DEVELOPMENT AND TESTING OF DIGITAL TOOLS TO SHARPEN WORKER INTUITION ABOUT WASTE RECOGNITION AND PRODUCTIVITY ENHANCEMENT FOR THE CONSTRUCTION INDUSTRY

A Thesis

by

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ABSTRACT

Embedded in most construction activities are multiple forms of waste. Waste adversely affects a project's delivery in terms of time, cost, quality, safety, and even stakeholder morale. Inherent to enhancing productivity on a lean project is the need to develop flow between activities such that the slopes of successive activities on a line-of-balance schedule become parallel. Achieving this disciplined level of parallel flows requires the ability to recognize wasteful practices. Toyota's process engineer, Taiichi Ohno, identified eight wastes that need to be recognized and eliminated to achieve flow.

Developing an intuitive understanding of where to place objects so that productivity can be enhanced would be of help to the construction industry which is notorious for cost and time overruns. In other industries, such as manufacturing, graphical tools such as Value Stream Mapping (VSM) are commonly used as a way to plot and measure a sequence of activities that contribute to a larger stream, including the inputs and outputs of individual activities.

Lean practitioners also recognize VSM as a valuable tool for those seeking to implement Lean since it facilitates analysis of the flow of processes, waste, and value. VSMs also help students and practitioners develop an understanding of additional Lean processes such as takt time. However, while traditional value stream mapping methods may make sense for those with a background in manufacturing or industrial engineering, they are arguably neither intuitive to construct nor easy to understand by those in the building industry. There is a need to find simpler ways to communicate opportunities for waste reduction and productivity enhancement that align with the visual management characteristics of those practicing within the construction industry. In this research, a Spaghetti Diagram is introduced as an improvement tool which has the potential to be used intuitively.

This research aimed to develop and test two online activities to determine if a video of a cook making spaghetti in a kitchen as well as an interactive online simulation game that generates spaghetti diagrams can help players develop an intuitive sense for identification and removal of embedded waste. The research methods used for this study were (i) *kaizen* (e.g., continuous improvement using plan-do-check-act cycles) design research methodology that involves iterative development, testing, and revision, and (ii) controlled experimentation. Feedback on both activities was collected, and modifications made accordingly.

Participant feedback from testing of the developed video and online game showed that both games were enjoyable to play. They appeared to increase participant awareness and were capable of helping participants identify waste and improve their performance.

DEDICATION

This work is respectfully dedicated to my parents, Mr. Masoud Arefazar and Mrs. Esmat Sadegh Pourazari; my sister, Ms. Nasim Arefazar; and beloved husband, Sayyed Amir Hossain Maghool whose constant support and inspiration made this thesis research possible. At the same time, my thanks also go to my supervisors under whose guidance I completed this thesis. They not only enlightened me with academic knowledge but also gave me valuable advice whenever I needed it most.

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This work was supervised by a thesis committee consisting of Dr. Zofia K. Rybkowski (chair) and Dr. David Jeong of the Department of Construction Science, and Dr. Jinsil Hwaryoung Seo of the Department of Visualization.

The data analyzed for Chapter 3 was provided by students of COSC 631 ("Advanced Productivity and Lean") at Texas A&M University, members from the San Diego Community of Practice, and the international research community of APLSO (Administering and Playing Lean Simulations On-Line).

All other work conducted for this thesis was completed by the student independently.

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NOMENCLATURE

VSM	Value Stream Mapping
APLSO	Administering and Playing Lean Simulations On-Line
SA	Situational Awareness
BIM	Building Information Modeling
VM	Visual Management
TPS	Toyota Production System

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1. INTRODUCTION

Students and construction management practitioners often find it difficult to understand abstract terms such as "waste," "value," "process," "conversion," and "flow." A value stream map (VSM) is a Lean tool for measuring performance and reducing waste and can help users visualize otherwise abstract concepts (Rother & Shook 2003).

On-site practitioners can use VSMs to see the day-to-day flow of work and to understand the effect of straightforward improvements to workflow (Simonsson et al. (2012). That said, users might not be able to apply VSMs effectively in a real-world setting if the concept is not presented in a way that resonates with them. As a result, experiential learning becomes crucial for efficient instruction and learning in programs for on-site training and construction management (Ramalingam, 2018).

Simulation games can be used in the classroom to promote learning, facilitate classroom instruction, and boost comprehension of the theory underpinning Lean Construction and its real-world applications among engineering students (Hamzeh et al. (2017). Furthermore, students expect university education to be entertaining and fun and simulation games can impart learning in this way (Kapp, 2012; Prensky, 2007).

Hadzialic and Weigel (2016) and Oberhausen and Plapper (2015) studied the application of VSM through laboratory experiments with student teams. For one of the Lean Construction course modules, Ramalingam (2018) used the concept of mapping BIM processes to teach Lean. However, such studies are limited, which suggests opportunities to test the VSM technique as tool to further student understanding of waste, flow, value, continuous improvement, etc. when teaching Lean.

VSM is process-oriented, and unless students are part of the process, they may not be able to apply the technique in actual practice (Lobaugh 2008). To this end, Bob Petruska (2014) created a VSM simulation, “The Pizza Game,” using poker chips and train tracks. Some of the tools discussed in this game included work balancing and spaghetti diagrams, where the team used VSMs to chart processes and to improve them (Arefazar & Rybkowski, 2022).

Also, a review of the relevant literature suggests that a spaghetti diagram is a powerful Lean tool for reducing unnecessary motions and ineffective regions. According to Kanaganayagam (2015) a spaghetti diagram is a method used to visualize the movement of an object in a system using a line to demarcate the path of movement. Using a spaghetti diagram, motion waste and ineffective operations are exposed, allowing for the reduction of superfluous labor and the implementation of changes to organizational structure or workstation layouts (Senderska et al., 2017) . The disadvantage of spaghetti diagrams is that they are static and time-consuming to create. Furthermore, currently available vision-based approaches allow researchers to do object-tracking and real-time monitoring of items in the construction field. Tracking motions through the use of spaghetti diagrams, on the other hand, offers the construction sector new methods to envision data.

This research suggests two online activities as a more graphically intuitive method for increasing performance awareness in the construction industry because it is necessary to find simpler ways to communicate opportunities for waste reduction and productivity enhancement that align with those practicing within the construction.

2. LITERATURE REVIEW

2.1. Value Stream Mapping

Process mapping can serve as a highly effective method for simplifying workflow. Process mapping generally describes the actions taken to specify *what* a business entity performs, *who* is responsible, *to what standard* a process should be performed, and *how* the success of a business process may be measured. Once a process has been effectively mapped, there should be no room for skepticism. Value Stream Mapping (VSM) is a relatively new strategy that focuses on the value stream of procedures (de Bucourt et al., 2011).

VSM method was first developed to represent production systems in a factory and emerged from the Toyota Production System. VSM is a visual tool that examines the entire material and information flow from raw material delivery to product sales (or output), time spent, and the percentage of time spent adding value to a client. A corporation can evaluate consumer demand and perform value-added activities to match customer demand by analyzing its value stream (Rother & Shook, 1999).

The interactions between the activities of a process can be graphically organized with a VSM. It is vital to map out the existing state, demonstrating the flow of processes, input, and information, before initiating a Lean manufacturing process (Womack & Jones, 1996). The main advantage of value stream mapping is that it concentrates on the entire value stream in order to identify system wastes and attempts to avoid the trap of optimizing specific local circumstances at the price of the overall optimization of the entire value stream (Wilson, 2010). Figure 1 shows the example of a traditional value stream map.

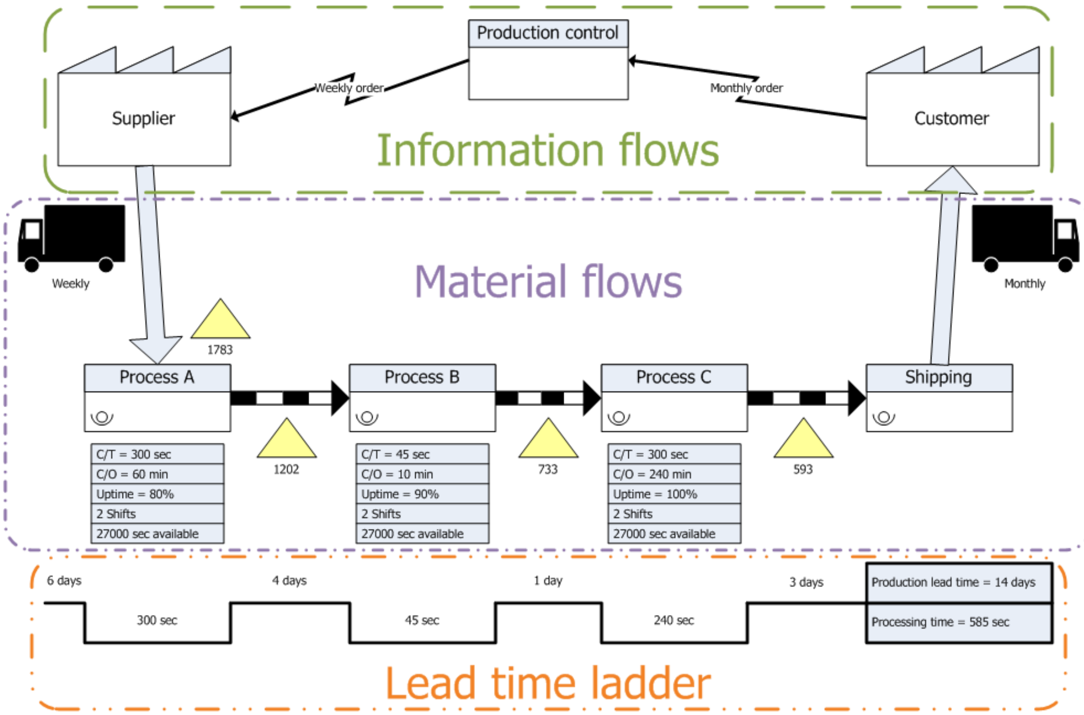


Figure 1. Diagram depicting the parts of a value stream map by Daniel Penfield (2013)

As stated by Lobaugh (2008), there are six steps in the value stream mapping procedure: 1) identify the process that needs to be improved; 2) build a current state map of the process; 3) choose an acceptable metric for improvement; 4) create a process future state map; 5) determine improvement techniques to move from the current state to the future state that meets the correct measure; and 6) implement changes.

