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3D Online Marshmallow Simulation Game for Target Value Design

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Abstract: Various lean design and construction methods such as target value design, pull planning, value stream mapping have successfully transformed the commercial building construction industry into achieving improved productivity, higher design and construction quality, and meeting the target values of construction projects. Considering the significant advantages of lean, the accelerated dissemination and adoption of lean methods and tools for construction is highly desirable. Currently, the lean design and construction body of knowledge is imparted primarily through publications and conferences. However, one of the most effective ways to impart this soft knowledge is through getting students and trainees involved in hands-on participatory games, which can quickly help them truly understand the concept and apply it to real-world problems. The COVID-19 Pandemic has raised an urgent need of developing virtual games that can be played simultaneously from various locations over the Internet, but these virtual games should be as effective as in-person games. This research develops an online 3D simulation game for Target Value Design that is as effective as in-person games or possibly better in terms of knowledge capture and retention and enjoyable environment and experience. The virtual game is tested on volunteers using feedback from pre-and post- simulation surveys to evaluate its efficacy.

Keywords: lean simulation, serious games and simulations, simulation-based learning, target value design, marshmallow TVD simulation

1. INTRODUCTION

Serious games and simulations have received considerable interest from the construction industry and academics. It is considered an effective tool to revolutionize the teaching and learning mechanism in the industry. Especially, serious games and simulations to instill the lean design and construction concept have been extensively developed to motivate the adoption of the concept [1][2].

The majority of games and simulations have been developed for an in-person setting because of enhanced engagement and easy facilitation. This setting has been demonstrated to be effective in teaching and learning for decades. However, several critical limitations of the in-person setting have been emerging recently. The outbreak of the COVID-19 pandemic severely impacted the education environment, leading to the shift towards a virtual and online education system [3]. Furthermore, playing simulations and games is a resource-intensive task. They require an expert, physical models and materials, and even maintenance of individual pieces, which is hard to control and hinders their accessibility [4]. In this context, many games and simulations traditionally played in-person among students have undergone adaptations to the online digital environment.

This background inspired the development of 3D online simulations, which are as effective as an in-person simulation to respond to changing teaching and learning environment and demand. This paper describes the development and testing of an online version of the Marshmallow TVD Simulation, first developed by Munankami (2012) [5]. Two valid research questions are developed and explored in this paper: *(1) "Is the 3D online simulation effective in imparting key concepts and principles of TVD?"* and *(2) "Can the 3D online simulation lead to a similar effectiveness to in-person simulation?"*

2. LITERATURE REVIEW

2.1. Serious Games and Simulations for Construction Management Education

A serious game is designed primarily for education and training purpose other than pure entertainment, but it is expected to include some fun and entertainment components to keep the players engaged. Simulations are models of real or hypothesized situations or natural phenomena that allow users to explore the implications of manipulating or modifying parameters within them [6]. They entail entertainment moments and enable the educational connotation along with the provision of a highly immersive environment. They have emerged in the construction management field because they provide an intuitive understanding of a new concept and may provide an enhanced understanding of it with variable manipulation ability and realistic scenarios. They often take the form of low-risk and small-scale controlled experiments that help participants determine the impact of the decision before scaling a proposed process up to a full project and bring practical lessons by creating a participatory and enjoyable environment. In recent years, digital games and simulations have gained popularity as the most powerful and highly engaging learning environment as well as productive pedagogical strategies to preserve the efficacy of learning. The use of the Internet with educational technologies has also grown exponentially under recent technological developments [7].

2.2. Descriptions of TVD Concept and the Marshmallow TVD Simulation

Target Value Design (TVD) is a collaborative and iterative process until the project design meets the target value and, ultimately, plot a progressive reduction in a project's estimated capital cost [8][9][10]. The project owner, designers, contractors, and trades become deeply engaged to define design options and make explicit their values until the design options are created and evaluated to meet the project requirements [8][9]. TVD concept is typically taught in the classroom with traditional lectures or even not taught, which results in TVD concepts and principles being relatively unfamiliar to stakeholders, especially those accustomed to more traditional project delivery methods such as design-bid-build [10].

