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TVD Simulation Game: Tracing the Journey and Moving Forward

Ganesh Devkar[1] and Zofia Rybkowski[2]

Abstract

Purpose: The purpose of this paper is to offer an aspirational framework for future lean simulation development that will maximize the benefits to those in industry as well as to those in academia. By way of example, the paper reviews the evolution of the TVD Marshmallow Tower Simulation Game as developed by multiple researchers to understand the strengths and weaknesses of variants of this simulation game and to suggest opportunities for continuous improvement. The aim is to challenge simulation developers to aspire to Conditions of Satisfaction that maximize a simulation's effectiveness and impact for stakeholders of the built environment.

Research Method: As a case study, the authors investigated peer-reviewed literature describing recent variants of the TVD Marshmallow Tower Simulation Game and identified opportunities for further continuous improvement by envisioning aspirational criteria and evaluating recent TVD simulation games against the criteria. This case study was used to help build a recommended simulation framework.

Findings: Although digital versions of the TVD simulation game offer scalability and geographic outreach benefits—and can reduce product waste—the in-person physical version of the TVD simulation appears to be more accessible to participants who are less comfortable with digital and VR headset gaming. The in-person physical format arguably also offers the opportunity to build greater levels of trust among stakeholders. The challenge is to create a digital version that offers the benefits of scalability, geographic outreach, and waste reduction, but that is also easy to use across multiple age groups and that has the capacity to incentivize collaboration and create trust among members of a stakeholder team.

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[1] Sr. Associate Professor, Faculty of Technology, CEPT University, Ahmedabad - 380009, India, +919099010303, ganesh.devkar@cept.ac.in.
[2] Professor, Department of Construction Science, Texas A&M University, College Station, TX 77843-3337 USA, zrybkowski@arch.tamu.edu, 1-979-845-4354.

Limitations: The authors' evaluation is based on their observations and perceptions after playing various versions of the published TVD simulations. While this is not a limitation, per se, it does represent a first step in the scientific inquiry process (e.g., hypothesis generation) with the expectation that further exploration is necessary.

Implications: The intent of this paper is to challenge researchers to develop digital versions of lean simulation games, such as the TVD Marshmallow Tower Game, that harness the benefits of digital and virtual simulations while also maintaining the benefits of physical format versions.

Keywords: Target Value Design, TVD, lean simulation games, digital and VR lean gaming

Paper Type: Full paper

Introduction

Integrated Project Delivery has been heralded as a means to improve collaboration during the delivery of capital projects (AIA 2007). This concept has evolved with the incorporation of lean principles in the planning, design, construction, and operation of capital projects. Target costing, which shares some of the goals of value engineering, was actualized in the St. Olaf Field House project (Ballard and Reiser 2004). However, while target costing primarily focuses on cost reduction, efforts were shifted to focus on value creation during the development of Sutter Health's San Francisco-based Cathedral Hill project. The improved process was renamed as Target Value Design (TVD) by the Sutter Health Team, which achieved the dual objective of not only progressively reducing a project's estimated cost but also maximizing its value for the facility owner by incorporation of Lean processes and tools that support the adoption of TVD such as: Co-location, A3s, Set-Based Design, and Choosing by Advantages (Hill et al. 2016; Suhr 1999; Rybkowski et al. 2022; Tommelein and Ballard 2016).

An analysis of projects implemented with TVD suggested that TVD-delivered projects cost up to 15-20% less than traditionally delivered projects (Do et al. 2014). While the implementation of TVD has spread following the Sutter Health TVD initiative, the concept is not yet practiced widely by OAEC[3] industry stakeholders and many are still relatively unfamiliar with this concept (Miron et al. 2015; Rybkowski et al. 2022). To address this gap, the TVD Marshmallow Tower Game was developed and validated by Munankami (2012) and Rybkowski et al. (2016). Simulation games are prominently used by academics and lean consultants across the globe to impart knowledge to students as well as professionals about lean concepts and tools (Bhatnagar et al. 2022; Rybkowski et al. 2021). Events such as the annual conferences of *the International Group of Lean Construction* and the *Lean Construction Institute* have been offering opportunities for both lean academic and professional communities to share their challenges and best practices. These conferences offer an important platform to showcase lean simulation games that make lean principles more accessible to a diverse range of stakeholders, including those from different countries and cultures.

[3] The paper intentionally uses OAEC as the acronym for Owners, Architects, Engineers, and Contractors, where "O" is placed first as a reminder that the Owner's Conditions of Satisfaction come first on a lean-IPD project.

A modified version of Peter Skillman's Marshmallow Design Challenge, the TVD Marshmallow Tower Game, was designed by Munankami (2012) and Rybkowski et al. (2016) to quickly introduce participants to the primary goal of TVD—to challenge team members to collaboratively and creatively reduce the cost of a tower they design from its initial *market cost* to an *allowable cost* and finally its *target cost*. The allowable cost is the estimated cost that the tower *must* reach in order for a project to proceed. The target cost is a desired stretch goal, though reaching it is not essential for the project to proceed.

The TVD Marshmallow Tower simulation game has been used by various academic faculty and professional trainers. Variants of the TVD Tower game subsequently emerged (Jacob et al. 2021; Kim et al. 2023; Kim et al. 2024; Munankami 2012; Ng et al. 2021; Rybkowski et al. 2016). The aim of this paper is to analyze the progressive evolution of the TVD Marshmallow Tower Game and understand the strengths of and "opportunities to improve" for each variant, in keeping with the lean principle of continuous improvement. Ultimately, this paper explores an aspirational ideal of the TVD simulation that would potentially optimize its effectiveness and then evaluates existing TVD simulations against criteria that could help actualize the aspirational ideal. It is important to state upfront that while additional and complementary TVD concept simulations have been developed (e.g., Rybkowski et al. 2011, Rybkowski et al. 2020, Solhjou Khah et al. 2019), this paper only investigates variants of the Marshmallow TVD Simulation introduced by Munamkami (2012) and Rybkowski et al. (2016) because it presents an overarching understanding of the primary goal of TVD and appears thus far to be the most commonly played TVD simulation to date.

TVD Simulation Game Variants

In the realm of lean simulation games, the Marshmallow TVD Simulation was the first known and published lean simulation game developed with the intent to enable students and professionals to grasp the concept of Target Value Design (TVD) in a simplified manner (Munankami 2012; Rybkowski et al. 2016). A description of the original TVD simulation game, as well as five of its variants, follows (Refer to Table 1).