VSM-ing is a concept that has been widely used in manufacturing, services, healthcare, and construction. The graphic has been used to identify the causes of environmental and production waste, quantify them, and suggest solutions to enhance efficiency. Despite its success in other industries, the use of VSMs in the construction industry remains limited (Gunduz & Naser, 2019).

Some research has focused on the use of VSMs to improve construction processes such as house construction (Yu et al., 2009), design processes (Lima et al., 2010; Torres et al., 2018), housing design (Leite & Neto, 2013), modular construction (Moghadam & Al-Hussein, 2013), environmental and production performance (Rosenbaum et al., 2014), and certificate of occupancy in real estate projects (Covarrubias et al., 2016; Kavosa & Lapiņa, 2020).

Other research studies have aimed to improve fundamental execution activities such as ceramic masonry (Pasqualini & Zawislak, 2005), sheet metal ductwork fabrication (da CL Alves et al., 2005), drywall and ceramic application (Bulhões & Picchi, 2011), concrete slab in residential buildings (Fontanini et al., 2013), structural masonry (Melo et al., 2017), concreting of columns (Germano et al., 2017), and blasting and coating (Kanai et al., 2021).

A few studies have investigated construction support processes such as supply chains (Arbulu & Tommelein, 2002; Fontanini & Picchi, 2004; Masood et al., 2017).

The studies summarized in Table 1 demonstrate that Value Stream Mapping aids in identifying bottlenecks in the construction process and reducing waste.

Table 1.Research studies on VSM in construction

Focus of Research	Examples	Researcher
Construction Process Improvement	House Construction	Yu et al. (2009)
	Design Processes	Lima & Rolim (2010); Torres et al. (2018)
	Housing Design	Leite & Barros Neto (2013)
	Modular Construction	Moghadam & Al-Hussein (2013)
	Environmental and Production Performance	Rosenbuam et al. (2014)
	Certificate of Occupancy in Real Estate Projects	Covarrubias et al. (2016); Lapina (2020)
Construction Execution Improvement	Ceramic Masonry	Pasqualini & Zawislak (2005)
	Sheet Metal Ductwork Fabrication	Alves et al. (2005)
	Drywall and Ceramic Application	Bulhoes & Picchi (2011)
	Concrete Slab	Fontanini et al. (2013)
	Structural Masonry	Melo et al. (2017)
	Columns Concreting	Germano et al. (2017)
	Blasting and Coating	Kanai et al. (2020)
Construction Support Improvement	Supply Chain	Arbulu & Tommelein (2002); Fontanini & Picchi (2004); Masood et al. (2017)

2.2. Experiential Learning and Serious Games

Experiential Learning often referred to as involved, evidential, or situational learning is a participatory, interactive, and practical style of learning (Hawtrey, 2007). It permits environmental interaction and exposure to highly varied and unpredictable processes (Gentry, 1990).

Experiential learning, in its more advanced forms, provides possibilities for "data learning" as opposed to assumption learning by requiring students to participate in the learning process actively and to engage in expression of their ideas, utilization of inductive reasoning, or collaboration within groups. In fact, when a student transitions from the role of a passive listener to become an active respondent, this process is known as experiential learning (Hawtrey, 2007).

Learning is seen as the outcome of real-world, intimate, reflective, lived experience. Real learning, in accordance with experiential learning, occurs when students put concepts into practice by having to figure them out in various contexts and go through the difficulties themselves. Making the student a stakeholder through experiential learning alone greatly enhances his or her capacity to learn (Hawtrey, 2007).

This research is focused on game-based learning, which supports experiential learning. The serious game movement is a reaction to the need to combine play and meaningful content with advanced abilities (Spires, 2008). Games in this category incorporate social themes or problems into the gameplay, giving players a fresh viewpoint through active participation (Johnson et al., 2012).

By allowing students to interact with and see representations of natural phenomena, simulations and games are uniquely positioned to support educators in implementing this new approach to science instruction (National Research Council, 2011). This will help students develop accurate scientific explanations for the phenomena they encounter. The ability for students to observe, explore, recreate, change variables, and get rapid feedback about knowledge and skills that would be too time-consuming, expensive, or dangerous to experience firsthand during regular school science classes is one of the significant benefits of serious games (Winn, 2002).

Because of the advancement of interactive, visual, and computational technology, games and simulations have grown more realistic and interactive (Gouveia et al., 2011). According to certain studies conducted by Cassidy (2003), Sacks et al. (2007), and Tommelein et al. (1999), computer simulations may be a more effective approach for teaching than traditional methods. However, each simulation should be tailored to the individuals involved (de Vin et al., 2018). In digital simulations, the participants' technological knowledge and device access must be taken into account. A user-friendly design with clear instructions (Gadre et al., 2011; Kuriger et al., 2010) and graphics to illustrate learning information (Kuriger et al., 2010) are crucial to enable easy access to the software, even if the technical expertise is limited. In response, this research developed a user-friendly and easy-to-play online game.

Most importantly, in order to learn how to improve after an experience, feedback is essential. Without feedback, a learner should not be permitted to draw conclusions about what they have learned (Gentry, 1990). Therefore, to provide feedback to a participant, this research incorporated a graphical spaghetti diagram and the numerical distance traveled as tools for sharing performance feedback with a participant.

2.3. Simulations and Games in Lean Education

Lean philosophy has given rise to principles and a set of tools to help identify and eliminate waste embedded within processes through the practice of continuous improvement. Elimination of *waste*, addition of *value*, *continuous improvement*, and a culture of *respect* are the four cornerstones of Lean philosophy (Rybkowski et al., 2018). Lean concepts primarily emerged from The Toyota Production System (TPS). Koskela (2000) is credited with being among the first to apply Lean principles to the construction industry.

Although many authors have stated that lean manufacturing is a technique for reducing waste, in reality, it maximizes the product’s value by reducing waste (Sundar et al., 2014).

The central notion in Lean is waste, which Toyota defines as "anything other than the absolute minimum quantity of materials, equipment, and labor required to add value to the product" (Alarcon, 1997, p. 1).

Taiichi Ohno listed the seven wastes: overproduction, time on hand, transportation, processing itself (e.g. overprocessing), stock on hand, movement, and defective goods. Ohno contends that getting rid of these wastes will lower production costs and boost profits (Ohno, 1988, p. 18).

Building operations can be optimized using Lean waste elimination principles and analysis of *value-adding* and *non-value-adding* activities. Simulation games can be a valuable tool to teach these principles and tap into the Lean philosophy's potential in the field of construction (Bhatnagar & Devkar, 2021).

While Lean concepts such as flow, value, waste, and value maximization are promising and have the potential to improve construction processes, a review of the literature indicates that the complexity of Lean philosophy and the lack of knowledge on Lean is considered a potential barrier to the adoption of its principles in the construction industry (Demirkesen et al., 2019).

Simulation games can provide hands-on learning, bridging the gap between theory and practice in Lean philosophy. Greg Howell and Glenn Ballard, two Lean pioneers, began experimenting with Lean Construction simulations in the 1980s. Outsiders have traditionally been taught Lean building practices through serious games and simulations (Tsao & Howell, 2015).

A simulation game aids teaching by simulating miniature, controlled experiments of real-world processes, which provide possibilities for participants to experience an "aha" moment. Lean simulations are used to demonstrate Lean concepts and obtain buy-in from individuals who will be putting Lean into practice (Rybkowski et al., 2020). Visual representations of processes and metrics allow these games to learn about the repercussions of decisions and strategies (Shannon et al., 2010).

Simulation games make it easier to understand Lean principles through hands-on experience in error-free, dynamic learning settings. Through the medium of realism, simulation games encourage physical activities for learning by doing, which translates knowledge into a skill (Galloway, 2004).

2.4. Spaghetti Diagrams

A spaghetti plot, also known as a spaghetti diagram, spaghetti chart, or spaghetti model, is a method used to visualize the movement of an object in a system using a line (Kanaganayagam et al., 2015).

Within the Lean manufacturing paradigm, spaghetti diagrams are commonly utilized as improvement tools (Gladysz et al., 2017). The spaghetti diagram is a straightforward but effective tool used for representing movement and travel (Wilson, 2010). The movement of a worker, material, or object can be traced and recorded. A production area or a workshop space typically serves as the environment in which a worker or object travels and its path is traced. Due to the likeness of the results to cooked spaghetti, the tool was given the name spaghetti diagram. A spaghetti diagram can be used to identify movement durations, several movements, overlapping and crossing motions, as well as their features, based on the classification chosen. Motion waste and ineffective activities are revealed using a spaghetti diagram, enabling the reduction of unnecessary labor, and modifications to organizational structure or workstation arrangements (Senderska et al., 2017).

