Journal of Construction Engineering, Management & Innovation
2024 7(1):01-09
DOI 10.31462/jcemi.2024.01001009

RESEARCH ARTICLE

Virtual reality simulation of highway bridges as a teaching tool in engineering

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Article History

Received 23 March 2023
Accepted 31 January 2024

Keywords

Virtual Reality (VR) technology
Highway bridges
Teaching in engineering

Abstract

The rapid advancement of interactive technologies, such as Virtual Reality (VR) and Augmented Reality (AR), has brought numerous possibilities for transformative applications in various areas. These innovations hold immense potential to revolutionize the construction industry. The dynamic progression of VR and AR not only introduces novel approaches but also fosters a range of applications in the field. In a recent study, the practical utilization of VR and AR was showcased through the development of a virtual highway bridge with reinforcement in a dedicated laboratory. This model, outlined in the paper, serves as an educational tool tailored for engineering students, offering a cost-effective and multifaceted learning experience in the realm of construction. The inherent connection between immersion and engagement in a virtual environment underscores the significance of these technologies. The ability to virtually interact with a constructed bridge model not only enhances the learning process but also provides a hands-on experience without the constraints of real-world costs and logistical challenges. Through this innovative approach, students gain valuable insights into construction practices, making the educational process more accessible and dynamic. The incorporation of VR and AR in the construction industry, as demonstrated by the development of a virtual highway bridge, signifies a paradigm shift in education. This pioneering method not only reduces costs but also expands the possibilities for interactive learning, offering engineering students a comprehensive and engaging exploration of construction principles.

1. Introduction

With the recent developments in technology over the last decade, teaching techniques have changed in engineering. Engineering education combines research and technical learning to promote innovation in both technology and education. This enhances problem-solving skills and creativity in recent graduates as they enter the technical workforce [1]. This change has also been supported by the change in the nature of the young generation in terms of their learning practices. This generation is more virtual environment friendly compared to previous ones. They are well integrated with a new style of reality and environment. Teaching in Engineering has also transformed over the years. Blueprints and 2D drawings were replaced by 3D drawings. With the change in the student profile,

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delivery methods have changed to accommodate this new generation to engage them in the learning process. VR plays an important role in this transition [2]. With its ability to demonstrate and integrate, VR carries engineering education to the next generation. There is various research work available in the field to investigate the integration of VR. Pantelidis [3] gives the following reasons to use virtual reality in education. Virtual reality provides new forms and methods of visualization, drawing on the strengths of visual representations. It provides an alternate method for the presentation of material. In some instances, VR can more accurately illustrate some features, processes, and so forth than by other means, allowing extreme close-up examination of an object, observation from a great distance, and observation and examination of areas and events unavailable by other means. Virtual reality motivates students. It requires interaction and encourages active participation rather than passivity. Some types of virtual reality, for example, collaborative virtual reality using text input with virtual worlds, encourage or require collaboration and provide a social atmosphere.

VR technology offers students the flexibility to navigate through an experience at their own pace, unconstrained by the rigid structure of a traditional class schedule. This adaptability is particularly beneficial for individuals with disabilities, enabling their participation in experiments or learning environments that might otherwise be inaccessible. Moreover, VR transcends language barriers, as evidenced by its ability to facilitate communication with students from diverse cultures. When coupled with accommodative useability, VR provides corresponding opportunities for interaction and allows users to engage in role-playing scenarios set in various contextual and graphical settings. In essence, VR not only empowers personalized and self-paced learning but also promotes inclusivity and technical communication through its immersive capabilities [5].

2. Literature Review

VR has been around for decades, the first VR headset was first created in 1968 by Ivan Sutherland, and through the years, it slowly developed because of technological limitations. The first big development was in 1989 when ATARI produced the first video game with 3D technology, and “soon after that, the virtual reality fever took off. In order to be in the driving seat of the Mars Rovers from Earth, Antonio Medina invented a VR system known as Computer Simulated Teleoperation.” After 5 years of development and new products coming to life, the hype for VR subsided as it hit another block of limitations. 2012 marked the beginning of a new era for VR, it opened the door for new applications like entertainment, education, and medical treatments for individuals that are easily accessible [4]. Deskin talked about the use of virtual learning and how it is becoming a viable option for learning; students from schools across the world gathered in a virtual room and helped write papers for their schools; it was an early form of VR as we know it now. He suggested the use of museums with virtual capabilities to teach kids in public schools, where they lack the funds to travel and learn about history [6].

