies and construction errors and improves coordination among construction partners.

When the 4D model is extended to include the cost, the model becomes a 5D model. BIM minimizes the manual take-off, which reduces the time and efforts needed for cost estimation (Azhar, 2011; Nassar, 2012) by generating take-offs, counts, and measurements directly from a model (Eastman, et al., 2008). Bryde, et al., 2013 in their extensive research, found that project cost was the one influenced most positively by BIM implementation followed by time. McGraw-Hill (McGraw-Hill, 2012) reported that contractors listed reducing rework, reducing overall project duration, and reducing errors in documents as the top benefits of adopting BIM. Having all the information included in the model will help in prefabrication ordering and delivery of the building materials and will assist in coordinating material ordering and delivery. That will reduce the cost and duration of a project (Ahn, et al., 2016; Azhar, 2011; Eastman, et al., 2008).

VR technology has gained tremendous potential in various disciplines for industrial and academic societies in the last two decades. Developed in the early 1990s, CAVE (CAVE Automatic Virtual Environment) was the first large-scale virtual projection system, enabled computational scientists to display their research in advanced interactive workstations (Cruz-Neira, et al., 1993). Although the AEC industry has used VR technologies, the primary use has been limited to marketing, visualization, and AEC professionals' training (Bullinger, et al., 2010; Pour Rahimian, et al., 2014). Virtual Reality applications provide an immersive, spatial, real-time platform for project model simulation that promotes safety, efficiency, and defect-free construction projects (Whyte, 2003).

VR has been used for safety training for construction workers by creating a set of safety training scenarios to examine and validate construction activities, and operations without being exposed to any risk (Shi, et al., 2006; Sacks, et al., 2013), and can help designers understand the effects of their designs on safety (Sacks, et al., 2015). VR-based training system for construction machinery showed to be successful for steel erection the design and installation of electrical systems (Zhao & Lucas, 2015.; Le, et al., 2015). VR-based training programs for cranes, excavators, and other construction equipment are reliable and tested technologies (Fang, et al., 2014; Hilfert, et al., 2016).

The use of VR helps the designer understand the model and increase the design team engagement, collaboration, and evaluation in all phases of design, resulting in a better understanding of complex designs and identifying design issues (Paes, et al., 2017). Field construction can also be more effectively designed, tracked, and managed by comprehensive visualization using VR technology (Kamat, et al., 2010).

Defect management has become much easier and more efficient thanks to virtual reality technology. There is no way to ignore it here. This procedure does not necessitate any physical labor. As a result, this form of the defect and quality control saves both labor and time (Ahmed, et al., 2017; Shen et al., 2010). The use of virtual reality in understanding occupant-system interactions related to thermal changes was also investigated (Ozcelik et al. 2017).

VR with BIM helps professionals interact with the rich information included in a BIM model in real-time. This visualization helps create a common understanding among major project stakeholders throughout the lifecycle of projects, reducing changes in design (Alizadehsalehi, et al., 2019; Balali, et al., 2020).

By combining the strengths of pre-construction prototypes, which give users a sense of presence, and BIM models, which enable users to analyze alternative design options in the models in a timely and cost-effective manner, VR-BIM can be used to engage end-users in the design phase of projects (Gopinath & Messner, 2004; Leicht, et al., 2010). That encouraged researchers to create a protocol for design evaluation session intents with end-users. These

protocols define all of the phases that must be considered to successfully implement immersive VR (Mastrolembo Ventura, et al. 2020).

It can also be used in facilities management by accessing the building plans, sensors, and systems, simulating human energy consumption and behavior during emergency evacuations (Frazier, et al., 2013; Goldstein, et al., 2011; Heydarian, et al., 2015). It has been used for construction project planning and scheduling and clash and error detection (Hollermann & Bargstädt, 2014; Fu & Liu, 2018).

2.2 VR-BIM In the Education

The introduction of BIM in AEC education in recent years has not been consistent. Architecture academic programs lead the use of BIM, followed by engineering and construction programs (Arashpour & Aranda-Mena, 2017). Less than 1% of construction programs had a stand-alone BIM course as of 2008, while 9% had BIM as part of their existing courses (Sabongi, 2009). These numbers increased as of 2013, when 54 percent of construction programs had BIM classes included in their curricula, and 52 percent said that BIM material was embedded in traditional courses (Wu & Issa, 2014).

The integration of BIM in education showed to have great benefits. Accessibility to information and visualization enhancement is the first benefit of using BIM in education (Zolfagharian, et al., 2013; Lu, et al., 2013), but it has far more benefits to students than visualization. Using BIM management tools in project management classes allowed students to work on more complex projects and use several management methods (Peterson, et al., 2011). Since university students lack building experience, teaching BIM methods for quantifying and costing large structures can give students a better understanding of the estimating process (Sylvester & Dietrich, 2010; Kim, 2012).

BIM is also used as a collaborative design tool in a multi-disciplinary team, a team formed from students from different backgrounds. This multi-disciplinary setup helps students develop their collaboration skills (Ghosh, et al., 2015; Peterson, et al., 2011). It was found that using BIM enhanced design skills, understanding of the basic concepts and the construction process (Holland, et al., 2010; Gledson & Dawson, 2016).

It is a good tool to teach fundamental structural concepts and improve students' understanding of the structure's full behavior (Nawari, et al., 2014). A study conducted by Irizarry et al. 2012 showed an increase of around 10% in the number of correct answers related to concrete construction when BIM 3D models are introduced to students (Irizarry, et al., 2012), as well as HVAC system components (Mokhtar, 2019).

Energy analysis concerning sustainability can be performed to design less energy-consuming buildings (Agirbas, 2020). Using 4D CAD models in education has improved students' understanding of construction sequencing issues (Messner & Horman, 2003).