Table 1. Existing TVD Simulations

Descriptors	Aspirational Version	Marshmallow Tower Rybkowski et al. (2016)	Block Tower Jacob et al. (2021)	TVDfDFAB Ng et al. (2021)	Keyboard Marshmallow Tower Kim et al. (2023)	VR Headset Marshmallow Tower Kim et al. (2023)	TVD Bridge Shah et al. (2025)
Description of simulation	Varies	To build physical 2 ft tall tower with marshmallow at top to target cost.	To build digital 26 cm tall tower from blocks with no spaces between to target cost.	To make aesthetically pleasing salad to target cost.	To build digital 2 ft tall tower with marshmallow at top to target cost.	To build virtual 2 ft tall tower with marshmallow at top to target cost.	To construct a 47m long bridge over a water body
Tested for educational attainment such as those delineated in the Bloom's Taxonomy and the Kirkpatrick models	Yes	No	No	No	No	No	No
Format	Varies	Physical	Digital (PowerPoint™)	Digital (PowerPoint™)	Digital (Unity™)	Virtual (Unity™)	Digital (PowerPoint™)
Materials needed	Minimal	Marshmallow (or similar), Dry spaghetti, drinking straws, bamboo skewers, coffee stirrers, masking tape, tape measure, table tops, Excel (for spreadsheet)	Computers (one per person), TVD simulation PowerPoint and program, Excel (for spreadsheet)	Computers (one per person), TVD simulation PowerPoint and program, Excel (for spreadsheet)	Computers (one per person), TVD simulation Unity program, Excel (for spreadsheet)	VR headsets (one per person), controllers, TVD simulation Unity program, Excel (for spreadsheet)	Computers (one per person), TVD simulation PowerPoint and program, Excel (for spreadsheet)
Time needed to execute	1 hour or less	50 min or 1 hr 20 min	50 min or 1 hr 20 min	50 min or 1 hr 20 min	50 min or 1 hr 20 min	50 min or 1 hr 20 min	50 min or 1 hr 20 min
Requires gravity (or simulation of gravity) to play	Varies	Yes (physical gravity)	No	No	Yes (simulated gravity)	Yes (simulated gravity)	No

Marshmallow TVD Tower Game

The following terms form the basis for the Marshmallow TVD Tower game (Figure 1):

1. *Market cost* represents the cost of project delivery based on prevailing market conditions; future cost savings are measured against this benchmark.
2. *Allowable cost* represents the cost that the owner is able and willing to pay and still generate a financially viable project. The project will proceed if and only if the stakeholder team is able to iteratively reduce expenses to the allowable cost because only at the allowable cost is the project considered economically viable for the owner.
3. *Target cost* represents a "stretch goal," meaning any additional first cost savings below the allowable cost level will be shared between the stakeholder team and the owner. In other words, although reaching the target cost is not essential for the project to proceed, a specified contractual structure can create incentives for the project team to pursue the target cost. For example, the stakeholders involved in the project delivery process are motivated to optimize the project as a whole rather than its parts by engaging in collaborative decision-making that permits the flow of funds across traditional disciplinary boundaries. There are two distinct compensation frameworks for TVD Projects: A) pain-sharing to carry the design between market cost and allowable cost, and B) gainsharing to carry the design between allowable cost and target cost.

The Marshmallow TVD Tower game is designed to increase OAEC stakeholder familiarity with both the processes and terms used in TVD. The participants involved in this lean simulation gain understanding on at least two fronts: the basics of collaborative cost savings using TVD and the value of integrated processes over traditional processes. The duration of the simulation game is about 1 hour 20 minutes, which is a typical duration for class periods in US-based universities as well as in other parts of the world, although a truncated version can be played in less than one hour (Rybkowski et al. 2016). The materials required for this game include masking tape, bamboo skewers, drinking straws, uncooked spaghetti, coffee stirrers, and marshmallows. Additionally, there are other supporting materials and resources required which include a two-foot-long ruler or tape measure, tabletops for the teams on which to construct the towers, pencils and pencil sharpeners, erasers, blank sheets of paper, a laptop computer (or equivalent), and a projector to facilitate display of a unitary costing sheet as well as a spreadsheet. Teams of three to five participants are created and instructed to design and build a free-standing 2-foot-tall (approx. 61 cm) tower on their tabletops with the supplied materials, which can support a marshmallow at the top and that is no more than 2 inches (approx. 5 cm) out-of-plumb. This simulation consists of two rounds where each team of participants playing roles of Owner, Designer, and Contractor must construct a tabletop tower. Each round has an approximate duration of 15-20 minutes. During Round 1, participants work within a traditional siloed structure, unaware of the cost of their towers. Following Round 1, teams are asked to report the unitary number of each type of material they used. These numbers are then entered into a projected spreadsheet with columns for each team.

Teams are also then made aware of the unitary cost of each item, and the total cost per tower is tallied as an average of all towers, establishing the *Market Cost*.

Participants are then challenged to drop their own tower's cost to 20% below the Market Cost in order to reach the owner's Allowable Cost, while still fulfilling the owner's *Conditions of Satisfaction*, namely a 2-foot tall, free-standing tower with a marshmallow at the top and that is no more than 2 inches out-of-plumb. Round 2 is a collaborative effort which involves designing the tower with the critical Allowable Cost as the team goal. Teams are additionally challenged to drop the cost even further, reaching their declared stretch goal, the *Target Cost*. A detailed description of this lean simulation game—along with a fictitious unitary cost listing of each item to share with teams following Round 1—is available in Rybkowski et al. (2016).

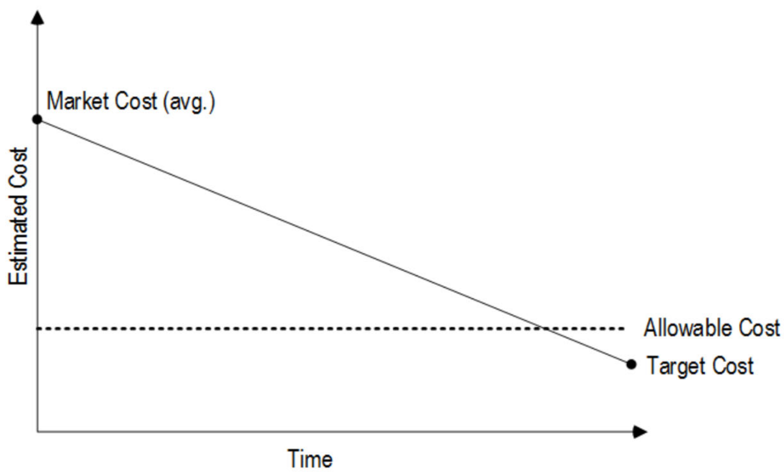

Figure 1. The TVD Marshmallow Tower Simulation Game is intended to accomplish multiple goals, including providing participants with the vision of what they will need to collaboratively and creatively accomplish during TVD exercises—i.e. taking a project from its market cost to its allowable cost and ultimately target cost. *Source:* Adapted from Rybkowski (2009; p. 131, Fig. 47)

The Marshmallow TVD Tower Game has undergone several adaptations with respect to its implementation in different locations and formats. The instructions and other supporting templates were translated into the German language in 2016 by Lean Ingenieure Consultant, Tobias Guller, and used in Germany. Musa et al. (2019) used the Marshmallow TVD Simulation to improve collaboration during the implementation of TVD on an actual project in Nigeria. Devkar et al. (2019) adapted the simulation to fit the context of studio-based pedagogy and the availability of local materials. For example, marshmallows were replaced with a more readily available material in India—cheese blocks of similar weight. According to his studio-based pedagogy, Devkar et al. (2019) used the TVD Tower game as a stepping stone toward the application of learned TVD concepts in ongoing construction projects. Adaptations of this TVD Tower Game indicate the relevance and need felt by lean researchers and professionals to quickly and effectively educate stakeholders in various geographical settings.

On the positive side, the materials required for the physical TVD simulation game are typically available or easily substitutable in most countries and locations. For example, Devkar et al. (2012) used cheese cubes, which are easily available in India, instead of marshmallows. Also, the instructions are relatively easy to follow. That said, the game has shortcomings. While the total cost of materials needed is low when there are relatively few participants, it can be more significant as the number of players increases. The simulation also generates substantial waste following play, such as unusable fragments of bamboo skewers and spaghetti. Also, because the simulation is played in person, it currently cannot be played synchronously with team members located in multiple locations. Also, when the number of players is large, facilitating the simulation can be challenging as individual teams typically ask questions during play.