This background motivated Munankami's (2012) research to develop and test the Marshmallow TVD Simulation. The Marshmallow TVD Simulation was developed to help participants intellectually grasp a simplified, conceptual framework of TVD. The simulation consists of two rounds. In each round, players need to build a tower that is 2 feet tall, capable of holding a marshmallow at the top, that is no more than 2 inches out-of-plumb, and that is free-standing. The main materials to build a tower are drinking straws, spaghetti, coffee stirrers, bamboo skewers, masking tape, and marshmallow. During round 1, market and allowable cost are calculated and target cost is established. During round 2, teams need to build a tower again, but this time will have the costing sheet available and the target cost as their goal.

It was originally intended to be administered in an in-person setting. The Marshmallow TVD Simulation was revisited and redeveloped in a 3D online environment to explore whether it is effective as an in-person setting and, ultimately, responds to the future education environment. The materials, methods, instructions, and rules of the game developed by Munankami (2012) were adopted to the 3D online environment in this research.

3. 3D ONLINE MARSHMALLOW TVD SIMULATION

3.1. Simulation Development- Unity Software

The 3D Online Marshmallow TVD Simulation is developed by the Unity software, which is designed to support and develop 2D and 3D simulations [11]. The Unity software is featured as multiple platforms, easy to operate, and user-friendly interface. It can also reduce the development time and cost significantly. The most crucial feature of Unity software is that it can imitate most physical characteristics such as material, mass, movement, and various reactions to establish the real-world scenes in computer animation [12][13]. Thus, the Unity Software was chosen for this research as the most suitable software to develop 3D online simulation, which can lead to similar effectiveness and engagement to the in-person Marshmallow TVD Simulation.

3.2. Players' Experience during the Simulation

(1) Simulation environment

The simulation is intended to be used in an online mode, thus, players do not need to install the simulation on the desktop. The materials on the simulation are intended to imitate the actual materials with higher reality, and the basic physical properties are reflected. For example, a slender column cannot stand alone as long as additional structural supporting elements are placed. The developed simulation also supports collaboration among players. There are 20 rooms, and each room allows a maximum of three players to play together. Using a three-button mouse with two buttons and a wheel, players can rotate, hold, put, set the materials, and change and rotate angles. Magnetism and snapping in place and auto-bounding system make high usability.

(3) Simulation process

Same with the in-person simulation, the 3D Online Marshmallow TVD Simulation consists of two rounds. In the first round, players cannot access the costing sheet. The first round aims to design and build a tower capable of holding a marshmallow at the top, which can stand alone and be built with given materials. Before the second round, the target cost is established and announced. In the second round, players can access the embedded costing sheet so that it is possible to check the total cost in real-time. After completing both rounds, whether players achieve the target cost or not is determined.