Educational institutions have been incorporating BIM either by teaching classes with one discipline and teaching the use of BIM software or concepts with students in the same course and background. Or Interdisciplinary courses by teaching BIM by collaborating with students from other disciplines at the same school or from distant schools (Barison & Santos, 2010).

Higher Education had used different methods to implement BIM in the curricula:

- Stand-alone course: This is achieved by introducing a new BIM course. The course is usually a lower-level class where students learn the concept for BIM and specific modeling skills. The course could replace the CAD course or an elective course (Lee & Hollar, 2013; Barison & Santos, 2010). Construction Management programs accredited by the American Council for Construction Education (ACCE) do not have clear criteria for BIM classes, leaving no space to provide a stand-alone class that teaches these techniques (Maghiar, et al., 2013). Also, providing stand-alone BIM courses without continuity in other classes does not promote long-term learning for students (Clevenger, et al., 2010)
- Implementing BIM in a capstone project is another way to teach BIM. It allows students to learn the BIM process throughout the project cycle, but it limits the learning process due to the course's limited timeframe (Huang, 2016).
- The integrating BIM into existing courses by dividing BIM content into smaller, more manageable subjects distributed over all years of the CM curriculum. Where the first two years focus on basic information as modeling skills, while the following years focus on more advanced BIM functions

estimating and scheduling (Sacks & Pikas, 2013). BIM is also used to create interactive teaching modules. These modules can be integrated into several courses to help students understand several concepts introduced in the curriculum (Lee & Hollar, 2013). Using only existing core courses that cover a considerable amount of information leaves teachers insufficient time to cover BIM's full potential (Clevenger, et al., 2010).

- A combination of both: stand-alone class and integration in the existing courses. Clevenger et al. 2010 recommend combining these two strategies so students can learn the general BIM concepts in a stand-alone course and prepare them for more advanced BIM concepts in the existing courses.

The criteria to choose the courses for BIM adaptation are not clear. Pikas et al. 2013 recommended selecting courses that cover both design and management concepts in all years of a curriculum and address the logical sequence of building BIM knowledge and skills.

Moving freely through an immersive environment enhances brain activity by producing a higher degree of cognitive processing within the working memory, which correlates with cognitive recovery to achieve greater success (Jaiswal, et al., 2010.). A study by Mikropoulos & Natsis, 2011 concluded that virtual reality usage in education leads to positive learning outcomes, first-order interactions, scale, transduction, autonomy, and presence. Nearly 87 percent of all construction engineering courses are taught using the passive lecture form (Bernold, 2005). The virtual environment interaction stimulates the participant to think critically, not passively.

Compared to 2D drawings, students showed more interest and motivation when using the VR system (Calderon-Hernandez, et al., 2019), allowing them to practice in a safe environment and clear the language barriers for international learners. Consequently, experiments carried out using this technology are much more cost-effective and less dangerous than those carried out in the real world (Alizadehsalehi, et al., 2019).

The early use of VR technologies in construction education was desktop-based VR. Desktop-based VR, as the platform for virtual activities, employs a simple computer monitor. It displays a 3D virtual world on a desktop screen without the use of tracking equipment (Chen et al. 2007). V-REALISM and the Interactive Construction Management Learning System (ICMLS) are two of the most significant developments in desktop-based VR in education (Wang, P., et al. 2018).

The desktop-based technology was the first step toward immersive VR. Immersive VR depends on the use of specialized hardware, such as CAVE, head-mounted display (HMD), and sensor gloves, to remove users from their physical surroundings.

Immersive VR depends on the use of specialized hardware, such as a head-mounted display (HMD) and sensor gloves, to remove users from their physical surroundings. Messner et al. 2003, on the other hand, used the CAVE environment to review 4D simulation. Students had a better understanding of the topic than they did using 2D representation.

Another way VR was used in Construction education is 3D Game-Based VR. Castronovo et al. 2019 developed an educational virtual reality game to teach the design process and develop evaluation skills, while Le et al, 2015 created a game-based VR platform to train students on reality defect scenarios. In another project, a game-like VR construction site simulator (GVRSS) was created to increase engagement through an immersive construction site environment to better understand real-life AEC problems (Pour Rahimian, et al., 2014).

Augmented Reality (AR) allows students to interact with virtual objects in the real-world environment. It was used to adjust equipment operations in the construction processes (Kim, et al., 2011), and in created CAM-ART, a platform created to be used in construction engineering undergraduate courses (Shirazi & Behzadan, 2014).

Also, 360 panoramic Augmented Reality was used to create a safety training environment (Pereira et al. ,2017), and for visualizing complex situations on real construction sites enabling students to view actual locations as if they were in those locations conducting site visits (Kim & Leatham, 2018).

BIM-Enabled VR enables users to take a building design and place it in a 3D virtual environment with all relevant building information, allowing them to experience the BIM model in a virtual environment. In recent years, there has been a lot of interest in developing BIM-based VR technology (Wang P., et al. 2018). Therefore, the use of VR-BIM in education is the focus of this study.

Sampaio et al. 2010 used VR to create an interactive module that simulates the progression of construction Jobsite and shows students a bridge deck construction process. Wu et al. 2019 used a VR module to train students on global engineering collaboration skills, including teamwork, problem identification and solving, and safety awareness. Researchers investigated VR's use for improving student's architecture visualization and design skills which enhanced the graphics and details of modeling (Castronovo, et al., 2017).