These diagrams are a tried-and-true method for finding layouts that work better (Bicheno & Holweg, 2008). It is frequently simple to identify opportunities to decrease movement waste when the transportation routes are laid out. This makes it possible to analyze each movement, revealing areas where they might be improved. In the study by Tanco et al. (2013), worker motions were tracked and depicted using a spaghetti diagram to identify any extraneous movements that could be eliminated.

The method of measurement using a spaghetti diagram is relatively easy. Staff members are observed performing their duties, and the route they take is graphically drawn onto a floor plan. The floor layout does not need to be exact. It will do to draw a rough map of the area with roughly proportional distances. Once the initial diagrams are generated, the steps are counted. Answers to several questions are required: (1) What is the best course of action for a worker to follow in order to complete the task with the fewest number of steps? (2) Can the workplace layout be rearranged? (3) Who is going to modify the path? (4) When will it be finished?

After adjustments have been made, the measurement procedure is repeated, resulting in new spaghetti diagrams that reflect the traveled distance and task completion time (Lean Consulting Group, 2016).

The nature of spaghetti diagrams is statistical. They also do not accurately reflect reality since employees who are aware that they are being watched are less likely to behave normally. A potential remedy to this drawback is to create a dynamic spaghetti diagram that can be built continuously without the knowledge of employees whose work is being analyzed. Gladysz (2017) investigated a dynamic spaghetti diagram, which enables the assessment of lead times by spotting arriving and departing inventory.

The spaghetti diagram adds clarity to the intricacy of work processes, particularly when it comes to the distances traveled by production and logistical staff. Historically developed structures often result in suboptimal material staging arrangements, resulting in waste from unnecessary transportation and empty travel. Fast visualization of such circumstances, even with modest technologies, is frequently a trigger for progress.

The majority of spaghetti diagrams are hand-drawn. To create a diagram, a worker's motions are tracked chronologically by drawing lines on a two-dimensional plan until the entire work cycle or takt time under study is completed. Producing spaghetti diagrams with the aid of software such as visTABLE® is thus logical (Weber, 2022). However, this kind of software cannot yet generate a real-time spaghetti diagram. Few studies have been conducted to develop a real-time, on-site spaghetti diagram. Therefore, this research aims to create a dynamic post-action spaghetti diagram incorporated into an online game to see whether or not it can effectively improve performance.

2.5. Situational Awareness

Situational Awareness (SA) is defined as "the perception of the elements in the environment within a volume of time and space, the interpretation of their meaning, and the projection of their status in the immediate future" (Ensley, 1995, p. 36). Continuously gathering environmental data, combining it with prior knowledge to create a coherent mental image, and using that image to predict future events are all parts of SA (Livnat et al., 2005).

The term SA is derived from the realm of military pilots (Endsley et al., 2003), and it is crucial for decision-making and performance across a wide range of industries, including air traffic control, driving, operating power plants, maintaining equipment, and military operations (Livnat et al., 2005).

The phrase can be used to refer to all workers on construction projects, although it was initially used to describe those who put a strong emphasis on safety management (Gheisari et al., 2010). It may be possible for both the project managers and the workers to make better, more proactive decisions on control actions by raising SA during the production phase. Enhancing communication and boosting the transparency of the procedures on construction sites are important techniques for raising SA.

Many researchers have investigated and used the SA model in the construction industry in recent years. The focus of such studies are improvements in workplace safety, the use of machines and equipment, applications of building information modeling (BIM) in SA (Li et al., 2018; Lonsdale, 2004; Niu et al., 2016; Oloufa et al., 2003), location-based planning and control (Dror et al., 2019; Görsch et al., 2020; Reinbold et al., 2019), and construction logistics management (Ghanem et al., 2018; Seppänen & Peltokorpi, 2016; Tetik et al., 2021).

Furthermore, an expanding number of research studies support the use of visualization as a tool for problem solving and SA enhancement. Visualization improves information comprehension by encouraging immediate linkage and perceived associations. In order to achieve this, information must be presented in a way that makes it easier for a user to process it and reduce the amount of mental adjustments needed (Livnat et al., 2005).

In the studies focused on raising energy awareness, for example, the visibility of energy consumption plays a crucial role. According to a survey by Hassan et al. (2009), increased visibility of energy use appears to motivate users to reduce energy consumption. Furthermore, a study conducted by Jachimowicz et al. (2018) declared that sharing energy use data with users resulted in energy savings varying between 0.81% and 2.55%.

Showing this kind of data to the users appears to increase their awareness and alter the direction of their actions to make appropriate changes. When unbiased measurements make them more aware of their actions, users appear to better grasp what they are doing that jeopardizes a goal and what they need to change to reach it. Firstly, increased data visibility helps catch the user's attention. Attention is correlated to the prefrontal cortex, commonly referred to as "the inner CEO," in terms of brain anatomy. This area of the brain is connected to controlling and allocating attention. The capacity to focus, connect, learn, and make judgments are all linked with prefrontal brain development. Once attention is strengthened through developing concentration, it can be used as a tool for other tasks, such as bringing concepts into awareness (Hunter & Scherer, 2009).

The use of visual management (VM) technologies has grown, and successful implementation instances have been recorded (Tezel, 2011). VM is a component of the Toyota Production System (TPS)and is frequently linked to lean construction (Koskela, 1992). Applications for visual management are designed to make information more easily accessible so that process participants can take appropriate actions at the right time (Koskela, 2001; Liker et al., 1995). Better situational awareness of construction resources on-site based on visualization in BIM can improve the identification and elimination of waste and the identification of workflow interruptions, potentially permitting better planning and increasing productivity. Analysis of the frequency and intensity of workers' and materials' movements can allow a better understanding of the causes of waste and non-value-adding activities. Improved situational awareness can offer to workers a real-time "snapshot" of an ongoing project when it comes to resource location and availability, real value-added time spent in production processes and adherence to planning and production (Reinbold et al., 2019).

Similarly, real-time detection and processing of events can help supervisors and project managers (and other stakeholders where applicable) improve decision-making and eventually save time and money (Ghimire et al., 2017).

2.6. Vision-tracking in Construction

In this research, integration of real-time object tracking with a post-action spaghetti diagram aims to provide visualization of movements and therefore enhanced participant awareness. An assumption of this research is that sharing elapsed time and distance of participants' movements will help them become mindful of their actions, increase their self-awareness, and help them identify opportunities to improve their performance.

2.6.1. Object Tracking in Construction

Advanced technologies have been invented and used to acquire data on construction sites in recent years. Laser-based methods, tag-based methods, and image-based methods are the three basic categories of these technologies. Image-based approaches have been shown in studies to be able to perform object recognition, tracking, and reconstruction in a nonintrusive and fast manner—especially since the image-based method captures spatial information in a relatively short amount of time. Object tracking is a popular computer vision technique that can be used on construction sites. Visual object tracking is the process of generating a visual path of an object's movement over time by determining its position in each frame of a movie (Wang et al., 2021).

Construction entities such as machinery, employees, and materials can be tracked to determine staff productivity, detect fall hazards, and track project progress. Sensor technologies such as radio frequency identification (RFID) and global positioning system (GPS) are often utilized for tracking. Sensor system deployment, management, and maintenance on large-scale building sites, on the other hand, can be costly and time-consuming (Brilakis et al., 2011). On the other hand, cameras have become common-place on building sites. Cameras offer the advantage of being less expensive and easier to deploy than sensors (such as RFID, GPS, and drones). Computer vision approaches for tracking building entities have emerged as a possible alternative to sensor technology. One of the core difficulties faced by the construction automation sector is tracking several construction machines using vision-based technologies, and there have been numerous investigations on this subject (Yang et al., 2015).

The two most common vision-based tracking approaches are *motion model* and *appearance model*. According to Bochinski et al. (2017), motion model tracking focuses on predicting an object's position in the current frame by modeling its motions in previous frames, which simply requires the pixel coordinates of objects. While motion tracking is capable of tracking at a reasonable pace, its robustness and precision are limited. The overlap between the tracked object areas and the item's ground truth areas is referred to as precision, while robustness refers to the ability to track objects in a variety of building contexts (Wu et al., 2015).

As suggested by Hare et al. (2015), in occasions where there are many objects or vast object regions, appearance model tracking uses both pixel location information and pixel features to track objects with high precision and robustness (Xiao & Kang, 2021).

In the construction industry, researchers have developed vision-based tracking algorithms that can deal with high-resolution images, frequent occlusions, and unique characteristics (e.g., vests to track workers). Based on both a filtering model and an appearance model, Konstantinou et al. (2019) proposed a vision-based tracking system for employees in a complex environment.

Modern object tracking technologies can be used on virtually any camera's real-time video streams. By sending the individual frames to a tracking algorithm, the video feed of a USB camera or an IP camera can be used to conduct object tracking. With real-time video inputs from one or more cameras, frame skipping, or parallelized processing, are standard ways to improve object tracking speed. Tracking algorithms are designed to not only execute accurate detections and localizations of objects of interest, but also to do so in the shortest time possible. For real-time object tracking models, increasing tracking speed is critical. The technique used to construct the object tracking model must either be tailored or carefully chosen to manage the time it takes for it to perform. The R-CNN approaches Fast R-CNN and Faster R-CNN can be used to speed up the most frequent R-CNN approach. Because CNNs (Convolutional Neural Networks) are often employed for object detection, CNN tweaks can make the difference between a quicker and slower object tracking model. Aside from the detection framework, design choices have an impact on the balance of speed and accuracy in an object detection model (Meel, n.d.).