Nevertheless, the physical version of the TVD game appears to be accepted and effective. This may be because the game's format is situated within the contextual framework of OAEC stakeholders. In other words, the game asks players to design, cost, and physically construct a structure, which OAEC stakeholders typically do as part of their jobs on a regular basis. The simulation is also enjoyable to play. It fosters collaboration and trust, which aid project success, so playing the game during the start of an actual project delivery process appears to unify and motivate team members, while also helping them understand basic TVD principles.

TVD Block Tower Game

The TVD Marshmallow Tower Game was published in the proceedings of *24th Annual Conference of the International Group for Lean Construction* in (Rybkowski et al. 2016). Since then, the simulation has spread to different parts of the world, with adaptations, indicating the popularity of the simulation, which may be attributed in part to its simplicity, the ubiquitous availability of needed materials, its relatively low cost, and its effectiveness in conveying the primary overarching goals of TVD. When the COVID19 pandemic struck and social distancing became a norm, lean educators and consultants were challenged to invent new formats to teach Lean Construction. The circumstances forced teaching activities into the virtual realm, and it pushed the lean community to evolve lean simulation games, which could be played digitally via collaborative platforms such as Zoom™. The first transformation of the TVD Simulation Game in the virtual world happened with the development of a virtual TVD Tower simulation by Jacob et al. (2021).

This virtual TVD simulation retained the following aspects of Marshmallow TVD simulation: (1) the number of rounds, (2) the types of rounds (design-bid-build and collaborative), (3) role playing, and (4) design and costing processes.

A key feature of the Jacob et al. (2021) virtual TVD simulation is that it uses Google Slides™ for participants to collaboratively play using a virtual communication environment such as Google Meet™ or Zoom™. Players are invited to design, construct, and cost a digital block tower of height and base width of 26 cm and 12 cm, respectively. A team of three to four participants, playing the roles of Owner, Designer, and Contractor, is challenged to build a tower of the required height and base with the shapes (i.e., square, rectangle, triangle, and their size variants) provided in the online game template. Two separate TVD Game templates based on Google Slides™ were developed for Round 1 and Round 2. These templates are used to share the Owner's brief, upload design proposals, and communicate RFIs and space requirements for the construction of the tower. A cost sheet template is shared with the game participants to arrive at the cost of the tower in both rounds. During validation, the simulation facilitators used Google Sheets™ to perform cost analyses for market cost, allowable cost, and target cost, and this sheet was made transparent to all game participants. This simulation game used the Google Meet or Zoom platforms to provide virtual spaces for “big room” meetings and individual breakout sessions for each team. Internet connectivity, personal computers, Google Slides, and a shared platform such as Google Meet or Zoom are needed. Unlike the in-person physical simulation, the game generates no waste materials to be discarded following play. It is also scalable to accommodate as many players as the facilitators can handle and can synchronously engage participants located around the world.

Since the Block Tower simulation game is played virtually, it does require computing resources, which amount to investments in the procurement of these resources. However, the virtual mode offers an immense opportunity in terms of scalability. The simulation can be conducted with multiple teams and in far-flung locations. Unlike the Marshmallow Tower Game, which results in the generation of waste following play, the virtual mode using Google Slides and Google Sheets leaves only digital clutter—in other words, no physical waste. That said, the Block Tower does pose some challenges. For example, because the players are divided into teams, the facilitator must navigate across different virtual breakout rooms to respond to questions and coordinate play. Also, because the players meet virtually, it may not build the same level of trust and collaboration among team members as appears to happen more easily with a physical in-person simulation. Also, issues such as poor or intermittent internet connectivity and computing resources further exacerbate the challenges in communication and collaboration between players. Unlike simulation games that are played with physical materials, which can be experienced in terms of flexibility, texture, etc., and are relatively easier to work with, a virtual simulation can be challenging to manipulate and navigate. The Block Tower simulation poses some challenges on this front because it requires players to be comfortable with manipulating a mouse and digital resources such as Google Slides, Google Sheets, etc.

Digital Fabrication (TVDfDFAB) online game

The lean research community continued to explore the possibility of developing virtual simulation games in the midst of the COVID19 pandemic. Ng and Hall (2021) published a digital TVD game they developed specifically for digital fabrication (TVDfDFAB).

The TVDfDFAB simulation game aims to teach players the principles of TVD as applied to digital fabrication. It uses online meeting platforms such as Zoom and open access cloud documents (i.e. Google Slides and Google Sheets) to facilitate the game. This game retained the principles of the TVD Marshmallow Game for the number and nature of rounds: Round 1 (the traditional design bid build (DBB) approach), and Round 2 (the TVD approach), but the roles and nature of making were quite different. As metaphorical stand-ins for Owner, Architect, Engineer, and Constructor, teams of four members each comprising the roles of Restaurant Owner, Artistic Chef, Recipe Chef, and Executive Chef are tasked with designing a plate of salad for a newly opened four-star restaurant. The salad must be prepared with provided ingredients that include carrots, cucumbers, tomatoes, and eggs, while keeping in mind customer requirements of "best design." The requirements are as follows: (1) a minimum weight of 500 g. (heavier is preferred); (2) utilization of given ingredients in an equitable manner in terms of weight; and (3) the salad design should be inspired by Vincent van Gogh's renowned painting, *The Starry Night*. Concepts such as market cost, allowable cost and target cost are taught in this simulation from the context of delivering an optimized salad to the customer, as compared to building a tower as was the object of the TVD Marshmallow Tower Game and TVD Block Tower Game. In addition to the virtual nature of the game, this simulation specifically added an *aesthetic* (architectural) Condition of Satisfaction (CoS) which was missing in the previous two versions of the game.

Characterization of the TVDfDFAB Simulation is similar to the Block Tower game in many ways because both simulations are played virtually and in a two-dimensional space. One benefit of the TVDfDFAB game over the two previously mentioned games, however, is that it includes the concept of “aesthetics” in the salad design as a Condition of Satisfaction; this aligns with the aspirations of architects and makes the simulation more inclusive of all OAEC stakeholders. That said, the context of “salad” may not be relevant for members of some cultures where the creation of an aesthetically pleasing salad is not common practice. Also, construction industry professionals are likely more comfortable making and constructing buildings and facilities, so salad preparation may not be as relatable to them. Also, as with the Block Tower Game, playing virtually, rather than face-to-face, may pose some challenges in fostering a collaborative spirit and trust among game players.

Computer-based and Virtual TVD Game

During COVID19, researchers working in the area of lean simulations continued the development of TVD games that can be played in a virtual environment. Kim et al. (2023) and Kim et al. (2024) created and tested two different versions of Marshmallow TVD simulation games: one that is computer/keyboard-based and one that is VR-based. In both simulations, the teams involving an owner, designer, and contractor were asked to construct a two-foot-tall tower with a marshmallow on the top. The rules, goals, and rounds of the physical format of the Marshmallow TVD simulation were followed such that both computer/keyboard-based and virtual reality games represent three-dimensional virtual versions of the TVD Marshmallow Tower simulation.