Fogarty, et al., 2015 used CAVE-type VR and HMD-VR as a replacement for hands-on laboratory space to enable students to learn about structural components and assemblies in static and dynamic models. It was used to understand the wood frame construction sequencing and assemblies (Lucas, 2018 a) and a structural steel erection sequence and how to build a reinforcing steel cage for a concrete wall (Kamat, et al, 2010).

The usage of VR in material quantity applications has been limited. Wang, et al. , 2018 used VR-embedded BIM immersive system for quantity surveying practice and education. They found that it improves quantity surveying, the efficiencies of decision making, and the precision in quantity by minimizing the number of assumptions made in 2D quantity take-off.

Nevertheless, the majority of these studies used VR at the level of one course or one module. The adoption of VR technologies in AEC curricula has been slow compared to the fast development of the methods and tools used to create VR materials (Wang P., et al. 2018).

2.3 Challenges facing VR-BIM in Education

There are many challenges reported in implementing these technologies in the curriculum; the lack of resources is one of the primary difficulties (Becerik-Gerber, et al., 2011). The resources include the number of experts to teach BIM courses, faculty time required to make curriculum changes, support from faculty colleagues and/or administrators, managing to keep the number of required courses while maintaining the accreditation requirement, and contents to use in the courses (Sharag-Eldin & Nawari, 2010; Lucas, 2018 b).

For students, the learner must master the interface and accompany the interaction tools before using the environment (Schitteck, et al., 2001). Another concern working with VR is cyber-sickness. It is defined as physical and physiological discomfort caused by using a simulated world to induce the brain into believing as if it were in motion (Lucas, 2018 a).

Few schools have overcome the challenges of implementing VR-BIM in their programs. The school of the Built Environment at Northumbria University integrated 3D modeling and VR into the curriculum. It was implemented to cover 17 topics, including surveying and drawing skills, construction economics, planning, design, and safety (Horne & Thompson, 2007). They found that the careful selection of VR systems may result in greater cooperation between AEC disciplines as visualization evolves to provide significant integrative ability. The University of Iceland provided its engineering students with VR experiences, helping them understand their textbooks' concepts (Thorsteinsson, 2013). That allowed students to gain the necessary knowledge they required.

3. THE RESEARCH OBJECTIVE

Although the use of BIM in the Industry has surged from 28% in 2007 to 71% in 2012 (McGraw-Hill, 2012), the Southern part of the USA, including Kentucky is still below average in adopting BIM. The extend of BIM adoption in Industry goes hand in hand with trained students, and the adoption of VR technologies in AEC curricula has been slow compared to the fast development of the methods and tools used to create VR materials (Wang P., et al. 2018), with the majority of the previous research used VR at the level of one course or one objective.

This research aims to present a framework to implement Building Information Modeling (BIM) based VR in the undergraduate construction management curriculum. To do that, a literature review is carried out on the use of BIM and VR in the Industry. Understanding the industry needs determines the area of focus in training the students for their future careers. A literature review to summarize the status of BIM and VR in education is also necessary to learn from previous experiences and build on them. After the extensive review presented earlier, a comprehensive study of the program curriculum is carried out to find the best method for the implementation, followed by designing the lab that will support the program. A summary of the research framework is shown in FIG. 1.



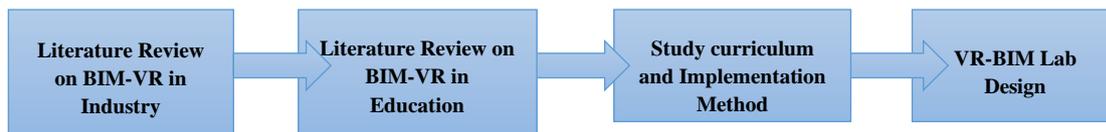


FIG. 1: Summary of the research framework

4. PROPOSED IMPLEMENTATION METHOD

4.1 The program background

The Construction Management (CM) program is part of the Applied Engineering and Technology School, College of Business and Technology. The program was accredited by the American Council for Construction Education (ACCE) in 1993. The program learning outcomes are the same as the ACCE Student Learning Outcomes (SLO) and the university critical thinking learning outcomes. ACCE-accredited CM programs have no apparent qualifications for a BIM class, although they have a 'Computer Applications' category as part of most construction curriculum topics.

The total curriculum requirements credits are 120 hours distributed as the following: total hours of university graduation requirements are 37 hours, major requirements are 59 hours, and supporting course requirements are 24 hours.

Based on the previous literature review, in-depth study of the program, and accreditation requirements, VR-BIM will be implemented throughout the curriculum by combining stand-alone course and integration in the existing courses method.

The terminology explained here will be used throughout the coming sections. First-year, second year, third year, and fourth year in the program are the freshman, sophomore, junior, and senior year levels. A course is a unit of teaching that usually spans one academic term and consists of a range of lessons on a specific subject. A module is a basically a self-contained unit of work in the course of instruction, and it is a teaching method focused on developing skills and experience in discrete units (Sejpal, 2013). SLO is the Student Learning Outcome required from the program. These terminologies may differ from program to program or among countries.

4.2 Methodology

The methodology that will be used in the implementation process is the following (FIG. 2):

1. Review the curriculum courses and identify the courses where VR- BIM can be implemented.
2. Adjustments should be made for the prerequisites.
3. Identify the objectives and ACCE SLO's of the course that can be achieved or improved using VR-BIM.
4. Identify the usage and methods to use for VR-BIM in the course.
5. Identify the assessment methods to measure the performance and success of the technique.
6. Monitor and measure objective achievements in each course.
7. Review the course objectives and methods used. Make changes if necessary.
8. Repeat the process.

A detailed review of all courses and objectives has been carried out. The VR-BIM will be implemented in 8 existing courses. These courses are spread out over the program years, with two courses in the freshmen year, two in the sophomore year, three in the junior year, and one course at the senior year level. Course distribution over program's years and their existing and proposed prerequisites are shown in FIG. 3.