A real application of an earlier version of the online game ultimately developed for this research as shown in Figure 2, was made possible by adaptation of object tracking using R-CNN approach and Spatial Augmented Reality.

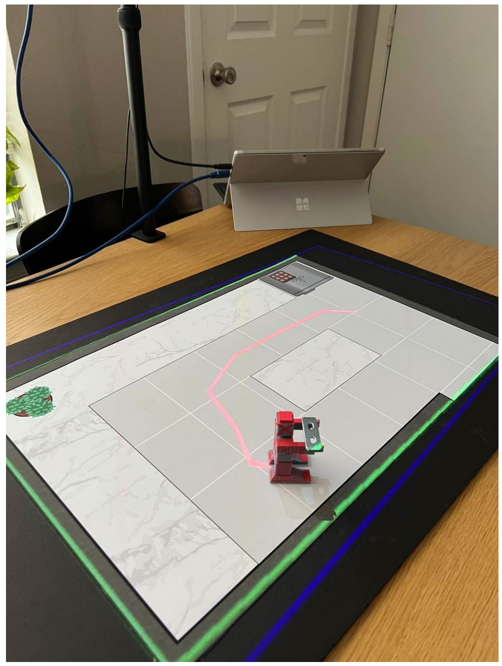


Figure 2. Illustration of physical object tracking and spatial augmented reality

3. PROBLEM STATEMENT

By displaying a real-time spaghetti diagram, this project sought to construct a simulation game to teach the notions of waste, value-adding / non-value-adding activities, and motion reduction. Creating an accurate spaghetti diagram requires time and practice. Moreover, most diagrams are static and do not depict transportation dynamics (Gladysz et al., 2017). In response to this need, a real-time locating system was incorporated into an online game developed for this research.

The following were the procedures and objectives of this research study:

a. Develop a simulation game and create a video to teach the notion of waste reduction and performance measurement.

b. Develop and incorporate a real-time spaghetti diagram into an online game which can measure distance.

c. Collect feedback to determine whether or not the video of the simulation game helps participants identify waste, and whether or not the spaghetti diagram generated by the online game can help participants identify opportunities for enhanced productivity.

The research questions were as follows:

1. Is the developed simulation an efficient tool for teaching the concept of waste reduction?
2. Can students and construction professionals enhance their performance (reduce motion) with the use of the visual spaghetti diagram incorporated in the developed online game?

4. RESEARCH METHODOLOGY[1]

This study reports on the developing and testing of a Lean simulation online game that challenges participants to see their impact of decisions in a shape of spaghetti diagram as a basis for value stream mapping for waste reduction and continuous improvement (kaizen). The simulation was inspired by the video "Toast Kaizen: An Introduction to Continuous Improvement & Lean principles" by GBMP to introduce the simulation participants a basic understanding of VSM and waste reduction. As an exercise, the presenter in the above-named video asks the audience to turn off the video and to try to identify ways the process can be streamlined. He then discusses how these practices relate to Ohno's seven wastes, namely: Motion, Waiting, Transportation, Storage, Defects, Processing, and Overproduction (GBMP, n.d.). The study shows how—in order to continuously improve—participants can efficiently and effectively map out current and future conditions by identifying wastes observed on a jobsite.

This study consisted of two parts: (I) developing and testing a three-part simulation video to help participants identify waste incurred during the process of making spaghetti (i.e., an activity recognizable by most players), and (II) developing and testing an online simulation to determine if the path participants took, made visible with a spaghetti diagram, enhanced participant awareness of ways to improve their performance.

[1] Part of the data reported in this chapter is reprinted with permission from "Developing & Testing a Value Stream Map Simulation: Helping the Construction Industry Learn to See" by Authors' Yasaman Arefazar & Zofia K.Rybkowski. 30th Annual Conference of the International Group for Lean Construction (IGLC), Edmonton, Canada, pp 342-353. Copyright 2022 by Name of Farook Hamzeh and Thais da C. L. Alves.

For Part I, Adobe® Illustrator was used, the animation was put together in Microsoft® PowerPoint and Adobe® After Effects. For Part II, the software Unity® was used to provide a real-time platform.

The research method used for this study is a design research methodology that involves iterative development and testing. This research was approved by the Texas A&M Institutional Review Board (IRB2022-0507).

4.1. Part I: Waste identification

Part I of this research was presented in a video that lasts 7 minutes and 30 seconds and depicts a man cooking pasta for his girlfriend in two attempts.

The cook completes the process in 4 minutes and 12 seconds during his first attempt. Intentionally embedded into the video are a significant number of wasteful practices, additional motions, unnecessary handling of materials, an inefficient ordering of tasks, etc. In Scenario One, the seven wastes were portrayed. Additionally, the spaghetti in Scenario One was inappropriate for his girlfriend who turned out to be allergic to chili; the cook had neglected to ask about her dietary restrictions, so the final outcome was deemed a defect and discarded.

By eliminating superfluous actions and completing several activities simultaneously to decrease waiting times, the cook was able to make spaghetti in 2 minutes, 32 seconds during Scenario Two. To boil water faster, two factors were altered in Scenario Two: the stove was replaced, and an electric kettle was used to boil the water. The difference in the layout is shown in Figures 3 & 4.

In the end, the cook's girlfriend was pleased because he had sought her opinion on the spaghetti before beginning the preparation. This time the result was satisfactory, and the procedure was free from defects.

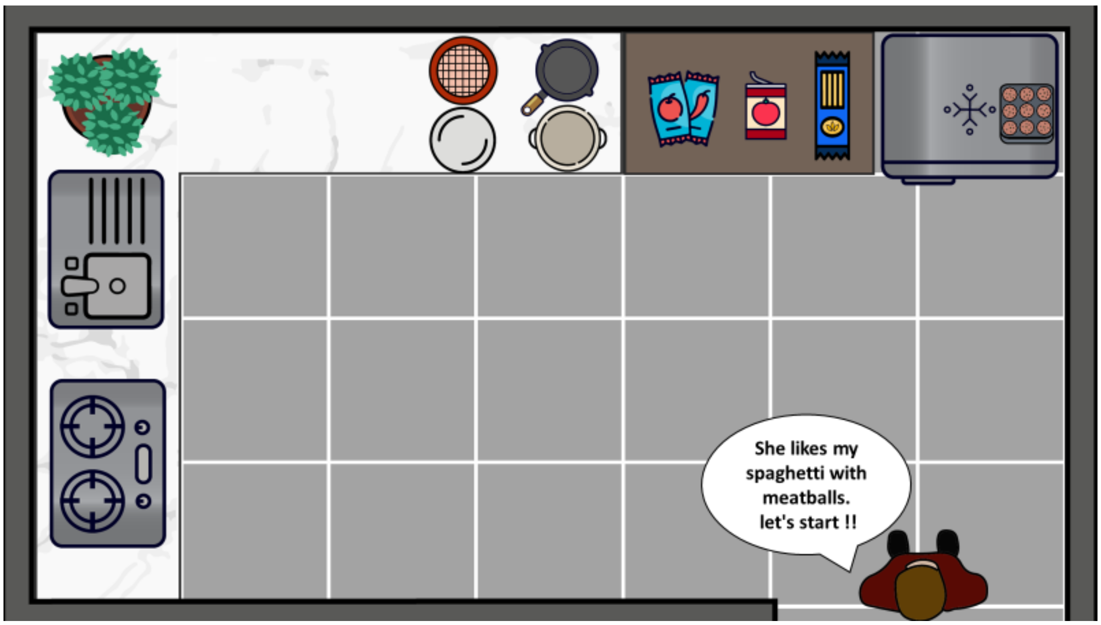


Figure 3. Scenario one of the Spaghetti Kitchen simulation
Reprinted from Arefazar & Rybkowski (2022)

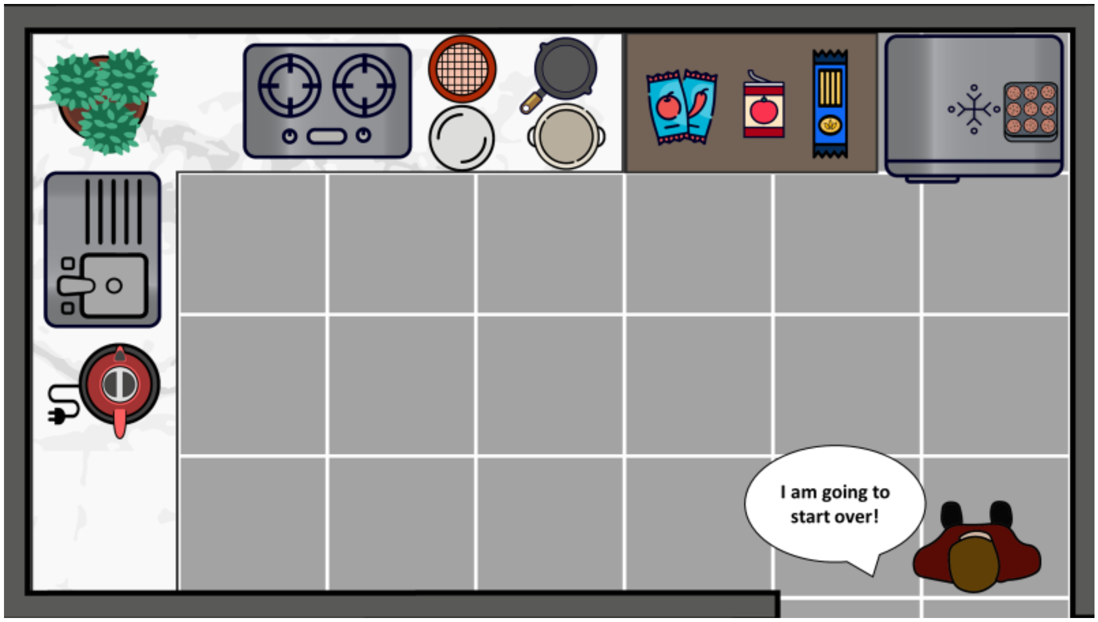


Figure 4. Scenario two of the Spaghetti Kitchen simulation
Reprinted from Arefazar & Rybkowski (2022)

4.2. Facilitating The Simulation

The simulation was shown to 48 graduate students enrolled in COSC 631 (Advanced productivity and Lean) in the Department of Construction Science at Texas A&M university.