Pantelidis conducted compressive research on the theories of using VR as training and a teaching tool, he created a model to determine when to use VR in education by following ten steps and doing multiple iterations of the environment until “it is shown to successfully measure or aid in the attainment of the objective” [7]. Pantelidis also categorized the levels of VR for different budgets and what software to use to achieve the optimum results. Merchant et al. explored different publications on virtual reality-based learning with regard to the outcomes in education. During the assessment, they found out there are many examples of VR being beneficial for learning and that “virtual reality-based instruction is an effective means of enhancing learning outcomes” [8]. Hilfert and Konig published the closest paper to this research, he presented a way to build a low-cost, highly immersive virtual reality environment for engineering and construction applications [9]. They presented a method to simplify and partly automate the process of reusing digital building models, which are already used in construction, to create virtual scenes instead of having to do parallel content creation for visualization.

These studies highlight a growing demand for Virtual Reality (VR) across diverse fields. However, the implementation of VR systems in certain areas might be hindered by financial considerations, preventing the actual deployment of these systems. The inherent need for a cost-effective solution that offers flexibility ensures safety during testing, and facilitates natural interactions has become increasingly evident. The appeal of VR is its potential to provide a low-cost and adaptable environment for testing. This environment not only addresses financial concerns but also promotes safe experimentation and fosters natural interactions. This becomes particularly crucial in fields where the presence of hazards limits the feasibility of trial-and-error testing in the physical realm. Applications facing challenges related to economy, safety, and risk can greatly benefit from the introduction of VR. By offering a simulated environment, VR allows professionals to conduct experiments and tests without exposing themselves to potential hazards. This creates a practical and secure alternative, reducing the limitations imposed by the real-world constraints of certain fields. The value of VR extends beyond its immersive capabilities; it serves as a strategic tool for overcoming financial barriers and safety concerns in testing environments. By providing a simulated space for experimentation, VR not only addresses the demand for innovation but also brings new possibilities in fields where real-world trial-and-error testing may be impractical or unsafe.

3. Investigation of the Highway Bridges

The highway systems in the US are an integral part of the current infrastructure and transportation systems and involve a huge investment on the part of the government and taxpayers. Bridges are the most challenging construction parts of the systems. The highways are rated D+ per the Infrastructure Report Card published by the American Society of Civil Engineers. It is estimated that $80 billion is spent annually on transportation systems in the US.

Construction is a very important phase of a highway and infrastructure investment, which typically incorporates the initial construction, rehabilitation, replacement, or addition of structural or non-structural elements. During the execution phase of a construction project, a successful construction project must comprise main components such as safety, sustainability, timely completion, cost-effectiveness, and quality. Adaptation of innovative technologies such as VR in US highway construction may potentially result in design evaluation in the real-time domain, reduction in cost, and timely completion of highway construction projects in the US.

In highway projects, there are various phases. Design, construction, maintenance, rehabilitation, and demolition are typical phases for highway projects. In between these phases, there is a need to support all these activities through the integration of new technology such as VR.

Complex processes such as quality assurance issues, communications among project participants, and management of highway infrastructure assets may be easier to complete and manipulate with the implementation of VR technology. In the present and the near future, VR has the potential to help construction projects in various different areas.

Highway systems are very important for the US transportation network. Bridges are one of the important tools of highway systems. The design and construction phases of the bridge start with the analysis, followed by the design check, and finally, the optimization. This sequence is repeated until a fulfilling project delivery is achieved. With the current technology, stages in the construction of transportation systems can be integrated for better production.

Many Departments of Transportation (DOTs) bridge designers and constructors have implemented various technological tools for integrated project delivery. There are two main processes during the construction stage. These are a) Transportation and b) Operation. In a normal life cycle, main transportation operations occur ‘‘to site’’, ‘‘from site’’, and “on-site”. An assessment has been conducted on the delivery of transportation projects, including the integration of transportation tools into the current environment. In this step, VR technologies provide a better understanding of delivery. The early adoption and implementation of new technology are critically important to DOTs that want to leverage possible competitive advantages over their competition.