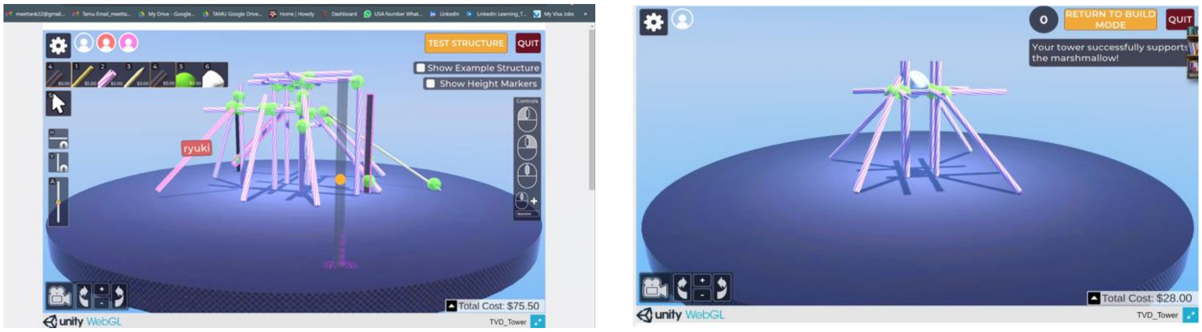

Figure 1. Snapshots of 3D Online Marshmallow TVD Simulation

4. SIMULATION TESTING

Volunteer participants majoring in Construction Science at Texas A&M University were recruited to test the 3D Online Marshmallow TVD Simulation. The experiments were conducted virtually, considering the ultimate use environment of the simulation. The participants were asked to complete the pre-and post-simulation questionnaire, which consists of their background knowledge and knowledge retentions using a 5-point Likert Scale, respectively. Munankami (2012) evaluated the game in the perspective of key TVD concepts and principles, including (A) mutual respect and trust; (B) mutual benefit and reward; (C) collaborative innovation and decision-making; (D) early involvement; (E) early goal definition; (F) intensified planning; (G) open communication; (H) appropriate technology; and (I) organization and leader. The same set of questions was used in this research. In total, 32 valid responses were collected in pre-simulation and post-simulation surveys. In addition, Munankami's (2012) previous questionnaire results were used to assess whether the 3D online simulation is as effective as in-person simulation.

5. RESULTS

5.1. Results of Research Question 1 - Effectiveness of 3D Online Simulation

To explore whether the 3D Online Simulation can successfully impart key TVD concepts and principles, paired two-sample t-test was used, and mean differences between pre-simulation and post-simulation were calculated. Graphed results from questionnaire responses are shown in Figure 2 and Table 1. Among nine key TVD concepts and principles, 3D online simulation successfully imparted (A) mutual respect, (C) collaborative innovation and decision-making, (D) early involvement, (E) early goal definition, (F) intensified planning, (G) open communication, (H) appropriate technology, and (I) organization and leader. Especially, (E) early goal definition and (F) intensified planning were highly successfully conveyed through 3D online simulation.

Meanwhile, the knowledge of (B) mutual benefit and reward and (I) organization and leader was not significantly obtained through the simulation. Mutual benefit and reward are indirect benefits of the TVD process, which are hard to be captured without additional debriefing. Also, every participant played the same role and shared their opinions equally in the 3D online simulation, making it hard to understand the role of active organization and leader.