After playing Scenario One, the video was stopped to encourage discussion among students about what could be done to improve the cook's performance. Following discussion, the facilitator resumed the video and Scenario Two was shared. After watching Scenario Two, the students were invited to offer suggestions about how they would depict a third scenario if they were asked to provide a layout for another round. The authors of this paper presented opportunities to visually capture the processes in the form of a traditional value stream map, a timeline, Gantt chart, and spaghetti diagram to map both scenarios (Figures 5, 6, 7, and 8). Cartoon characters in the figures were added to visually communicate that the diner's conditions of satisfaction were fulfilled in Scenario Two, but not in Scenario One (e.g. in Scenario One, the diner was allergic to chili; the cook unfortunately discovered this only *after* cooking the meal, which turned the entire process into waste.)

Ultimately, the students were asked to individually offer feedback on what they liked about the exercise (i.e., "plus") and what they thought could be improved (i.e., "delta"). The plus/delta responses were collected anonymously to encourage frank feedback (Arefazar & Rybkowski, 2022). For two additional first run studies, the simulation was run during a Zoom meeting with nine experts from the San Diego Community of Practice, and then later, with 14 Zoom participants during an APLSO (Administering and Playing Lean Simulations On-Line) meeting, administered by the Department of Construction Science at Texas A&M. Participants were asked to respond to an online Google™ form survey which asked about their education, current profession, and past training with value stream maps (VSMs). Participants used a variety of visual aids to capture process flows and identify types of waste. It was observed that those previously familiar with VSMs and spaghetti diagrams tended to use these tools. Those mostly with construction experience alone tended to generate Gantt Charts.

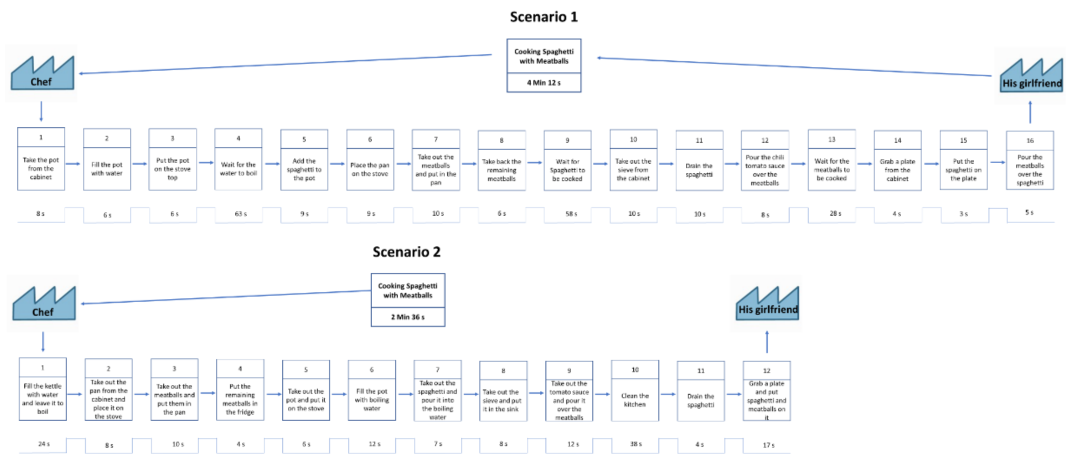


Figure 5. Conventional VSM for spaghetti making process
Reprinted from Arefazar & Rybkowski (2022)

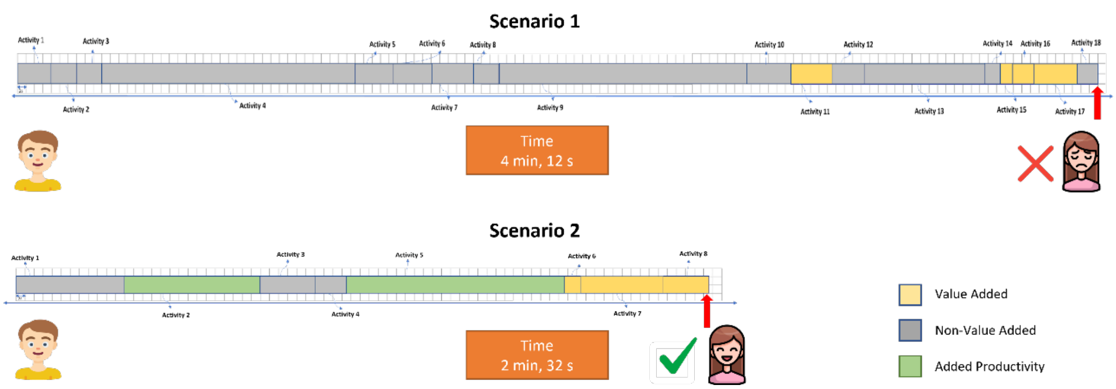


Figure 6. Comparison of two scenarios using timeline
Reprinted from Arefazar & Rybkowski (2022)

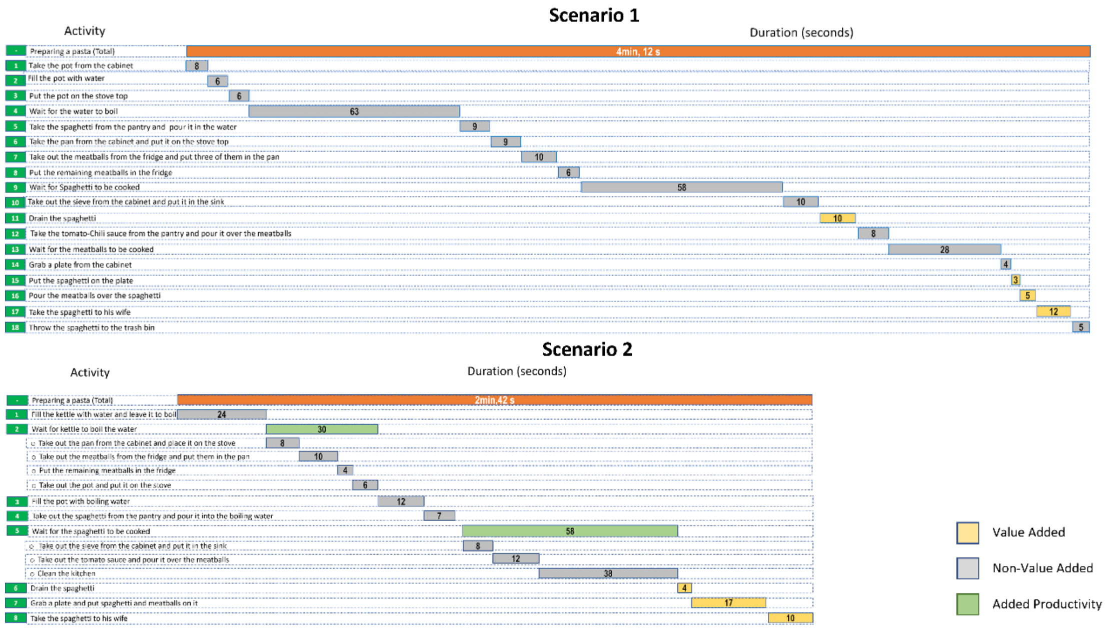


Figure 7. Comparison of the scenarios using Gantt chart
Reprinted from Arefazar & Rybkowski (2022)