Transportation systems in the US are very important and critical due to its economic and vital role in daily life and the economy [10]. With the developing technologies, there is considerable use of high-tech approaches in various stages of the transportation system. However, the construction is very complex, multi-stage, and integrated. In the transportation system, VR technologies can play an important role in the development and success of project delivery. In this manner, new technology adaptation is an ongoing and developing process for the state transportation agencies. The first pass through it, which most state transportation agencies have largely accomplished, is the most challenging due to its complexity. With a variety of components, most of the current strategies become ineffective for such a huge transportation network in the US.

4. Research Methodology

In the present study, VR/AR applications have been demonstrated on a Highway bridge model. The research began with an initial publication, serving as the foundation for subsequent advancements in the present study. In this current research endeavor, significant enhancements have been made, culminating in the development and thorough investigation of a representative bridge. The methodology involved leveraging Michigan Department of Transportation documents, specifically from the bridge design division, and adhering to structural codes for the design of beams, slabs, and columns.

In modeling, creating the modules has particular importance. The accuracy of 3D modeling is essential to develop the right platform for the implementation of the body and all components. After creating the model with the provided data to the system, model validation was carried out by comparing the outputs of the model with the existing model. An iterative model validation process has been carried out for each component and considering the provided data. The process involves multiple steps to refine and improve the model's performance using the data. Updating and revalidating the model in a productive environment provides a meticulous process. This process includes referencing the bridge design manual from the Department of Transportation in Michigan, ensuring compliance with established standards. Structural codes were then applied to meticulously design the various components such as beams, slabs, and columns. The entire process, including the intricacies of the 3D modeling, has been meticulously documented as an integral part of the research.

In summary, the research builds upon an initial publication, showcasing a comprehensive and improved investigation into bridge development. The use of authoritative documents and adherence to structural codes ensures the accuracy and reliability of the designed components, with all details meticulously documented, including the 3D modeling aspects, contributing to the robustness of the research findings.

4.1. Modeling the 3D highway bridge

The 3D model of the highway bridge that is discussed in this paper is a continuation of the VR simulation of the highway bridge developed by Korkmaz and Tanbour [11]. As per the requirement of the highway bridge, the bridge will cross two lanes of two-way roads and an island in between. The space allows for constructing 3 columns and foundations as a whole part; the selection of this specific design will allow for a wider variety of knowledge to be shown. Using Solidworks makes design the columns and foundation in more specific environment. Using these details, an Isometric and transparent drawing is seen in Fig. 1.

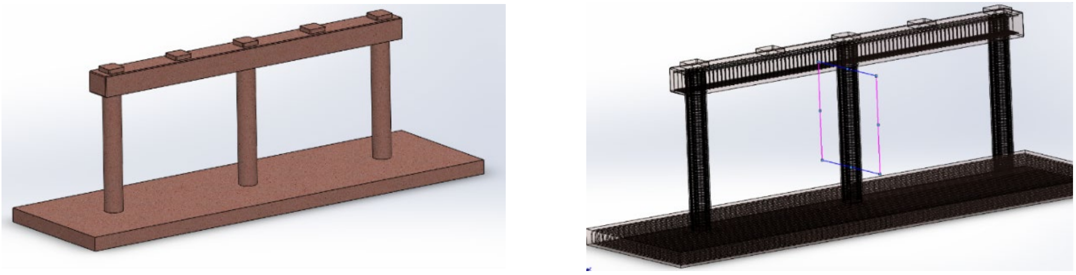

Fig. 1. Isometric and transparent view of the columns and foundation

Based on the highway bridge requirements and the columns spacing, the length of the beams is 55’, the depth is 4.5’, and other dimensions are per code. Five beams are needed on the columns to hold the bridge to distribute the load. Based on the highway bridge requirements, the bridge slab will be a one-lane two-way toad plus sufficient road shoulder. The reinforcement for the bridge slab will contain varying diameters of steel bars and stirrup ties to give more visuals to the students. Fig. 2 gives the assembly.