At the freshman year level, VR-BIM will be incorporated to achieve better recognition of basic construction methods and visualizing. It will be used as learning modules as students at this level have not yet developed the essential background to use BIM. Two courses are selected: construction materials and methods I and II. These two courses cover the basic materials used in construction: steel, wood, concrete, and masonry.

In sophomore year, the two classes that were chosen are construction graphics and construction survey courses. The construction survey course will focus on 3D modeling and topographic surveying. Construction graphics is currently the 2D graphic course. It will be revised to be an introductory course to BIM, basic 3D modeling, and

construction drawings reading. Studies have indicated that students don't need CAD after learning to use BIM software. Students with CAD experience have had greater difficulty learning BIM tools (Sacks & Barak, 2010), and the use of BIM to soon replace CAD (Wong, et al., 2011).

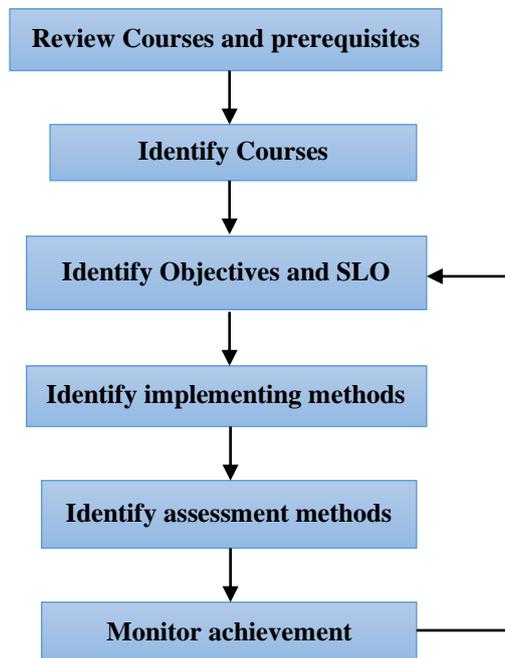


FIG. 2: The methodology used in the implementation process

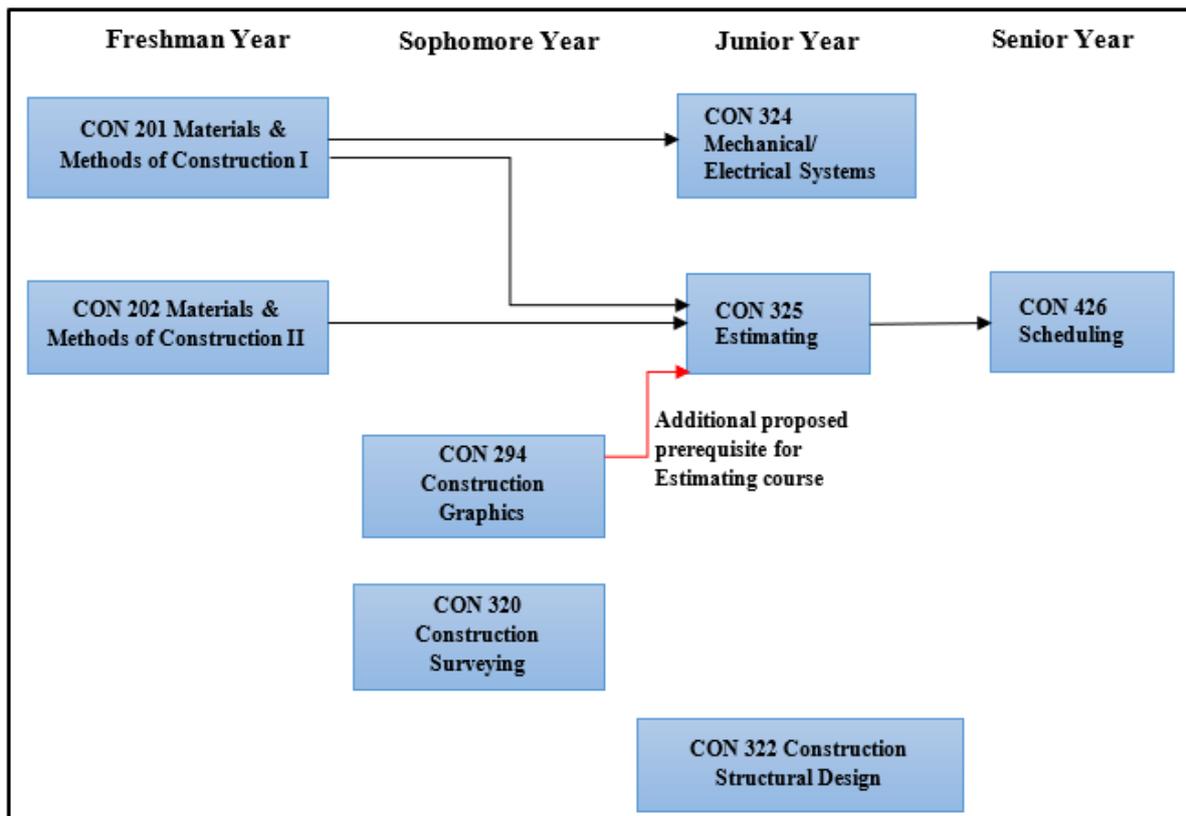


FIG. 3: Proposed progression of BIM Curriculum

The three courses to be revised at the Junior year level are Estimating, structural design and Mechanical/Electrical Systems. In the Estimating class, VR-BIM will be used to perform quantity take-off. The course will be divided into groups to work on a real project. That will also give students a better understanding of construction plans. Students will still be performing quantity take-off using a 2D plan as a huge part of the Industry still use it. An adjustment to this course prerequisite is required to ensure that students will take the construction graphics course before and be familiar with BIM basics. Construction Structural Design course will use VR-BIM technology mainly to visualize the nature of structural design and behavior through interactive modules. Connecting the BIM platform to other structural analysis applications will also enable students to gain collaborative experience as they learn structural design principles.