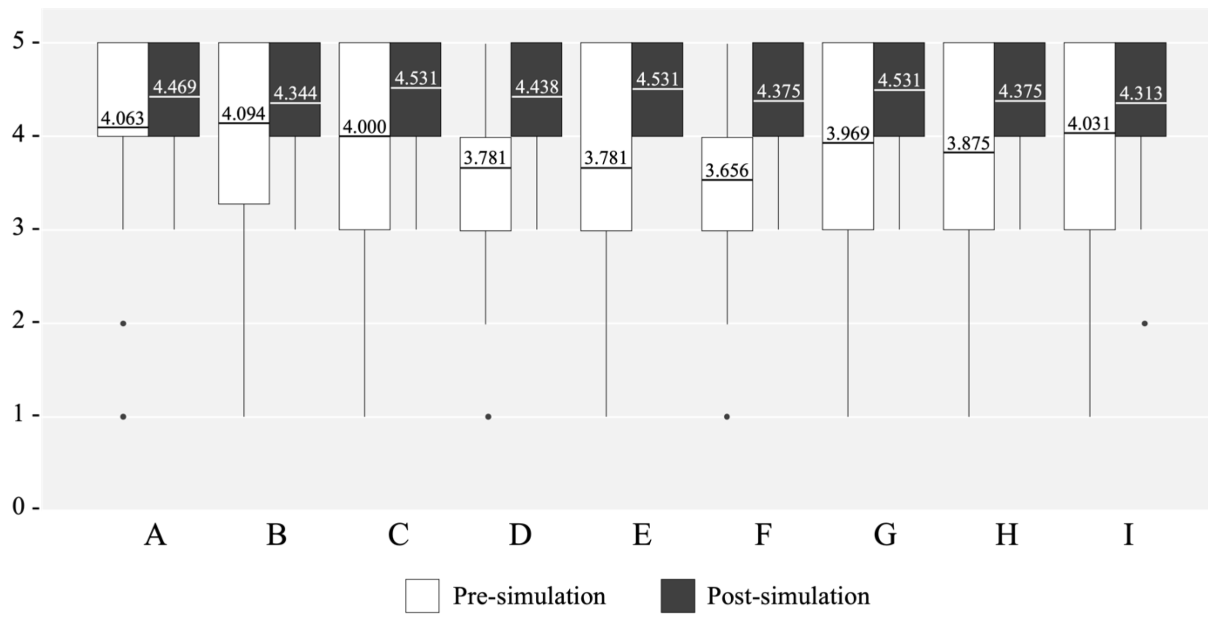

Figure 2. Box-and-Whisker plot of pre-simulation and post-simulation

(Note: (A) mutual respect and trust; (B) mutual benefit and reward; (C) collaborative innovation and decision-making; (D) early involvement; (E) early goal definition; (F) intensified planning; (G) open communication; (H) appropriate technology; and (I) organization and leader.)

Table 1. Results of paired two sample for means t-test (post simulation – pre simulation)

TVD concepts and principles	Paired Differences			t	df	Sig. (2-tailed)
	Mean	Std. deviation	Std. error mean			
Mutual respect and trust	0.406	0.310	0.055	2.204	31	0.035*
Mutual benefit and reward	0.250	0.435	0.077	1.052	31	0.301
Collaborative innovation and decision-making	0.531	0.569	0.101	2.278	31	0.030*
Early involvement	0.656	0.420	0.074	2.888	31	0.007*
Early goal definition	0.750	0.592	0.105	3.410	31	0.002*
Intensified planning	0.719	0.450	0.080	3.395	31	0.002*
Open communication	0.563	0.410	0.072	2.414	31	0.022*
Appropriate technology	0.500	0.301	0.053	2.184	31	0.037*
Organization and leader	0.281	0.293	0.052	1.139	31	0.263

(Note: $\alpha=0.05$, * represents $p < 0.05$)

5.2. Results of Research Question 2 – 3D Online Simulation versus In-person Simulation

The independent samples t-test was used to compare the means of two independent groups and determine whether there is statistical evidence that the associated population means are significantly different. Munankami's (2012) previous experimental data, which are the results of the in-person simulation, were used as a control group. Table 2 and figure 3 describe the results.

As a result of the independent sample t-test, null hypotheses (“the two population means are equal.”) were accepted in eight TVD concepts and principles, which include (A) mutual respect and trust, (B) mutual benefit and reward, (C) collaborative innovation and decision-making, (D) early involvement, (F) intensified planning, (G) open communication, (H) appropriate technology, and (G) organization and leader. The knowledge retention of those eight concepts and principles is not significantly different between in-person simulation and 3D online simulation. In other words, 3D Online Marshmallow TVD Simulation is as effective as in-person Marshmallow TVD Simulation in respect to imparting those eight concepts and principles.

The knowledge of (E) early goal definition through in-person simulation and 3D online simulation is significantly different, suggesting that 3D online simulation was more effective than in-person simulation (average 4.531 in 3D online simulation and 3.979 in in-person simulation). These results imply that 3D online simulation has the potential to be an alternative to in-person simulation, and even some knowledge areas can be achieved better in a 3D online environment.