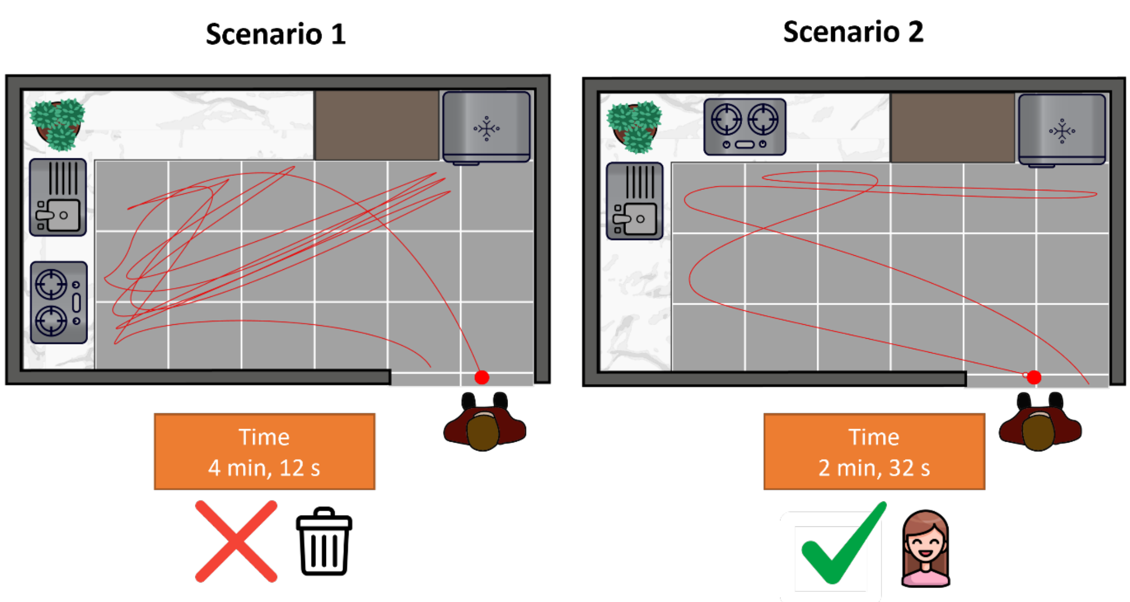


Figure 8. Spaghetti diagrams for two scenarios
Reprinted from Arefazar & Rybkowski (2022)

4.3. Part II: Heightening productivity awareness

For Part II, the cross-platform game engine Unity® 3D by Unity Technologies was used in this research to develop a game to determine if a spaghetti diagram could heighten player awareness of ways to improve worker productivity. A majority of platforms, including personal computers (PCs), consoles, mobile devices, and the internet, may be used to create video games with Unity.

The game was designed in such a way that it could be played using a laptop. The game was designed in 3D view and the view that appears in the game is the plan view. The game depicts a kitchen layout that includes the kitchen appliances, utensils, and ingredients needed to make a full plate of spaghetti with meatballs. An avatar cook starts walking whenever the player clicks on a desired destination. When the cook is close to an object, the object will automatically become highlighted, which signals that the cook can grab the object. By pressing and holding the "F" key on the keyboard, the player is able to lift and carry the selected object. By releasing the "F" key, the object will be deposited at its desired place. There are some rules that have been defined in the game which leaves the player to figure out the correct order of completing each activity. One of the important features of this game is that it is able to track, record, and measure the total distance the cook has walked and display it to the right of the kitchen's layout after each scenario is completed. The ordering of the activities is not important in this game. The goal is to deliver the cooked dish (spaghetti with meatballs) using the shortest distance possible. Two versions of the simulations were made available to players: In the *control* version (Figure 9; orange background), the player does not have access to a spaghetti diagram of the cook's movements. In the *experimental* version (Figure 10; green background), the player can see a complete history of the cook's movements via a spaghetti diagram which appears on the screen at the end. The rules of the simulation are depicted in Figures 11 through 17.

Figure 9. Spaghetti Kitchen online game (*control* version)

Figure 10. Spaghetti Kitchen online game (*experimental* version)

The rules of the game are as follows:

- The pot needs to be filled with water before the cook can place it on the stovetop.

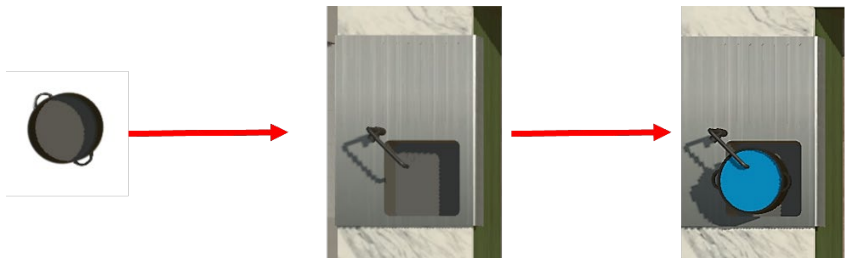


Figure 11. Rule 1 of the Spaghetti Kitchen online game

- The water in the pot should be boiling before the cook can toss in the spaghetti.

Figure 12. Rule 2 of the Spaghetti Kitchen online game

- The pan needs to be placed on the stove before the cook places meatballs in it.

Figure 13. Rule 3 of the Spaghetti Kitchen online game

- The meatballs should be grilled before the cook can pour tomato sauce over them.

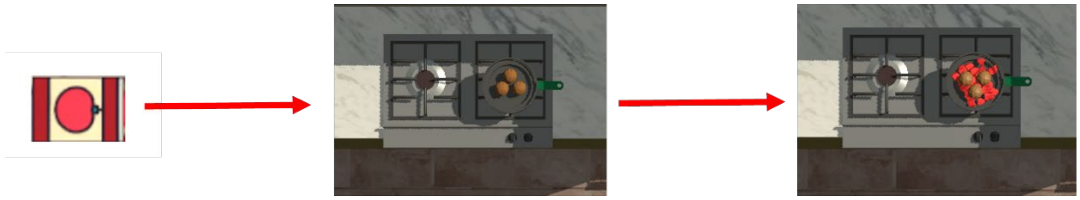


Figure 14. Rule 4 of the Spaghetti Kitchen online game

- The sieve needs to be near the sink before the cook can drain the cooked spaghetti.

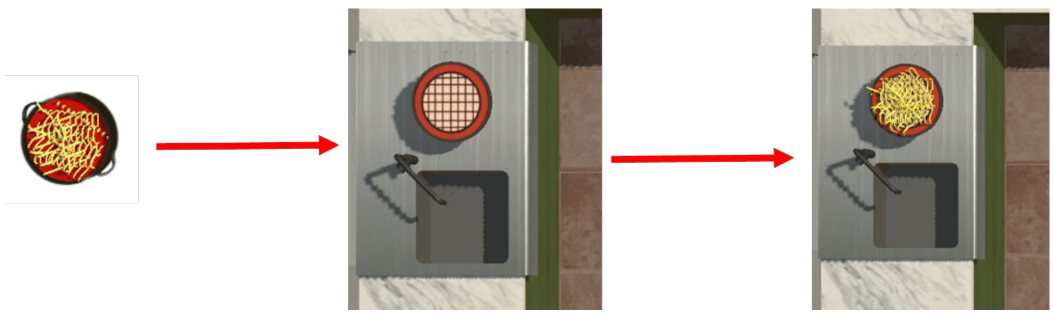


Figure 15. Rule 5 of the Spaghetti Kitchen online game

- The spaghetti should be drained before the cook can pour it over the meatballs and tomato sauce.

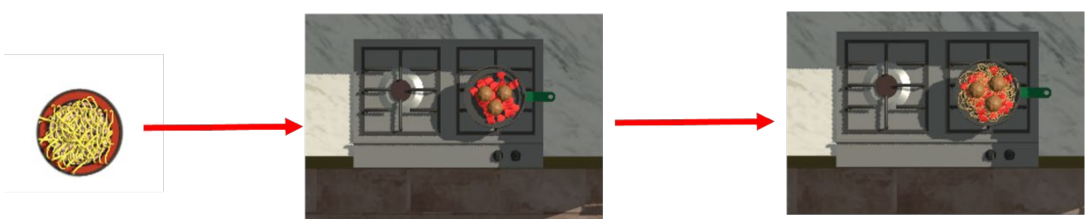


Figure 16. Rule 6 of the Spaghetti Kitchen Online Game

- The plate needs to be placed on the table before the cook can place the prepared food onto the plate.

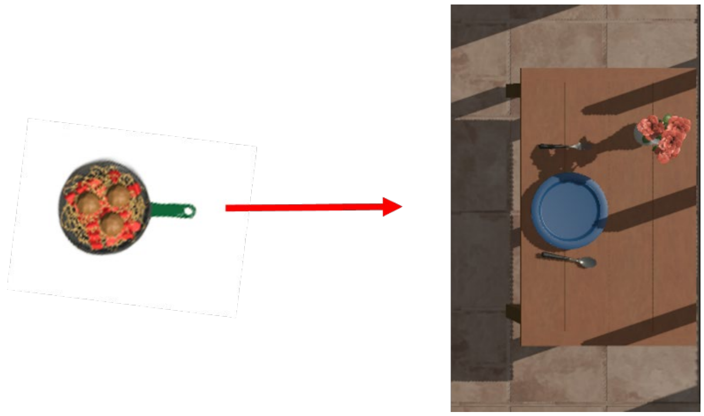


Figure 17. Rule 7 of the Spaghetti Kitchen online game

4.4. Facilitating The Online Game

The online game was facilitated during the fall of 2022 in COSC 663: *Sustainable Construction*, a graduate-level course of the Department of Construction Science at Texas A&M University (Figure 18). Prior to the day of the experiment, permission was attained from the course instructor and an email was sent to the 37 students enrolled in the course. Consent forms approved by the TAMU Institutional Review Board were sent to students via email.

Figure 18. Facilitating the online game

The students were asked to bring their laptops and their mice to class during the day of the experiment. The students were divided into two groups (Groups A & B). Group A students were selected as the control group, and Group B students were selected as the experimental group. Students were given access to the simulation game of both groups via links in an email; however, they were asked to connect to only to the group link to which they were assigned.