4.2. Transferring the 3D model to VR

Choosing Solidworks was because of what the program offers in total, the ability to design single parts and then assemble them, many simulations and tests that apply to different materials that have a good visual that can be used for education, and the ability to edit the simulation Pantelidis to achieve better education results [7]. After creating the 3D model, the model was transferred from Solidworks to unity, and an add-on to export the file was used in (.fbx) format to be compatible with Unity. As detailed in Fig. 3, the model needs to be calibrated, retextured, and reapplied materials due to limitations in exporting the file from Solidworks. After checking the model and comparing it with the original one to check for more errors, the file was exported to Middle VR.

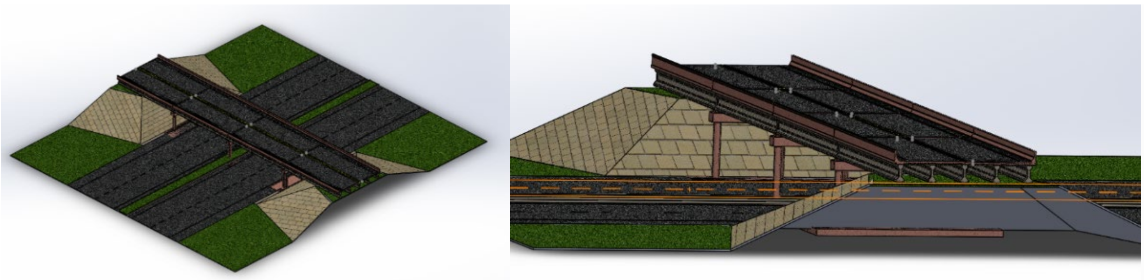

Fig. 2. Final assembly of the highway bridge

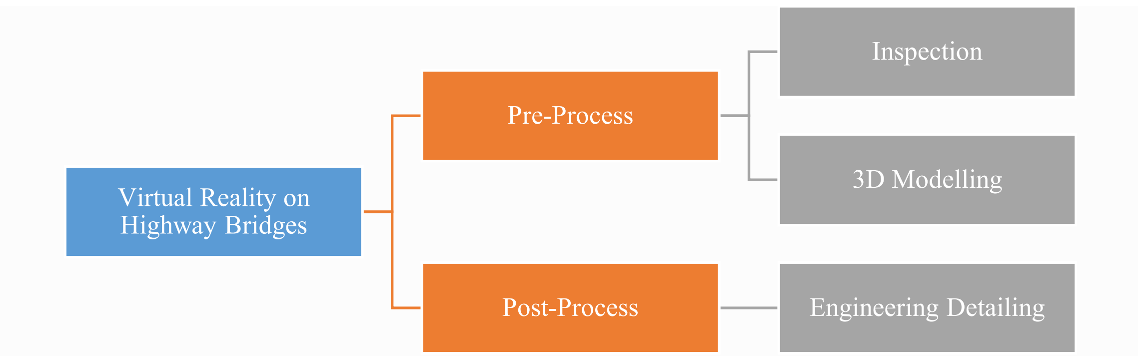

Fig. 3. Flowchart for VR on highway bridges

As seen in Fig. 4, the laboratory consists of three walls of immersive and active VR environment. Each wall is 8 ft in height and 11ft in width. The laboratory is equipped with rear projection rigid walls and the latest stereoscopic LED projection technology. A tracking system utilizing the latest technology of optical tracking is also integrated into the lab facility. The laboratory is also supported by very high-end workstations and mobile computing support with the latest hardware and VR software. The laboratory will be the development, integration, and testing grounds of available VR applications in highway construction. The laboratory is also supported by a long list of research software packages that are adequate to test and integrate VR into highway construction practices. CAD packages that are needed to develop highway construction content into real content are also available. The laboratory houses a fully integrated software system that takes virtual CAD content into a gaming-like interface. The content is then introduced to a VR-enabling software that is proven robust in converting virtual CAD content into VR content.