The Mechanical/Electrical Systems course is unique and independent when compared to other courses. The course's primary objective is to recognize the main components of Mechanical, electrical, and plumbing systems. Students will visualize these systems and see the interaction between different systems and perform clash detection.

In the last year of the program, the VR-BIM will be used in the Scheduling course. Students will connect the schedule to the actual 3D model. That will help students see the logic of the construction sequence and collaborate in real-life projects. The traditional scheduling techniques will still be part of this class.

A summary of the VR BIM concept and implementation methods for each course is shown in Table 1.

Table 1. Details of VR-BIM Usage and Methods

Year	Course	Concept	VR-BIM Usage	Method
Freshman	CON 201 Materials & Methods of Construction I	-Materials and methods of wood construction and framing -Materials and methods of steel construction and framing	-Construction sequence -Site trip -Visualization	Interactive Modules
	CON 202 Materials & Methods of Construction II	-Materials and methods of concrete construction and framing -Materials and methods of masonry construction	-Construction sequence -Visualization	Interactive Modules
Sophomore	CON 294 Construction Graphics	-Introduction to BIM -Basic 3D modeling skills -Learn the basic building components. -Recognize construction drawings	Build a 3D interactive model	Use 3D modeling software (Revit, Sketchup)
	CON 320 Construction Surveying	-Profile leveling, topographic surveying	-Volumetric Surveys -Site Modeling and Lay Outing	-Revit Toposurface -Carlson
Junior	CON 325 Estimating	-Perform quantity take-off -Pricing and markup -Change order -Collaboration in construction projects -Employ construction plans	-Find quantities and price real project using BIM	Material quantity take-off and schedule (Revit, Navisworks)
	CON 322 Construction Structural Design	-Represent structural elements in 3D -Recognize the interconnected nature of structural design and behavior	-Visualization -Analysis and interaction	-Interactive Modules -Robot Structural Analysis
	CON 324 Mechanical/Electrical Systems	Identify the components of Mechanical, electrical, and plumbing systems	-Visualization -Clash detection	-Revit Systems -Navisworks
Senior	CON 426 Scheduling	-Creating schedules -Simulating activities -Collaboration in construction projects	-Clash detection -4D scheduling -Construction sequence	-Navisworks -Primavera P6, MS Project

The relationship between the main objectives throughout the program and Bloom's Taxonomy is shown in FIG. 4. The curriculum's goals will be aligned with the six levels of Bloom's Taxonomy's cognitive learning process (Bloom, et al., 1956).

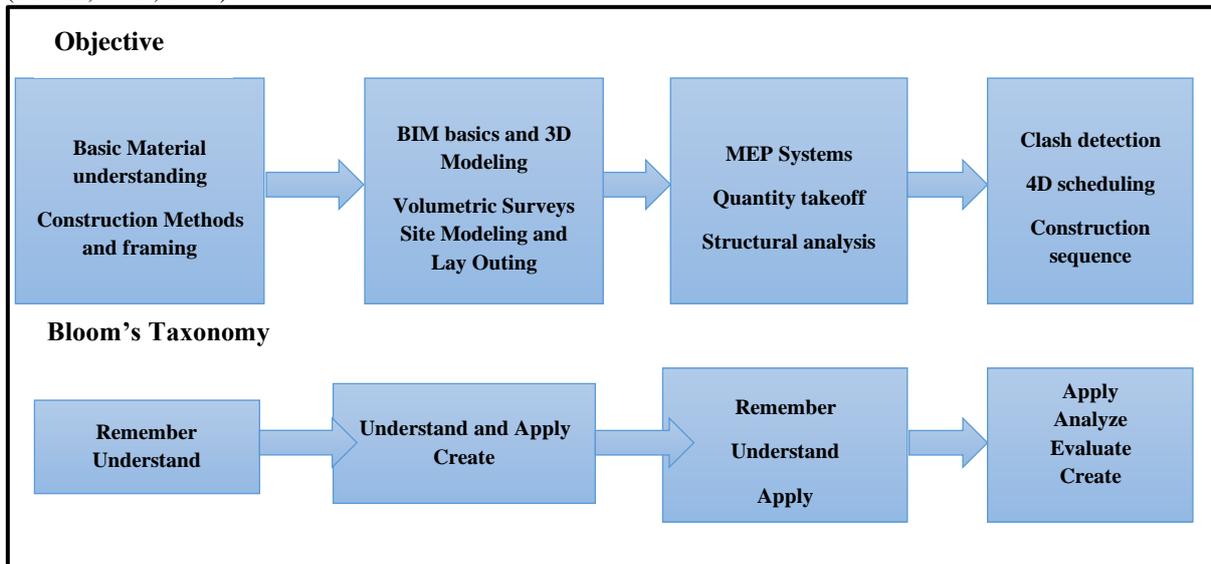


FIG. 4: The relationship between the program objectives and Bloom's Taxonomy

4.3 Proposed Evaluation Plan

After the initial plan is implemented in the program, it needs to be evaluated and adjusted. Participatory action research methodology (PAR) will be used as part of the evaluation plan. PAR is described as the direct and active participation of all stakeholders in the research process to solve an issue or improve a situation in a collaborative manner (Jacobs, 2016). Students' involvement in PAR can significantly enhance the curriculum as a whole (Atweh & Burton, 1995).