The resources required for playing these simulations are as follows: (1) for the computer/keyboard-based format, a three-button mouse and computer with a keyboard, which can allow users to select objects in the scene, rotate, position and delete the object, turn the camera, and zoom in and out with the mouse and keyboard; and (2) for the VR-based format, a VR headset and controllers. Each controller should contain two buttons: a grab button and a trigger button. Grab buttons facilitate gripping and releasing an object while trigger buttons enable users to activate functions such as a "gravity test" in the VR environment. In addition, a graphical user interface, a panel itemizing materials, costs, and test/return buttons, were included in the VR-based format. In both versions, the simulation games harnessed the three-dimensional gaming software Unity™ to simulate gravity, a characteristic that was missing in the TVD Block Tower and Digital Fabrication game, which were played in two dimensions. The ability to simulate gravity, so that a team-created tower can stand or collapse, enabled the researchers to replicate the original TVD Marshmallow Tower game in digital format using virtual drinking straws, dried spaghetti, bamboo skewers, coffee stirrers, tape, and tabletops. However, unlike the physical version, these digital versions enable participants located in different parts of the world to collaborate together in teams. Also, because the games are completely virtual, they eliminate the waste generated during the playing of the physical version, where used materials are discarded.

All of the above TVD simulation games were systematically tested by their authors and deemed successful in terms of participant understanding of key TVD concepts following play. In many of the simulations, authors reported their participants were asked to rate on a Likert scale how effective they felt the simulation was with respect to demonstrating (a) mutual respect and trust; (b) mutual benefit and reward; (c) collaborative innovation and decision-making; (d) early involvement of key partners; (e) early goal definition; (f) intensified planning; (g) open communication; (h) appropriate technology; and (i) organization and leadership. Participants were also asked to use their own words to explain their understanding of market cost, allowable cost, and target cost—the three key milestone concepts of target value design.

The distinguishing feature of these two simulation games compared to the other two virtual variants, namely TVD Block Tower and TVDfDFAB, is the use of the gaming software Unity that allows participants to build a tower in three-dimensions. Using gaming software creates an opportunity to automate the playing of the simulation without the presence of a facilitator. However, the VR-based Marshmallow Tower Simulation, especially, requires high-end computing resources in terms of faster internet connectivity and a VR Headset, which has comparatively higher cost implications that are not readily available in certain geographical locations, such as remote construction sites. Although VR technology is making inroads in the OAEC industry, it has not yet become a standard for construction industry practices. The operation of VR controls also takes practice, which is not comfortable for all players. Hence, the use of a VR platform in this simulation can cause inconvenience to some game players.

TVD Bridge Game

In the original physical tower version of the TVD simulation, the Conditions of Satisfaction for success are defined by whether the participants' 2 ft. tall tower can stand freely (unattached) and be no more than two inches out of plumb (i.e., not leaning). Therefore, the inability to mimic gravitational pull proved to be one of the limitations of simulating the building of a tower using two-dimensional Google Sheets. Shah et al. (2025) addressed this concern by defining success differently. Instead of asking teams to create a tower, the simulation asks participants to develop a *bridge* that spans fully between two abutments.

Similar to the marshmallow tower game, the TVD bridge game designers created components of varying costs. In this case, the components included: foundations, superstructure, connectors, reduced trusses, and attachments.

Like the TVD Marshmallow Tower simulation, during Round 1, participant teams are given the opportunity to develop a design for their bridge while unaware of the costs of the various components. Component costs are then revealed to the group, and each team's total bridge cost is tallied and entered onto a collective spreadsheet. Teams are then challenged to build a new bridge during Round 2, while reducing their total costs by 15%. Researchers found that while one team reduced its costs by 11%, three out of four teams managed to reduce their costs by 30-34% during Round 2, while still fulfilling the required Conditions of Satisfaction. This finding is consistent with the claim that most TVD exercises have been shown to reduce costs by 15-20% on actual construction projects.

Educational Theory behind the TVD simulation

In the educational sphere, Bloom's Taxonomy is frequently used as a touchstone to enhance learning outcomes (Bloom et al. 1956). The taxonomy represents a hierarchy of learning in six successive stages: (1) gain knowledge, (2) develop understanding, (3) apply, (4) analyze, (5) evaluate, and (6) create. The TVD simulations represented in this paper address the first three stages of Bloom's taxonomy; those who have participated in the TVD simulation have been shown to develop *knowledge* about and *understanding* of TVD's overarching goal after playing the simulation (Munankami 2012). Because the simulation also gives participants a chance to practice TVD during play, they also fulfill the *apply* criteria of Bloom's taxonomy. The simulation is intended to represent a clear and simplified introduction for those who are being exposed to TVD for the first time. The last three criteria (*analyze*, *evaluate*, and *create*) arguably happen to some extent during play but then intensify once OAEC stakeholder teams begin to implement TVD on an actual project.

The second educational model that informs this research is the Kirkpatrick and Kirkpatrick Evaluation Model (2006). The Kirkpatrick model is ideally suited for those who are developing learning materials to enhance business outcomes. The model may be viewed as a pyramid comprising four levels, namely: (1) reactions, (2) learning, (3) behaviors, and (4) results. Testing for *reactions* involves checking to see if learners are satisfied with their experience in terms of enjoyment and perception of relevance to their working lives. Testing for *learning* assesses whether desired knowledge and skills have been acquired, based on surveys and quizzes. Testing for *behavior* looks for real-world effectiveness based on observations, performance reviews, feedback from peers and managers, etc. Testing for *results* involves evaluating whether training has impacted revenue and if any changes in customer satisfaction can be attributed to training. Research by Bhatt et al. (2016) during a simulation game demonstrated correlations in the financial performance of teams that elected to pay for upfront training on how to solve a mathematical puzzle versus those teams that did not.

Although the need for effective training may seem intuitively obvious, an investigation of current TVD training practices facilitated by various lean consultants revealed a range of consistencies and inconsistences in the training of stakeholder teams (Rybkowski et al. 2022). Without training consistency, it is difficult to confidently forecast the financial impact of TVD exercises on an actual construction project.

One goal of this paper is, therefore, to formulate criteria for an aspirational simulation that not only helps participants enjoy the process as they learn about TVD but that can also be shown to change stakeholder behavior that enhances business revenues for all involved. Although evidence of return-on-investment is currently anecdotal, the observations that lean consultants are playing the simulation with OAEC stakeholders before implementing TVD on actual projects suggests they believe the simulation is worth making the effort to play.

Research Question

Target Value Design exercises implemented during the development of an actual capital project can consume months or even years, depending on the size and complexity of the project and the cultural diversity of its stakeholders. It is therefore not uncommon for stakeholder teams to become impatient with TVD exercises if they do not understand the overarching goal and value that TVD brings to the final project. To help stakeholders grasp the larger picture of what they will be being asked to do, lean consultants and champions often engage stakeholder teams in simulation exercises, such as the TVD game, which can typically be played in less than 90 (or even 60) minutes.

TVD simulation games have proven their usefulness because they are voluntarily being used by lean champions, consultants, and educators to pre-train stakeholder teams in the basic principles of lean processes, such as Target Value Design. The TVD simulation games give participants a fundamental understanding of the need to collaboratively and creatively lower the capital (first) cost of a project to a level that fulfills the Owner's stated *Conditions of Satisfaction* (CoS) while at least reaching the Owner's required *Allowable Cost*—and potentially even beyond to an optional *Target Cost*. However, given the changing environment where many businesses have shifted to remote work and where employees in multinational companies may work on a common project while residing in different geographical locations, it is necessary to ask the question: **What would be the characteristics of an ideal TVD simulation game that is scalable and therefore cost effective, and that can be played virtually and synchronously in multiple locations around the world?**

Methodology

The methodology for this paper comprised a three-step approach. Firstly, the authors conducted an extensive literature review to analyze existing, published lean simulation games in the construction industry. The findings from this systematic review were discussed in Bhatnagar et al. (2022). The review unearthed variants of the TVD Marshmallow Tower Game, as reported in the literature. The authors read in detail the papers discussing these variants to understand the development and testing of each simulation game. Because the emergence of iterative versions of the TVD simulation points to its effectiveness in illustrating the basic principles and concepts underlying the practice of TVD, the authors of this paper sought to develop an aspirational vision for future TVD simulation developers and to assess how the versions created are faring thus far.