One of the most innovative ways in which this technology is being used is on the construction site. Construction of a bridge can be difficult in many cases. Understanding stages and consequences is critical for decision-making and project delivery. Most of the issues surrounding inter-discipline collisions during new bridge design and construction are detected and resolved while the project is still in design. Thus they are eliminated before they make it to the construction field. However, various factors still exist in the field that generates rework; stakeholder changes, material substitutions, and construction errors can all contribute to rework in the highway construction zone. This is where VR can be applied to facilitate resolutions. When issues do arise in the construction zone, construction managers can use VR to facilitate resolutions. First, the construction manager can access the assembly instructions, which can be retrieved through a VR interface to ensure the work was installed correctly. Second, the Construction Manager can check the as-built conditions against the as-designed installation right in the field using VR technology. A representative bridge was created. The bridge CAD model that was used in this study can be created in less than three hours' time by an engineer with medium to advanced training in CAD. The model is created using a solid modeling native CAD platform readily available in most engineering and construction institutions. To bring the CAD model of the bridge into VR-ready content was executed. The process of bringing the CAD content into VR-ready content has been optimized to cut the lead time. The current bridge used in this paper was taken from CAD content to the VR-ready stage in less than one hour by one VR lab operator with less than three months of training experience.

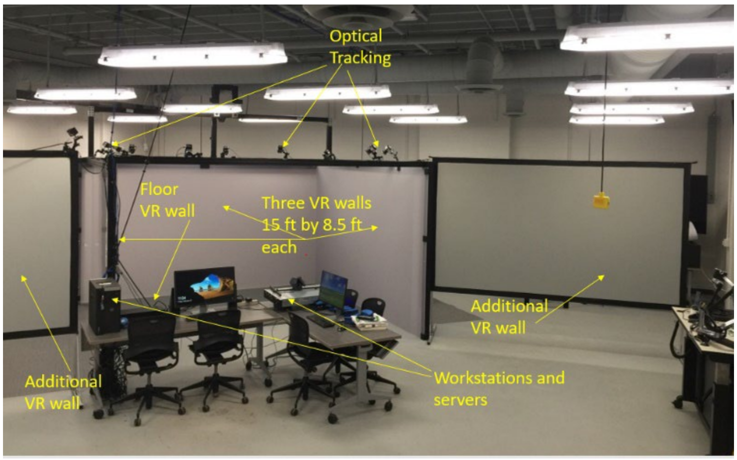

Fig. 4. VR Lab 3-wall system

A construction manager can review the 4D sequencing of the project where the VR can build the individual pieces of work right before the application, just as if it is seen installed in real-time. In bridge design, VR defines the environmental adaptation of the transportation system. For a scenario where a state DOT is planning a highway construction, a model bridge can be adapted to the environment. The next step in a traditional workflow would be for the DOT to lay out the bridge before construction, as seen in Fig. 5. For the VR-enabled workflow, the state DOT personnel are mobilized on site with material ready to be installed and get ready with VR glasses.

4.3. Outcomes of using VR as a teaching tool

VR-based immersive and experiential learning has the potential to create a deeper level of engagement with target topics in a distraction-free environment. Since VR requires interacting with the simulation, students don't have the time to be distracted by their phones or classmates. Language differences can be challenging in today's multicultural societies. Eastern Michigan University enrolls a lot of international students, and while they need to achieve fluency in English to be enrolled, some students still struggle with the language barrier. VR visualizations can be experienced in any language. Fig. 6 shows lab applications. Fig. 7 shows the rebar details.

5. Conclusion

The present study focused on exploring the educational applications of a VR system in the context of highway construction within engineering education. The EMU VR lab was used to develop a representative bridge model for this purpose. The paper presents a model of highway bridge as a model to be used in engineering education.