PAR stands for "practical testing." Participatory action research is cyclic, moving through different iterations of organizing, behaving, witnessing, and reflecting rather than following a traditional linear research model.

The data is collected about the program and method of implementation is built (Plan), the planned method is implemented and put into place (Act), and its effects and outcomes are observed (observe). Reflect is the stage where the students examine the plan, then evaluate and address their concerns. If the reflection shows the implementation (action) is effective, the process starts over to build on the initial plan. But if part of it needs attention, then these outcomes are considered in the planning for an adjustment or some kind of new action in the next cycle, and the action and outcomes are monitored again. The process continues in a sequence of repeated cycles (FIG. 5).

This method will be conducted at several levels: The module level, the course, and the curriculum level. While both the module and the course level PAR cycle will be within the course time frame, the cycle at the curriculum level will have a longer time frame.

Several measures will be considered (monitored). The learning objectives of each course identified previously need to be monitored as well as ACCE SLO's associated with the class. Students will complete an evaluation for the course, which is usually performed at the end of the course. And finally, compare the student's evaluations before implementing the plan with assessments after the implementation.

The assessment methods will vary based on the level of the level the assessment implemented, the course objective, and the methods used in the course. Diagnostic assessment can help recognize the current knowledge of a subject. pre-test and post-test, as well as self-assessments, are two of the diagnostic evaluation that will be used. The formative assessment offers feedback and information during the instructional process. Surveys and journals will be created to record the students' input. Once the plan is fully implemented and adjusted, the focus will be shifted toward the summative assessment methods, including exams and projects.

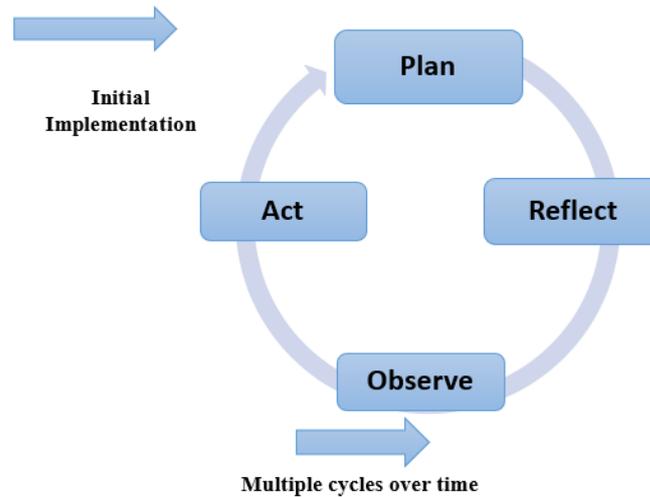


FIG. 5: Participatory Action Research (PAR) method used to evaluate the plan.

4.4 Challenges

The implementation of the VR-BIM into most construction programs will face several challenges:

- Collaborate efforts between faculty members. As the VR-BIM will be applied to several courses, teachers of these courses should work together to deliver high-quality education and close all gaps in the curriculum.
- Faculty members' ability to use BIM software and other required applications, which will require efforts, time, and financial support.
- Availability of educational modules and projects.
- A computer lab classroom equipped with a high-quality computer and required VR tools is needed for construction management students only. The space configuration should support the nature of virtual reality applications and teamwork collaboration.

To overcome these challenges, a few steps should be considered:

- A workshop will be held with all faculty members in the department to discuss the objectives, techniques, and approaches to achieve the level of use of VR-BIM in the course. Afterward, continuous support will be provided to faculty to ensure the completion of the process.
- Faculty training on BIM software can be provided by working with department partners in the Industry. This partnership with the Industry will help faculty members to focus on the topics of importance to the local companies.
- A set of modules and learning scenarios will be created for several classes. At this stage, teacher assistant (TA) students' involvement will be essential, as these modules take time to develop. It will also improve TA skills in BIM. The department partners in the Industry can provide complete projects to provide students with real-life experience.
- Design a new computer lab classroom that will be used by students. The basic design is discussed in the next section.

5. VR-BIM LAB DESIGN

5.1 Proposed Lab Setup

Upgraded classroom equipment and software infrastructure is required to provide access to computers and tools and to facilitate team communication (Clevenger, et al., 2010).

To facilitate effective VR-BIM integration, space has to be designed to include supporting technology and tools. It should also support collaboration as group work. This method enables students to recognize their strengths (Hativa & Birrenbaum, 2000).

There are strong links between the physical and social settings and their impact on student learning, teaching style, and computer lab classroom overall assessment (Challahan, 2004). Comfortable classroom seating helped boost the students' attention span and improved the retention of information (Swanquist, 1998). Flexibility is key to the effective design of classrooms. The flexible classrooms may provide space for both teacher-centered, as well as student-centered teaching approaches (Jamieson, 2000).

Typical classroom spaces only featured traditional rows desk layout. This style helps students concentrate their attention on the instructor and limits students' collaboration (Balli, 2009). Another layout is "U" shape, which places desks side by side in the classroom, in a broad semi-circular pattern which helps computer-enhanced courses (Niemeyer, 2003). Based on Bonus and Riordan's study, the U-Shaped configuration created the most social interaction between the students and is a valuable layout to promote discussion, role-playing, or other cooperative learning activities (Bonus & Riordan, 1998). This design needs a significant amount of classroom space to accommodate large numbers of students.

The third layout discussed here is the pod layout. This layout sets up desks in groups of students facing each other but may also turn slightly to see the professor in front of the classroom if necessary. It is designed to enable computer-based collaborative work (Challahan, 2004) and provides all groups with high visual and audio exposure (Ghosh, 2012).