Table 2. Differences between in-person simulation versus 3D online simulation on nine tests

TVD concepts and principles	In-person simulation		3D online simulation		df	t	p
	M	SD	M	SD			
Mutual respect and trust	4.229	0.751	4.469	0.671	78	1.458	0.149
Mutual benefit and reward	4.229	0.831	4.344	0.653	78	0.656	0.514
Collaborative innovation and decision-making	4.313	0.829	4.531	0.567	78	1.302	0.197
Early involvement	4.313	0.879	4.438	0.619	78	0.697	0.488
Early goal definition	3.979	0.729	4.531	0.507	78	3.722	0.000*
Intensified planning	4.083	0.821	4.375	0.554	78	1.759	0.082
Open communication	4.396	0.792	4.531	0.621	78	0.814	0.418
Appropriate technology	4.313	0.719	4.375	0.707	78	0.383	0.703
Organization and leader	4.021	0.956	4.313	0.738	78	1.459	0.149

(α=0.05, * represents $p<0.05$)

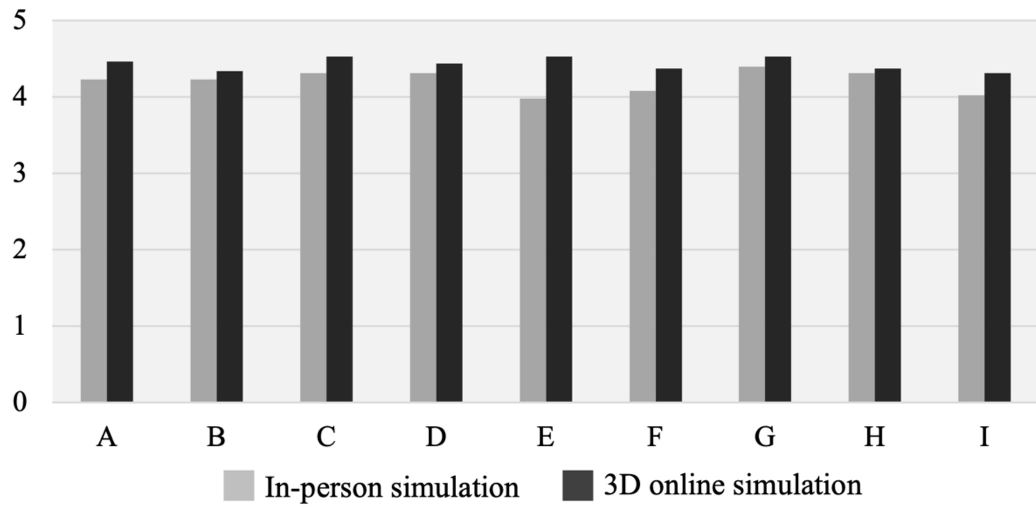

Figure 3. Differences between in-person simulation versus 3D online simulation

(Note: (A) mutual respect and trust; (B) mutual benefit and reward; (C) collaborative innovation and decision-making; (D) early involvement; (E) early goal definition; (F) intensified planning; (G) open communication; (H) appropriate technology; and (I) organization and leader.)

6. DISCUSSION AND CONCLUSION

The lean community has played the Marshmallow TVD simulation to illustrate and teach the TVD concept, and it is under continuous adaptation and improvement. This research developed a 3D online version of Marshmallow TVD simulation and tested its effectiveness by comparing students' knowledge retention before and after simulation as well as comparing it to in-person simulation. As a result, the 3D Online Marshmallow TVD Simulation appears to have served as an effective replacement for the in-person simulation. Especially, early goal definition can be more effectively imparted in the 3D online mode. It implies that some knowledge areas can be more easily transformed through online settings and can be promising signs of the future 3D online learning environment. Despite this research's groundbreaking attempt, this study presents several limitations that may inspire future research. First, some students who are not familiar with computer manipulation have difficulties using 3D online simulation. In addition, different from the in-person simulation, additional time needed to be assigned to make participants adapt to the controls in a 3D online simulation. Future research and practice to address those limitations are expected to revolutionize construction management education and respond to the fast-changing future education environment.

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