In this context, the second step of this research study involved validation of the simulations. The variants developed by the authors were tested in academic as well as professional settings. Additionally, the authors of this paper helped the developers of the variants run an additional level of validation to test and improve the effectiveness of their simulations through live, virtual sessions with participants. Active in the development of lean simulations ourselves, and because one co-author in particular is the largest contributor of peer-reviewed publications of innovative Lean Construction simulations in the world (Bhatnagar et al. 2022), as well as the founder and chair of APLSO (Administering and Playing Lean Simulations On-Line), an international forum which included 174 participants from 21 countries at the time of authorship of this paper, the authors offered live, first-run study test sessions of the simulations where the developers facilitated their digital simulations with APLSO members (Rybkowski et al. 2021). Among APLSO members, 35% are affiliated with industry and/or serve as lean consultants, and 65% teach and/or research at academic institutions.

In fact, as shown in Figure 2, some of the authors of this paper were associated with assisting in the development of all evaluated variants of the Munankami (2012) and Rybkowski et al. (2016) physical TVD simulation, namely: Jacob et al. (2021), Kim et al. (2023), and Kim et al. (2024). While they did not directly help create the variants of Ng et al.(2021) and Shah et al. (2025), the authors of this paper did assist these latter authors through online testing and offering feedback at APLSO.

During an APLSO session and following play, simulation participants are requested to share their feedback with simulation developers. Participants are invited to vocalize what they learned ("takeaways") and to help with the construction of a "plus"/"delta" feedback table—those elements of the simulation that should be retained (plus) as well as those parts that can be improved (delta). It is common practice among the facilitators of lean simulation games to conduct plus/delta analyses to determine the overall effectiveness of a session in teaching fundamental lean concepts.

Although admittedly subjective, the purpose of this assessment is to: (1) help lean consultants, champions, and educators select the right TVD simulation game version given their situation, and (2) challenge TVD simulation game developers to continuously improve their versions to meet an aspirational goal where industry needs are more completely met.

The third step of this effort is to envision an ideal aspirational version of the TVD simulation based on expressed and observed industry needs and to assess how existing simulations compare. For example, in addition to demonstrating the basic principles of TVD, the Conditions of Satisfaction for an aspirational TVD simulation game should ideally:

- Generate little or no waste following play
- Be easy to play regardless of the abilities of the participant
- Be simple to facilitate
- Be scalable

- Be synchronously playable by multinational organizations located in geographically disparate locations, and
- Develop trust among stakeholders

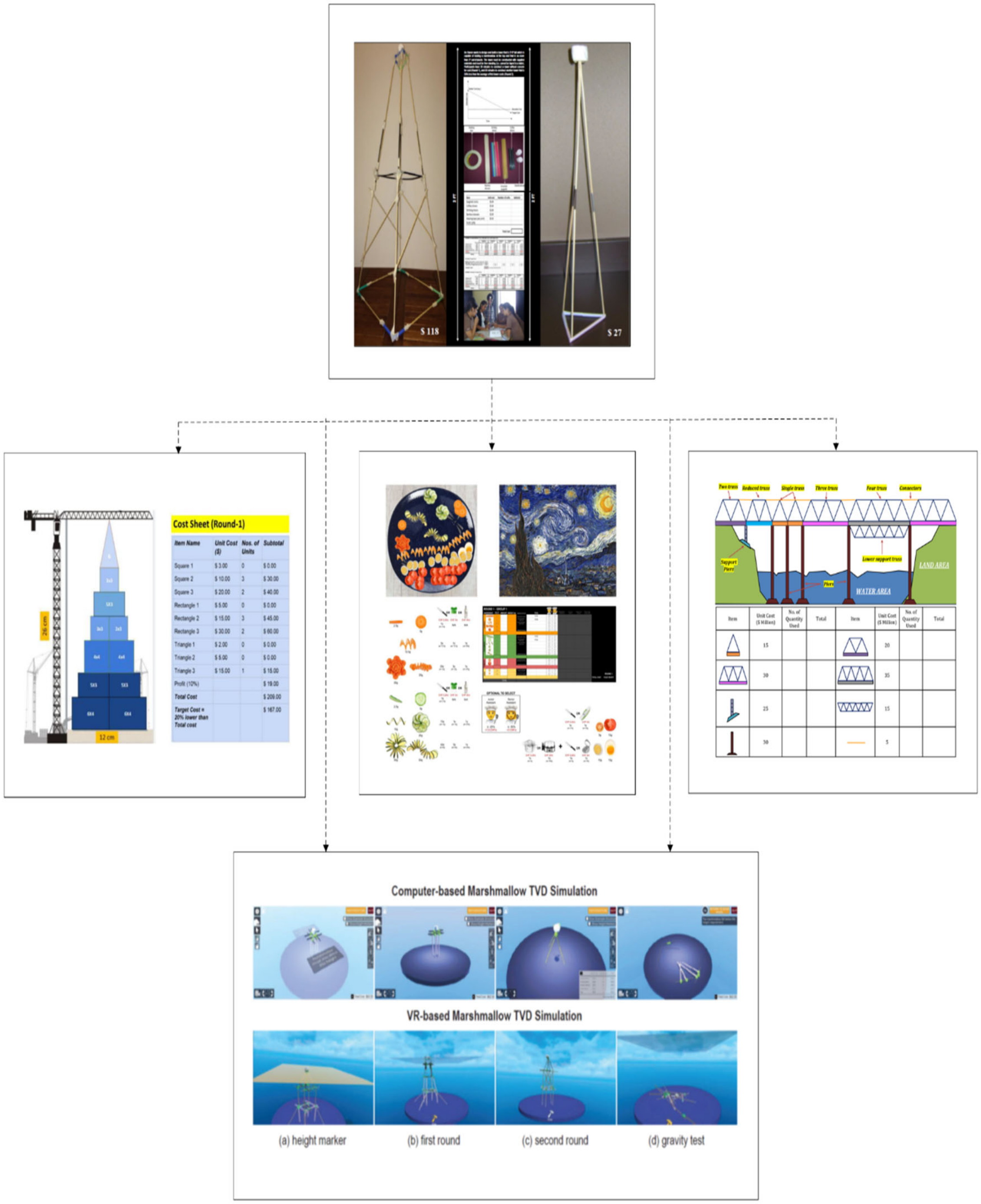

Figure 2. Evaluated TVD simulation games include: (top) Adapted from Munankami (2012) and Rybkowski et al. (2016), and left to right (middle tier): Jacob et al. (2021), Ng and Hall (2021), Shah et al. (2025), and (lower) Kim et al. (2023; 2024).

Complete lists of recommended criteria are included in Tables 2 and 3. These tables depict how the authors rated each described version of the TVD simulation on a number of desired characteristics, using ratings of "high," "medium," and "low" (Table 2) or "yes," "somewhat," and "no" (Table 3). The first column of each table contains evaluations of criteria for an ideal TVD simulation based on Kirpatrick's Evaluation Model that would potentially ensure a more significant, desirable impact for a business aiming to implement TVD.