Based on that, the lab classroom layout design will be flexible to be adjusted to all three layouts to accommodate all learning styles and objectives. The capacity of the lab will be 27 students. Chairs and tables will have wheels to adjust the layout as necessary. Trapezoid desktops will be used to give higher flexibility to the arrangements. These tables can be joined in a set of three, which will form nine groups. Due to the desks' shape, the layout will be a combination of "U" and pod layouts (FIG. 6 a). This merge will maximize the benefits by combining the advantage of both layouts. FIG. 6 c shows an internal view of the lab.

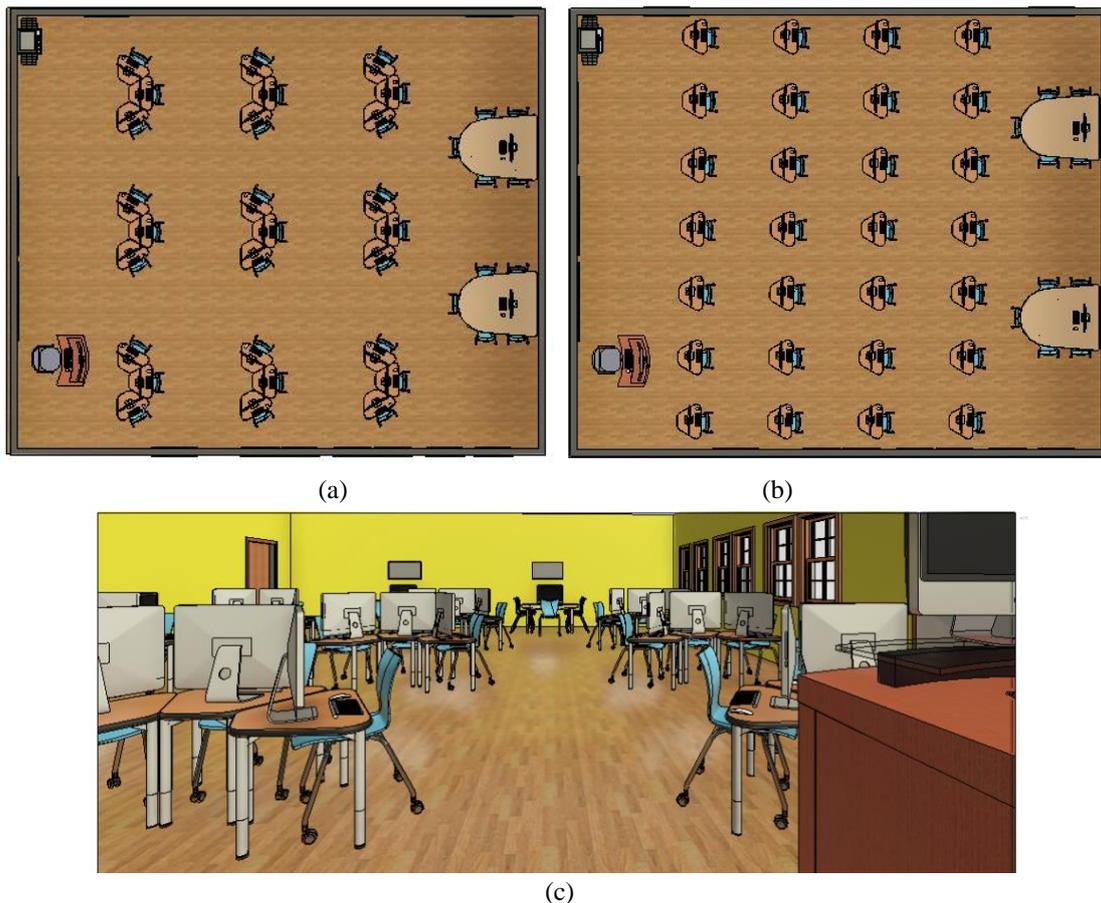


FIG.6: The lab design setup.

The original setup can be adjusted in several manners: the number of students in each group can be changed without compromising the quality of view and collaboration; the desks can be arranged to "U" layout or traditional rows desk layout (FIG. 6 b).

Two collaboration tables will be available with wall-mounted LCD screens connected to the front projection screen and a virtual reality headset. The classroom will be equipped with high-quality computers, a printer, and a teacher station.

As this lab is designed to serve a wide range of the department's courses, several software needs to be available to students during and outside class time. The companies provide most of the software for free if used for educational purposes. The following software will be available: Revit; Sketchup; WinEst; On-screen Take-off; Primavera; MS Project; Navisworks; Carlson; and Revizto/ Enscape.

5.2 VR Equipment

5.2.1 Introduction

Immersive systems have been based on a large head-mounted screen for decades, with limited resolution and field of view (Febretti, et al., 2013). The original CAVE, created in 1992, set up a Virtual Reality paradigm change. CAVE systems require specially built rooms and low ambient light rates, making it challenging to incorporate them. Add to that the high price. The other technology is the Head-Mounted Display (HMD) system, a basic virtual reality device worn on the head. There has been significant progress towards its hardware in recent years, which made it more affordable, widespread, and accessible. The main goal of a VR headset is to be a visual device with metrological features corresponding to the human visual system's full potential.

VR HMD's are available in three main categories: mobile tethered and stand-alone. Mobile headsets do not require exterior computer hardware or wiring and relatively cheap such as Google Cardboard and the Samsung Gear VR. The drawback that phones are not designed for VR. Therefore, they can't offer the best experience, and they have not been updated. Tethered headsets like the Oculus Rift S, the HTC Vive Cosmos, are physically connected to PCs. The usage of a unique display in the headset instead of your mobile increases the quality considerably. Stand-alone headsets like the Oculus Quest and Lenovo Mirage Solo, offer maximum physical freedom. They don't need a computer or a smartphone to have a VR experience as they have built-in processors, GPU, sensors, battery, memory, and displays.