The first ten minutes of the session were allocated to explaining the rules and instructions for playing the game. A tutorial was incorporated into the game. The students were asked to play the tutorial several times if needed to become familiar with the game environment (Figure 19). Once they completed the tutorial, they were instructed to click on "I am done with the tutorial" and start the game.

Figure 19. Spaghetti Kitchen tutorial
(accessible to both control and experimental groups)

In the first round, the students played the game in a layout given to them by the researcher. After they played the first round, they could view metrics of their performance which included the elapsed time, travel distance, and a spaghetti diagram (if in group B; the experimental group). Group B was asked about how the spaghetti diagram might help improve their performance—if at all—during upcoming rounds (Figure 20).

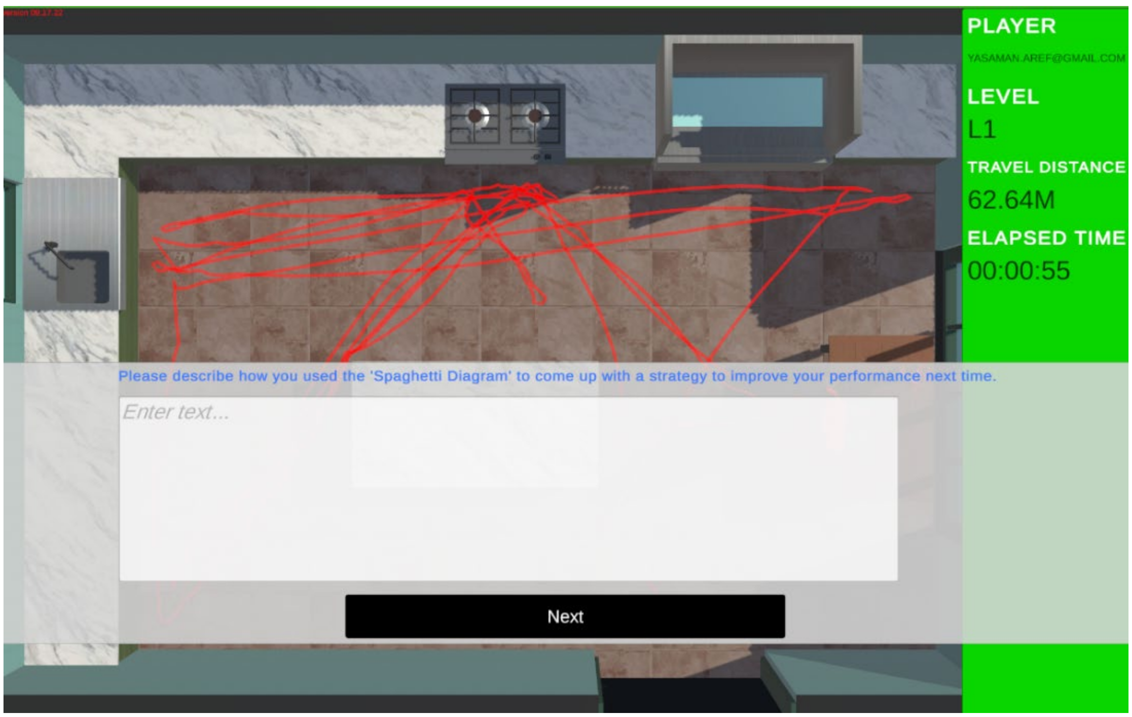


Figure 20. Question asked from experimental group after the first round

Group A (control group) was asked about their strategy to improve their performance in subsequent rounds. The final screen shown to those in the control group after playing each round is captured in Figure 21.

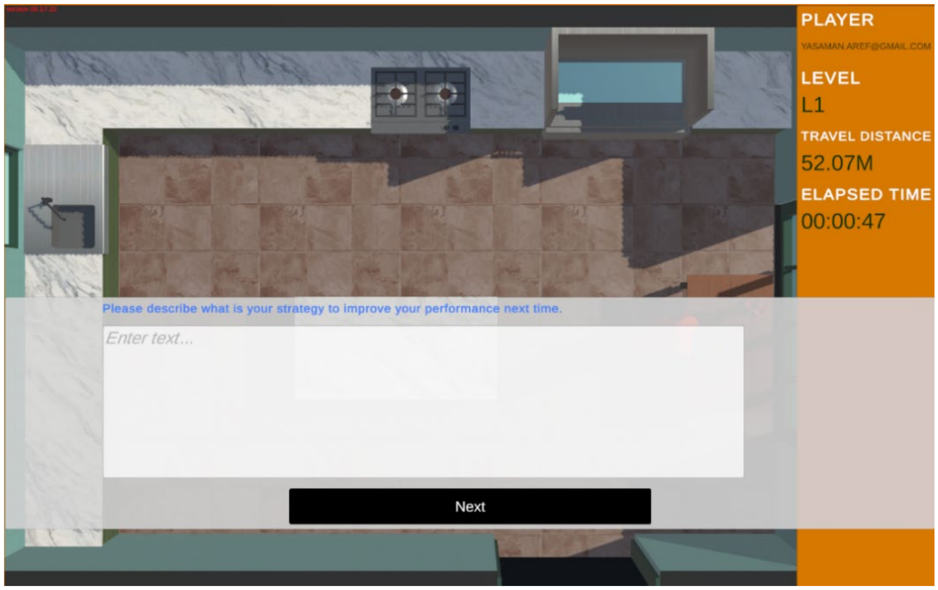


Figure 21. Question asked of those in the control group after the first round

After the first round, the participants were offered three options, as shown in Figure 22, to relocate a stovetop on the countertop.

Figure 22. Different stovetop layout options given to participants
(shown to both control and experimental groups)

The participants chose their preferred option and started to play rounds 2, 3, and 4 with the same questions being asked after they finished each round. At the end of round 4, they were asked to list items in a "plus" box (What did they like about the game?) and "delta" box (What could be done to improve the game?). The screen that appears for Plus/Delta is shown in Figure 23.

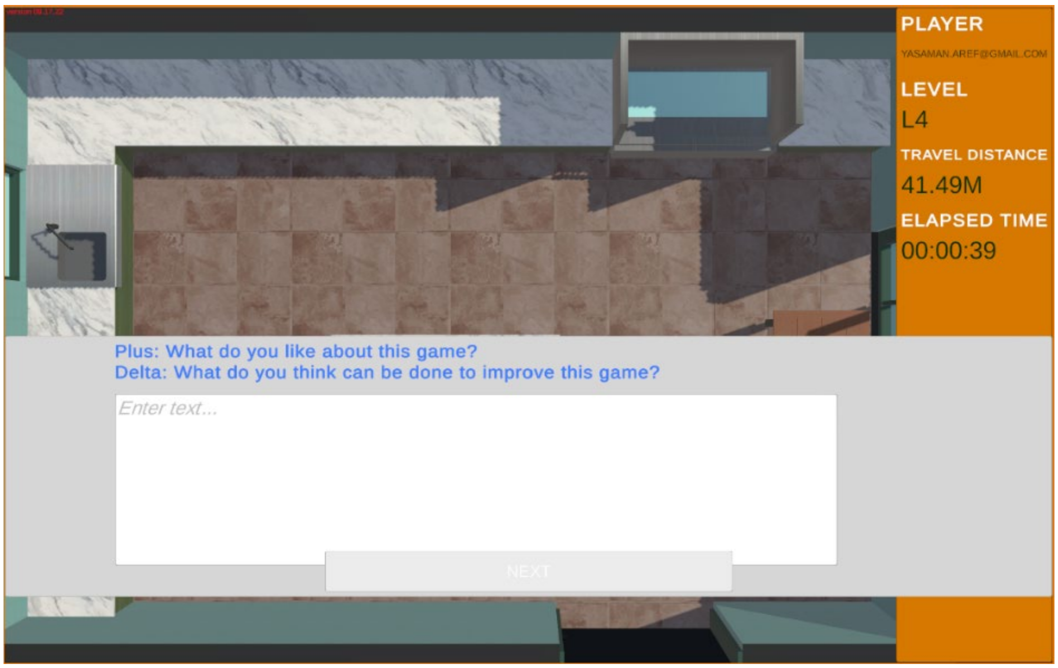
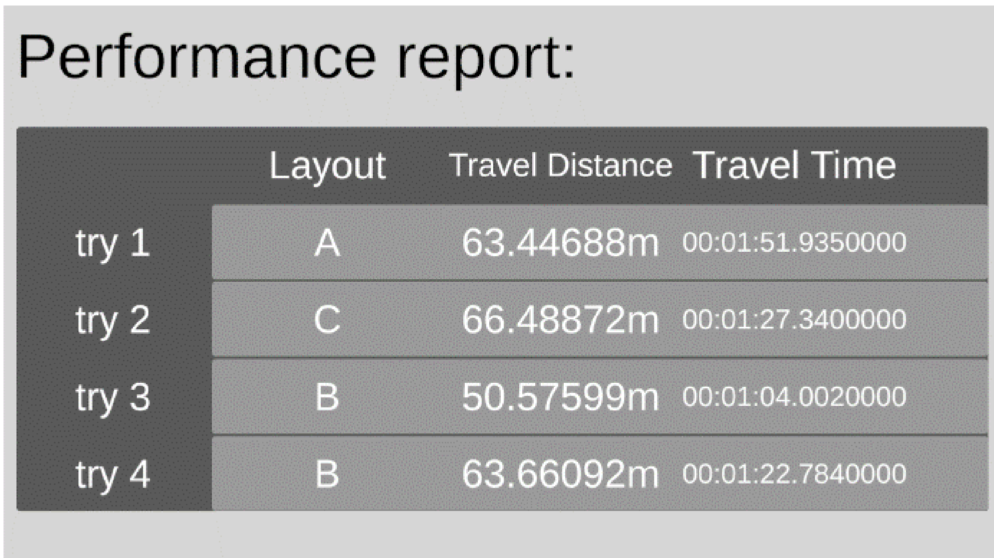


Figure 23. Plus / Delta asked from participants at the end of the game
(shown to both control and experimental groups)

After Plus/ Delta, a performance report appeared on the screen, sharing with participants their performance regarding time and travel distance of each round. An example of a performance report is illustrated in Figure 24. The data of each player was automatically compiled in Google forms for data analysis.