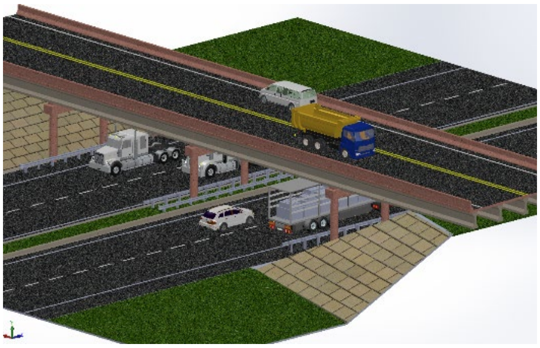

Fig. 5. 3D model creation for implementation

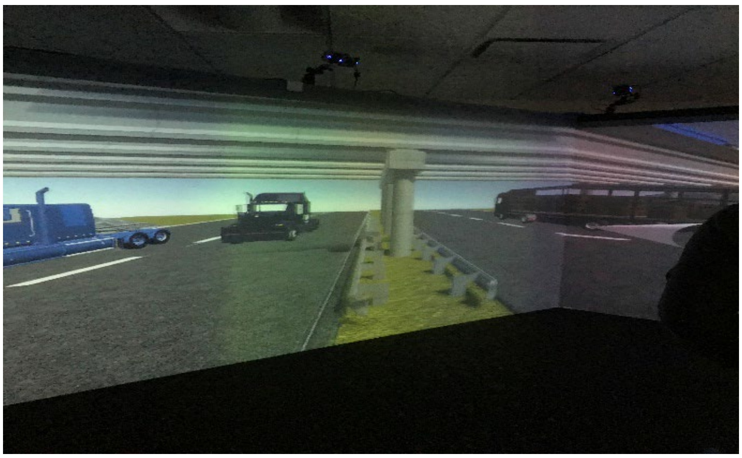

Fig. 6. 3D demonstration of transportation

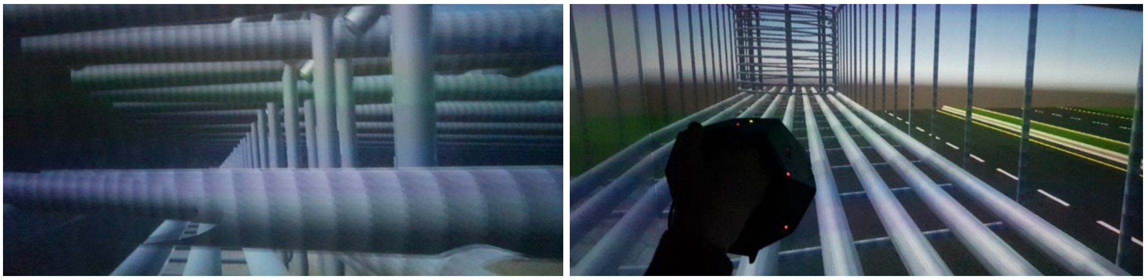

Fig. 7. Rebar details

The research has limitations, specifically within the examined example presented. To address these limitations, future research endeavors should broaden their scope by investigating additional examples within the construction field. As a follow-up study, a quantitative assessment of the impact of AR/VR on education will be provided.

The construction industry is in rapid development, especially after the Covid era, attracting significant interest from the new generation entering the field. In terms of competition, there is a compelling case for market participants to embrace early adoption of technology. VR is emerging as a potentially transformative trend within the construction community. Considering its potential impact, industry players are advised to seriously consider becoming early adopters of VR technology to stay ahead in the evolving market landscape. By integrating translation into VR technology, existing barriers that might hinder students from reaching their educational objectives can be effectively overcome. The use of VR simulations brings avenues for students to immerse themselves in diverse realities, offering an alternative and enriching learning experience beyond the confines of traditional classrooms. This technology enables students to engage with high-quality educational visualizations, significantly enhancing the overall learning process and contributing positively to their educational journey.

VR can help students easily understand complex concepts, theories, and subjects. They are able to digest and retain complex information at a much higher rate. If the students get information through personal experience and according to Edgar Dale's con of experience, "after two weeks the human brain tends to remember 10% of what is read, 20% of what is heard, 30% of what is seen, and 90% of simulations or personal experience", more research on the actual relation between VR simulation and personal experience could solidify VR as a valid method of teaching. Wang et al. showed that using VR for memorization showed an 8.8% improvement overall in recall accuracy using the VR [12]. VR has great potential for the Architecture, Engineering, and Construction industries, as a person can experience realistic first-person situations without having to care about injuries [13]. Automated processes for the simplification of content creation, leveraging existing models, and the usage of visual programming languages enable even nonprogrammers to create scenarios to their needs. This paper is an example of using a bridge as an example to use as a learning tool.

Declaration

Funding

This research received no external funding.

Author Contributions

E. Tanbour: Conceptualization; K. Korkmaz: Resources; S. Ashur: Methodology; O. F. Almousa: Writing- Reviewing and Editing.

Acknowledgments

Not applicable.

Data Availability Statement

No new data were created or analyzed in this study.

Ethics Committee Permission

Not applicable.

Conflict of Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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