Using an HMD device provides a closer look at the generated model so that the user feels as if the simulation cycle becomes a virtual reality within the environment. This interaction level between the user and the virtual environment generated is termed immersion, which is of a higher immersion level than the VR equipment (Alhalabi, 2016). HMD has been used in the AEC industry and education successfully (Balali, et al., 2020; Hilfert, et al., 2016; Lyne, 2013). Lucas, 2018 a, indicated that the students responded positively to the HMD simulations and their classroom use capability with minimum physiological discomforts such as eyestrain, vertigo, and nausea.

5.2.2 Major Characteristics

As the models that will be used are complex and needs high memory and interaction levels, the focus here will be on tethered headsets that will need to be connected to the PC. The main characteristics that affect the experience's quality are reviewed in this section to choose the right headset for the AEC applications.

The main characteristics that influence the HMD choice are:

- Screen type: There are various forms of display technology: LCD made from layers it blocks light to create a picture on the screen and always starts with backlight; AMOLED/OLEDs have their source of light.
- Resolution: The resolution determines the smoothness of on-screen data. It is defined by pixel count per inch.
- Frame rate update (refresh rate): As the objects are moving, the user's view must be updated continuously. The displayed images' frequency should not be too low compared to the visual system's need to perceive images without flickering (Fuchs, 2017).
- Field of view (FOV): The magnitude of the virtual environment visible via HMD or can be described as the viewing angle from the user's eye to the lens (Mehrfard, et al., 2019). Humans have approximately a

180°–200° horizontal field of view. The wider the FOV display in the VR, the more realistic and comfortable the experience becomes (Liu, et al., 2017).

- The Interpupillary Distance (IPD): The distance between the centers of your eyes. Either the mechanical setting or the optics must be provided with sufficiently large outlets so that anyone can use it.
- Tracking including cameras, area, and Degree of freedom (DOF). DOF is the ability to track movement and rotation around the three perpendicular axes (3 angles and three distances).
- Weight: The VR headset's weight will trigger physical symptoms to increase (Fuchs, 2017).
- Cost: The comparison was limited to HMD costs around \$1,000. As technology keeps improving and changing continually, it is essential to keep the price reasonable.

5.2.3 Comparison of General Characteristics of VR Headsets

A comparison between different types of HMD headsets is carried out (Table 2). The headsets chosen are the one that works on computers, not discontinued, and with cost around \$1,000. Based on the comparison, the valve index provides the best performance. The only downside that this HMD needs Base Stations for tracking. And the price is at the upper end. Oculus Quest is mainly used as a stand-alone, which compromised other important characteristics.

From the three other HMD, HP Reverb G2 will be chosen for the following reasons: It is a new headset that will be released soon. It is recommended to select the most advanced equipment as this technology advanced quickly (Bell & Fogler, 1997). It has a higher resolution and FOV. The price is within the average range. As this technology continually changes, an upgrade or change development platforms is possible.

Table 2. Comparison of General Characteristics of VR Headsets

Company name	HP Reverb G2	Oculus rift S	Oculus Quest	Valve index	Vive Cosmos
Display	LCD	LCD	OLED	LCD	LCD
Resolution (pixels per eye)	2160 x 2160	1280 x1440	1440 x1600	1440 x 1600	1440 x 1700
Fame rate update (Hz)	90	80	72	120	90
Field of view (FOV)	114°	115°	NA	130°	110°
Tracking Cameras area (DOF)	4 infinite area (6)	5 Infinite (6)	4 NA (6)	6 Area up to 33' x 33' (6)	4 NA (6)
IPD (mm)	Adjustment 60 - 68	Digital Fixed 63.5	Adjustable 58-72	Adjustable 58 – 70	Adjustable 61 - 73
Weight (g)	453.6	500	571	809	680
Cost (\$)	599.99	399	399-499 (+\$79.00 Cable)	999.00	699

6. CONCLUSIONS

As the Industry moves to incorporate BIM in construction projects, sufficiently trained students and professionals are essential for this change. The necessity became obvious for the construction management programs to include Building Information Modeling (BIM) in the curricula. Adding Virtual Reality (VR) technologies to BIM will revolutionize the Architecture, Engineering, and Construction (AEC) industry. And 3D virtual learning can be a powerful resource to enhance students' ability to understand several construction concepts.

The paper introduces a methodology to implement the VR-BIM in the construction management undergraduate curriculum. Based on the previous literature review, in-depth study of the program, and accreditation requirements, VR-BIM will be implemented throughout the curriculum by combining stand-alone class and integration in the existing courses method. It will be implemented in 8 classes spread out over the program years, while the 2D course is converted to serve as an introductory class for BIM. This method will enforce learned



concepts over several years. The VR-BIM concepts and methods are detailed for each course as well as the level achieved in Bloom's Taxonomy.

Several challenges may face the program when implementing the VR-BIM: Collaborate efforts between faculty members and their ability to use BIM applications, availability of teaching materials, and availability of required hardware and technology. Few steps can be considered to overcome these challenges: workshops and training for faculty members to align their efforts, followed by continuous support, partnership with Industry, the involvement of teaching assistant students, and provide a new computer lab classroom.

The lab classroom layout is designed to be adjustable for several layouts to accommodate all learning styles and objectives. A comparison between different HMD headsets is carried out to choose the appropriate equipment for the lab.

The methodology described in the paper cannot be generalized for all construction management undergraduate programs. A detailed investigation is needed for the program curriculum to produce the best method of implementation.

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