Table 2. Desired/Aspirational Material & Resource Characteristics

Characteristics	Aspirational Version	Marshmallow Tower Rybkowski et al. (2016)	Block Tower Jacob et al. (2021)	TVDfDFAB Ng et al. (2021)	Keyboard Marshmallow Tower Kim et al. (2023)	VR Headset Marshmallow Tower Kim et al. (2023)	TVD Bridge Shah et al. (2025)
Initial cost	Low	Low	Medium	Medium	Medium	High	Medium
Long-term cost	Low	High	Low	Low	Low	Low	Low
Generates waste	Low	High	Low	Low	Low	Medium	Low
Ease of access to required materials/resources in multiple geographic locations or easily portable.	High	High	Medium	Medium	Medium	Low	Medium
Potential to play synchronously and asynchronously in multiple locations, as needed	High	Low	High	High	High	High	High
Ease of facilitation	High	Medium	Low	Low	Low	Low	Low
Capacity to be fully automated without a facilitator	High	Low	Medium	Medium	High	High	Medium
Potential for scalability	High	Low	High	High	High	High	High
TOTAL POSSIBLE POINTS of ALIGNMENT	8	2	4	4	5	4	4

Legend: Cells shaded in yellow suggest alignment with the envisioned aspirational version, which is shaded in green.

Table 3. Desired/Aspirational Attributes to Introduce Players to Lean Culture

Attributes	Aspirational Version	Marshmallow Tower Rybkowski et al. (2016)	Block Tower Jacob et al. (2021)	TVDfDFAB Ng et al. (2021)	Keyboard Marshmallow Tower Kim et al. (2023)	VR Headset Marshmallow Tower Kim et al. (2023)	TVD Bridge Shah et al. (2025)
Instructions are simple an easy to understand	Yes	Yes	Somewhat	No	Somewhat	Somewhat	Somewhat
Serves as a team ice breaker	Yes	Yes	Currently unknown	Currently unknown	Currently unknown	Currently unknown	Currently unknown
Builds cohesion/trust among stakeholders	Yes	Yes	Somewhat	Somewhat	Somewhat	Somewhat	Somewhat
Motivates collaboration	Yes	Yes	Somewhat	Somewhat	Somewhat	Somewhat	Somewhat
Represents all OAEC stakeholders, including aestheticians (architects)	Yes	No	No	Yes	No	No	No
Accessible to multiple generations (i.e. even those who are less "tech-savvy")	Yes	Yes	Somewhat	Somewhat	Somewhat	No	Somewhat
Relatable across cultures	Yes	Yes	Yes	Somewhat	Yes	Yes	Yes
Relatable to construction professionals	Yes	Somewhat	Yes	No	Somewhat	Somewhat	Yes
Multiple players (all OAEC stakeholder) can be engaged	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Leads to long-term retention of TVD principles and goals by participants	Yes	Currently unknown	Currently unknown	Currently unknown	Currently unknown	Currently unknown	Currently unknown
TOTAL POSSIBLE POINTS of ALIGNMENT	10	7	3	2	2	2	3

Legend: Cells shaded in yellow suggest alignment with the envisioned aspirational version, which is shaded in green.

Note that in some instances, the criteria of variants are aligned with the aspirational version, and in other instances, they are not. The intent is to challenge simulation developers to better serve the needs of OAEC stakeholders who will be embarking on TVD exercises for an actual project. These criteria emerged from a research study performed by the authors focusing on a systematic review of lean simulation games in the construction industry (Bhatnagar et al. 2022), where it was observed that simulation games could be classified according to the following parameters: (1) learning outcomes (cognitive skill and effectiveness); (2) focus of specified lean principles; (3) players (single player vs. multi-player); (4) delivery format (non-computer-based vs. computer-based); (5) stakeholders (academic, designers, constructers, etc.); (6) interactive style (competitive, collaborative, or individual); (7) adaptability; and (8) portability.

The parameters mentioned in Tables 2 and 3 were specifically crafted to align with the objectives of this paper. The observations and notes taken by the authors during Plus/Delta analyses and further detailed analyses of the development and facilitation of each simulation game variant formed the basis for the ratings mentioned in Tables 2 and 3. The characteristics for consideration are shaded in blue. Cells shaded in yellow suggest alignment with the envisioned aspirational version, which is shaded in green. The sums at the bottom of each version indicate the amount of alignment of each game with the aspirational version. While the aspirational simulation game has a total rating of 18, the ratings of existing simulation variants range from 6 to 9. The intent is to challenge lean simulation authors to find ways to maximize the effectiveness and scalability (reach) of lean simulations, using the TVD simulation as one example of how this might be done.

Results

Characteristics - Comparisons of existing TVD Simulations

The formats of Target Value Design (TVD) simulations have evolved from physical to digital, resulting in four distinct variants: 2D digital versions using Google Slides™ or PowerPoint™, and 3D versions—both keyboard-based and Virtual Reality—developed in Unity™. This rapid evolution was driven by the necessity of social distancing during the COVID-19 pandemic and the increasing accessibility of technological platforms for a generation of students and professionals already accustomed to virtual controls. However, these digital formats require specific physical and digital infrastructure, such as VR headsets, desktop or laptop computers, and uninterrupted internet connectivity, which can create financial or logistical barriers if participants lack these resources at their specific workplace or construction site.

By contrast, physical TVD simulations utilize locally sourced materials designed for high accessibility, such as marshmallows and straws, which can be adapted to regional contexts—for instance, substituting cheese cubes for marshmallows or using bamboo stirrers to meet environmental standards. Despite this adaptability, physical simulations present significant logistical challenges, particularly for large groups, requiring painstaking effort to estimate material orders and secure sufficient tabletop space. Furthermore, unlike their digital counterparts, the materials used in physical tower construction cannot be reused and therefore constitute waste, presenting a sustainability disadvantage compared to the reusable nature of digital simulation platforms.

With the exception of the VR headset version, digital versions of the simulation offer advantages in terms of ease in scaling at the click of a button. One of the common threads among the different variants of TVD simulations is the possibility of engaging multiple players simultaneously and remotely, and it is one of the key strengths of administering these simulations among large groups of professionals and students. Since the Marshmallow Tower Simulation requires a tower to be built that is structurally sound, no more than two inches out-of-plumb, and that can bear the weight of marshmallow, gravity is needed to create episodes of failure or success. The TVD Block Tower and TVDfDFAB ("salad") Simulation do not require the interplay of gravity for successful implementation. However, the computer/keyboard-based Marshmallow Tower and VR-headset-based Marshmallow Tower versions of the simulation game resolve the gravity dilemma by using the gaming software Unity™ to simulate gravity. The novelty of the TVD Bridge Game is that no physical or simulated gravity is required to successfully create a viable bridge.

The facilitator for lean simulation games plays a crucial role. In terms of supervision and intensiveness of support required for the game participants, the VR headset Marshmallow Tower game is demanding and requires a vigilant and active facilitator. The other digital variants, with the use of digital space and resources for the conduct of simulation, do not require as extensive involvement of the facilitator.

Desired Attributes to Introduce Lean Culture

The fundamental objective of the TVD Marshmallow simulation game is to introduce the concept of Target Value Design to the participants and to make them aware of collaborative lean culture. It is necessary to decipher the variants of TVD Marshmallow simulation game to understand to what extent they can fulfill expectations. The TVD Marshmallow simulation game uses physical space and resources; hence, it is relatively easy for the facilitators to provide instructions for each round and conduct post-simulation discussions. Participants of the physical version can intuitively assemble materials using their own hands and become involved in the act of making, often appearing at ease. However, in the case of digital variants, the facilitator must carefully explain the instructions of the graphical user interface and reconfirm understanding with the participants. Any mistake or deviations from the instructions can create stress for the participants and facilitator because the hardware and software of the digital realm are not always as intuitive as the physical world.

One of the most exciting characteristics of the TVD Marshmallow Tower simulation is its ability to promote "team spirit"; it typically serves multiple functions as a practice session for TVD processes and as an ice breaker to introduce students and professionals to one another. The simulation game also builds cohesion and trust among the team members and illustrates the importance of collaborative efforts toward a larger shared goal. Although the digital and virtual variants also co-locate the participants in digital space, observations by the authors suggest these versions are still limited in certain aspects such as: (1) not facilitating a sense of trust among team members; (2) creating an intimidating technological environment in which some individuals do not feel comfortable participating (they appear to struggle or "sit out" when asked to play the digital/computer-based or VR versions); and (3) creating an anonymous environment such that one gender has expressed feeling uncomfortable when another player assumes control to the detriment of others.

Although, all the stakeholders—owner, architect, engineer, and contractor—are represented in the role play of all variants, aesthetic value takes a backseat in most of variants except in the TVDfDFAB ("salad") game. Unless the participant playing the role of "Owner" specifies a need for aesthetic considerations, the teams designing the constructed tower only need to fulfill functional Condition of Satisfactions (e.g. specified height, free-standing, and no more than two inches out of plumb). The TVDfDFAB on the other hand, brings aesthetics to the center stage, aligning the roles of aestheticians and architects who must direct the creation of an aesthetically pleasing salad in the spirit of a Van Gogh painting while meeting target cost. That said, the challenge of creating lean simulations is to engage participants in an activity that is relatively relatable to most players. For example, while the introduction of aesthetic considerations is one benefit of the salad game, the very concept of being asked to create a salad may not be relatable in cultures where salads comprising raw vegetables are not generally included in their diet.

It is expected that a simulation game should be accessible to multiple generations and individuals of diverse abilities. The Marshmallow Tower game alone with its use of locally sourced physical resources as well as physical design and construction techniques connects equally well both with the "brick and mortar" and more tech-savvy participants. There could be a slight disconnect between digital variants of the game and those players who are uneasy with digital formats and controls. For example, some participants appear more comfortable with VR headsets than others. Finally, it has been observed that OAEC professionals tend to feel more connected to a simulation game that involves building a recognizable, constructed structure. In this context, the Block Tower scores higher over some variants because it involves constructing a tower with provided shapes; the game template includes a tower crane to playfully simulate a construction site environment. Similarly the TVD Bridge simulation is relatable to constructors; it also eliminates the need for real or simulated gravity.

In summary, the characteristics of TVD simulation games variants indicate that a variety of parameters must be considered. None of the lean simulation game variants align perfectly with all parameters. This assessment prompts the need for continuous improvement toward an aspirational TVD simulation game.

Aspirational TVD Simulation Game for Lean Culture

The Marshmallow Tower Game was first released in 2012 among the Lean Construction community. Since then, it has been used in various countries (e.g. US, Brazil, Ireland, Germany, India, Nigeria, etc.) in academic classrooms and in professional training workshops. There was sudden spurt in the emergence of on-line variants of the simulation game starting in 2021, likely due to COVID19, and it is expected that the simulation game will continue to further evolve.

This paper provides a recommended direction for the evolution of the TVD simulation game based on the informed judgment of the authors who are extensively experienced in the development and validation of lean simulation games. The authors themselves were either involved in various capacities in the development and/or testing of the simulations described and discussed in this paper or provided an extensive "Plus/Delta" analysis following participatory playing of two of the simulations. Given the needs of both the industry and academia, it is the observation of the authors that an aspirational lean simulation game should at least embody the following traits:

- The instructions to play should be easy for players to understand and for facilitators to facilitate.
- Multiple players, including all OAEC stakeholders, should be engaged.
- The simulation game should help to "break the ice" among players working together for the first time.
- Interaction and discussions should be done in a way that makes the simulation inclusive and helps build cohesion/trust among stakeholders.
- Aesthetics should be included as a criterion for success.
- The simulation should be scalable so it can cater to a large number of game participants.
- It should offer the potential of being fully automated so a live facilitator is not absolutely required, paving the way for a project team to bring late on-boarders up-to-speed as needed.
- It should be relatable to those in construction who perform a variety of roles, as well as to those from different cultures.
- It should be inexpensive to implement for facilitators and participants alike.
- Gaming materials should be easy to access in multiple geographic locations.
- It should be capable of being played synchronously and asynchronously across multiple time zones.
- It should be capable of being played by multigenerational participants with varying levels of digital skills.
- If a facilitator is involved, it should be easily portable to new locations.
- It should keep waste low, be enjoyable to play, and not require furniture or tabletops to play.
- It should motivate collaboration among OAEC stakeholders.
- It should result in long-term knowledge retention of TVD principles and goals by participants.
- It should be tested for educational attainment such as those delineated in the Bloom's Taxonomy and the Kirkpatrick models.

Limitations and Delimitations

The scope of this research is the generation of a hypothesis or theory—the need for an aspirational TVD simulation—which is the first step of the scientific process. Testing that hypothesis, using educational models such as Bloom's taxonomy and the Kirkpatrick model, will be the task of future research. Another delimitation is that full implementation of TVD involves engagement of a number of tools and culture-setting frameworks, such as Set-Based

Design, CBA, A3s, IPD, etc. This paper focused only on the single overarching idea of TVD—that of cost and value management—and not on attendant tools and concepts.

The authors of this paper are highly experienced in lean simulation development and testing and have actively participated in either the creation and/or testing of the simulations presented in this paper. They have served as Lean Construction educators in both academic and commercial settings. Nevertheless, one potential limitation of the work is that the generation of the hypothesis/theory presented in this paper did not include evaluators beyond the authors of the paper. Characteristics of an aspirational TVD simulation could be further refined in future work by involving additional lean academics, as well as commercial, on-site evaluators.

Discussion

Analyzing TVD simulation variants against the aspirational criteria in Tables 2 and 3 reveals significant trade-offs. For instance, the variant scoring highest for culture (Table 3) ranks lowest regarding material and resource characteristics (Table 2). This distinction highlights that TVD simulations are utilized in two disparate contexts—educational and professional—each with unique training objectives. While educational settings prioritize fundamental concepts and terminology, professional environments focus on cultivating a lean culture of collaboration and integrated decision-making. Consequently, these findings underscore the need for future lean simulation development. By examining these variants as a case study, this paper proposes an aspirational framework designed to provide an effective TVD onboarding mechanism for project stakeholders.

The researchers investigated the development of various TVD simulation variants as a case study to envision an aspirational simulation framework. The above findings reinforce a underlying purpose of this paper, that is, to serve as a “call to action” for the development of future lean simulations.

Conclusion

Fundamental to lean philosophy is the concept of continuous improvement. Continuous improvement can be built on the current state situation of a single organization’s practices. It can also be built on the practices of an ecosystem. This paper seeks to benchmark the current state of the TVD simulations emerging from the modest ecosystem of TVD simulation game developers—and to propose an idealized future state Conditions of Satisfaction criteria toward which the ecosystem of TVD simulation game developers and testers can aspire. While the need for social distancing during COVID19 incentivized the development of digital and virtual versions of the TVD game which have created opportunities for synchronous play across continents, scaled to a large number of participants, and designed to eliminate material waste following play, the physical in-person version of the game still appears to offer unparalleled benefits such as serving as an ice-breaker, providing ease of play for players who appear to be less comfortable manipulating virtual game controls, and helping stakeholders build much-needed trust among members who are about to collaboratively design an actual project together. The need to address these softer requirements such as ice-breaking and trust formation are in evidence by the voluntary return to physical simulations following the waning of the COVID19 pandemic.

Futuristic and emerging technologies such as full-size holograms that help remote players feel as though they are co-located in the same room with teammates may ultimately help address some of the concerns of digital simulations such as the need to enhance trust-building and are certainly worth exploring as technology matures. The focus of this research has been on recommending improvements to the simulation of a single lean concept, namely TVD. However, the larger intent is a “call to action” to inspire future lean simulation developers to consider more aspirational criteria in the development of additional simulation games. Also, testing the training effectiveness of a simulation as measured by Bloom’s Taxonomy or fulfillment of an organization’s revenue enhancing goals, as suggested by the Kirkpatrick model, offer exciting opportunities for future research.

References

American Institute of Architects, AIA. (2007). *Integrated Project Delivery: A guide*. AIA, Washington, DC.

Ballard, G. and Reiser, P. (2004). “The St. Olaf College Fieldhouse Project: A case study in designing to target cost.” In: *Proc. of 12th IGLC International Group for Lean Construction*, Copenhagen, Denmark.

Bhatnagar, S., Jacob, G., Devkar, G., Rybkowski, Z. K., Arefazar, Y., and Obulam, R. (2022). “A systematic review of lean simulation games in the construction industry.” *Architectural Engineering and Design Management*, 19:6, 701-719.

Bhatt, Y., Rybkowski, Z. K., Kalantar, N., and Fernandez-Solis, J. L. (2016). “Trainathon lean simulation game: Determining perceptions of the value of training among construction stakeholders.” *Proceedings of the 24th Annual Conference of the International Group for Lean Construction*; July 20-22, 2016: Boston, MA, 53-62.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., and Krathwohl, D. R. (1956). *Taxonomy of educational objectives: The classification of educational goals*. Vol. Handbook I: Cognitive domain. David McKay Company, New York.

Do, D., Chen, C., Ballard, G., and Tommelein, I. (2014). “Target Value Design as a method for controlling project cost overruns,” In: *Proc. of the 22nd Annual Conference of the International Group for Lean Construction*, June 25-27, 2014: Oslo, Norway, 171-181.

Devkar, G., Trivedi, J., and Pandit, D. (2019). “Teaching Target Value Design: Learnings and Challenges.” In: *Proc. of the 27th Annual Conference of the International Group for Lean Construction*, July 3-5, 2019: Dublin, Ireland, 479-490.

Hill, K., Copeland, K., and Pikel, C., eds. (2016). *Target Value Design, Practitioner Guidebook to Implementation*, Lean Construction Institute, 173 pp.

Jacob, G., Sharma, N., Rybkowski, Z. K., and Devkar, G. (2021). “Target Value Design: Development and testing of a virtual simulation.” In: *Proc. of the 29th Annual Conference of the International Group for Lean Construction (IGLC29),* Alarcon, L.F. and González, V.A. (eds.), Lima, Peru, 320–329.

Kim, S., Mainardi, P., Jeong, D. H., Rybkowski, Z. K., and Seo, J. H. (2024). “Technology-driven serious games and simulations for construction management education.” *Journal* *of Construction Engineering and Management, ASCE* (technical paper, accepted for publication).

Kim, S., Rybkowski, Z. K., and Jeong, H. D. (2023). "Developing and testing computer- and virtual reality-based target value design simulations." In: *Proc. of the 31st Annual Conference of the International Group for Lean Construction* (IGLC31), June 26 – July 2, 2023: Lille, France, 629–638.

Kirkpatrick, D. L. and Kirkpatrick, J. D. (2006). *Evaluating Training Programs (3rd edition): The Four Levels*, Berrett-Koehler Publishers, San Francisco, CA.

Miron, L. I. G., Kaushik, A., and Koskela, L. (2015). "Target Value Design: The challenge of value generation," In: *Proc. of the 23rd Annual Conference of the International Group for Lean Construction* (IGLC23), July 29-31, 2015: Perth, Australia, 815-825.

Munankami, M. B. (2012). "Development and testing of a simulation (game) to illustrate basic principles of Integrated Project Delivery and Target Value Design: A First Run Study," Graduate Thesis, Texas A&M University, College Station, TX.

Musa, M., Pasquire, C., and Hurst, A. (2019). "Using TVD simulation to improve collaboration." In: *Proc. of the 27th Ann Conf of the Intl Group for Lean Construction* (IGLC27), *Pasquire C. and Hamzeh F.R. (ed.),* Dublin, Ireland, 503-514.

Ng, M. S. and Hall, D. H. (2021). "Teaching Target Value Design for digital fabrication in an online game: overview and case study." In: *Proc. of the 29th Ann Conf of the Intl Group for Lean Construction (IGLC29),* Lima, Peru, July 12-18, 249–258.

Rybkowski, Z. K., Arroyo, P., and Parrish, K. (2022). "Assessment of current target value design practices: consistencies and inconsistencies of application," *Construction Management and Economics*, Volume 40, Issue 7-8, 20 pp. https://doi.org/10.1080/01446193.2022.2037146

Rybkowski, Z. K., da C. L. Alves, T., and Liu, M. (2021). "The emergence and growth of the on-line serious games and participatory simulation group 'APLSO.' In: *Proc. of the 29th Annual Conference of the International Group for Lean Construction* (IGLC29), Lima, Peru, July 12-18, 269-278.

Rybkowski, Z. K., Munankami, M., Gottipati, U., Lavy, S., and Fernández-Solis, J. (2011). "Impact of cost constraints on aesthetic ranking following Target Value Design exercises." In: *Proc. of the 19th Annual Conference of the International Group for Lean Construction,* Lima, Peru, July 13-15, 448-457.

Rybkowski, Z. K., Munankami, M., Shepley, M. M., and Fernández-Solis, J. L. (2016). "Development and testing of a lean simulation to illustrate key principles of Target Value Design: A first run study." Proceedings of the 24th Annual Conference of the International Group for Lean Construction (IGLC33), June 2-8, 2025: Boston, MA, USA, 133–142.

Rybkowski, Z. K., Forbes, L. H., and Tsao, C. Y. (2020). "Chapter 19: The evolution of lean construction education at US-based universities," *Lean Construction: 25 years of development*, Taylor and Francis, edited by Patricia Tzortzopoulos, Mike Kagioglou, and Lauri Koskela, 387-407.

Shah, M., Bharadwaj, D., Ehsas, H., Ramalingam, S., and Rybkowski, Z. K. (2025). "Dissemination of Target Value Design principles through a bridge construction online simulation: Overview and case study." *Proceedings of the 33rd Annual Conference of the International Group for Lean Construction* (IGLC33), June 2-8, 2025: Osaka and Kyoto, Japan, 1463–1473.

Skillman, P. (2006) "Peter Skillman Marshmallow Design Challenge." <https://www.youtube.com/watch?v=1p5sBzMtB3Q> (accessed on April 30, 2016).

Solhjou Khah, F., Rybkowski, Z., Pentecost, A. R, Smith, J. P., and Muir, R. (2019). "Development and testing of an innovative architectural programming simulation as a precursor to Target Value Design." In: *Proc. of the 27th Annual Conference of the International Group for Lean Construction* (IGLC), González, V.A. (ed.), July 3-5, Dublin, Ireland, 515-525.

Suhr, J. (1999). *The Choosing by Advantages Decision-making System*. Quorum, Westport.

Tommelein, I. D. and Ballard, G. (June 2016). Target Value Design: Introduction, Framework & Current Benchmark, Lean Construction Institute, Arlington, VA, 73 pp.