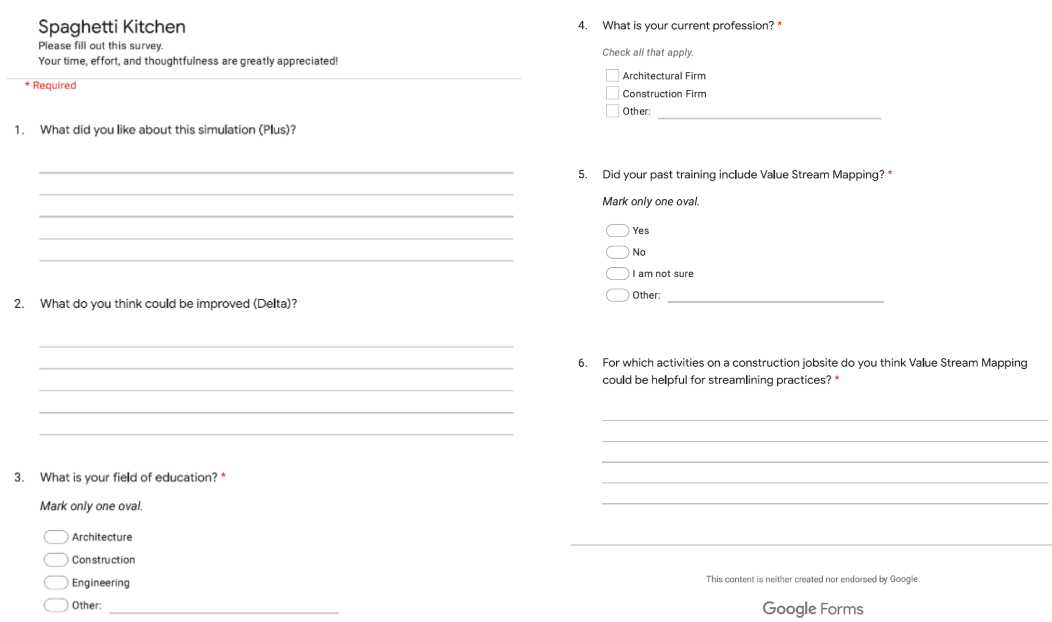

Performance report:

	Layout	Travel Distance	Travel Time
try 1	A	63.44688m	00:01:51.9350000
try 2	C	66.48872m	00:01:27.3400000
try 3	B	50.57599m	00:01:04.0020000
try 4	B	63.66092m	00:01:22.7840000

Figure 24. Performance report shown to participants after four rounds of the game
(shown to both control and experimental groups)

5. DATA COLLECTION

To answer Question 1—“Is the developed simulation an efficient tool for teaching the concept of waste reduction?”— the video from Phase I was tested as a pilot study on: (i) 48 graduate students taking Lean “Advanced Productivity and Lean” course at Texas A&M University (ii) 14 students and construction experts who voluntarily participate in the APLSO (“Administrating and Playing Lean Simulations online”) meeting which is held over the internet via Zoom® on first Monday of each month and (iii) 9 experts from the San Diego Community of Practice, also over the internet via Zoom. Participants were asked to provide feedback on the video in a form of a survey provided in Figure 25. Modifications were made based on participant feedback. Both tests took place during the spring of 2022.


Spaghetti Kitchen
Please fill out this survey.
Your time, effort, and thoughtfulness are greatly appreciated!

* Required

1. What did you like about this simulation (Plus)?

2. What do you think could be improved (Delta)?

3. What is your field of education? *

Mark only one oval.

- Architecture
- Construction
- Engineering
- Other:

4. What is your current profession? *

Check all that apply.

- Architectural Firm
- Construction Firm
- Other:

5. Did your past training include Value Stream Mapping? *

Mark only one oval.

- Yes
- No
- I am not sure
- Other:

6. For which activities on a construction jobsite do you think Value Stream Mapping could be helpful for streamlining practices? *

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Google Forms

Figure 25. A pilot study survey generated by Google™ Forms

To answer Question 2— "Can students and construction professionals enhance their performance (reduce motion) with the use of the visual spaghetti diagram incorporated in the developed online game?"— The modified simulation was turned into an online game capable of tracking and recording the movements of the cook in the kitchen and measure the traveled distance.

This research engaged two participant groups: a control group and an experimental group. The control group played the game without being provided with a spaghetti diagram, while the experimental group was provided with a spaghetti diagram shown to them after each round. The experimental group participants' movements were tracked, and a spaghetti diagram was generated on the screen. During the first found, the kitchen layout was pre-set by the program and the layout was identical for each participant; however, during the second round, participants were able to change the layout of the kitchen only by relocating a stove (to one of three locations) during upcoming rounds.

After each round, the experimental group participants were asked about how they used the spaghetti diagram to identify a strategy to improve their performance.

After completing the game, both groups were asked to provide plus/delta feedback. Their feedback was used to improve the game and fix any deficiencies.

The *null hypothesis* (H0) and *alternative hypothesis* (H1) of this research were as follows:

- **H0:** There is no significant difference in improved performance between the control group and the experimental group. Spaghetti diagram do not help the participants improve their performance.

- **H1:** There is a significant difference in improved performance between the control group and the test group. Spaghetti diagram do help the participants improve their performance.

Each participant's performance was measured in the two study groups and results were compared. The researchers wanted to see whether the spaghetti diagram was effective in helping the participants improve their motion reduction performance. The researcher collected data from 30 participants from the experimental group, and 30 participants from the control group. A unpaired t-test was selected to statistically test the alternative hypothesis.

6. DATA ANALYSIS[2]

6.1. Analysis the Data Collected from the Pilot Study (Part I)

For the pilot study, the feedback (plus and delta), the participant's educational background, current position, and familiarity with VSM were collected and analyzed using quantitative and qualitative methods. The participant's information is summarized in Table 2. All the 48 graduate students (Section 1, Table 2) are the ones without prior familiarity with the concept of VSM.

Regarding those who had prior experience with Lean (Section2, Table 2), a group of 23 Lean specialists were shown the simulation through Zoom, and they were asked to complete a Google® form survey after the session.

Table 2. Pilot Study Participants and Dates

1	Students without familiarity to VSM	48 master's students taking Lean "Advanced Productivity and Lean" course at Texas A&M University	01/27/2022
2	Lean experts familiar to VSM	9 Lean Experts from San Diego community of Practice	02/23/2022
		14 Lean Experts from APLSO	03/07/2022

[2] Part of the data reported in this chapter is reprinted with permission from "Developing & Testing a Value Stream Map Simulation: Helping the Construction Industry Learn to See" by Authors' Yasaman Arefazar & Zofia K.Rybkowski. 30th Annual Conference of the International Group for Lean Construction (IGLC), Edmonton, Canada, pp 342-353. Copyright 2022 by Name of Farook Hamzeh and Thais da C. L. Alves.

According to the results of the survey, 54.2% of the participants had a construction background, 20.8% had an engineering background, 8.3% had an operations management background, 8.3% had an architecture background, and 8.3% have a technology and project delivery background.

A quarter of the participants (25%) worked in construction firms, 23.3% worked as consultants, 8.4% worked in architectural and engineering firms, and the balance are academics and students from academia. A high percentage of the participants (75%) said that they had previously received VSM training which would have likely heightened their awareness of inefficiencies and waste (Figure 26, 27 & 28).

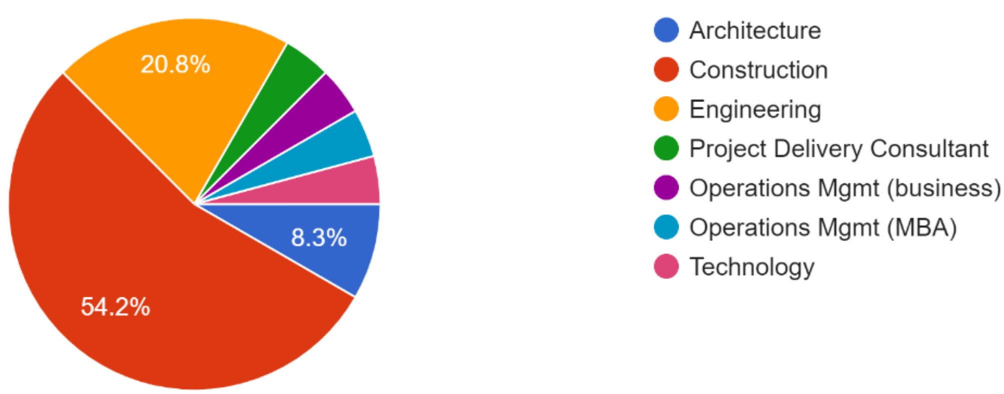

Figure 26. Participant's field of education

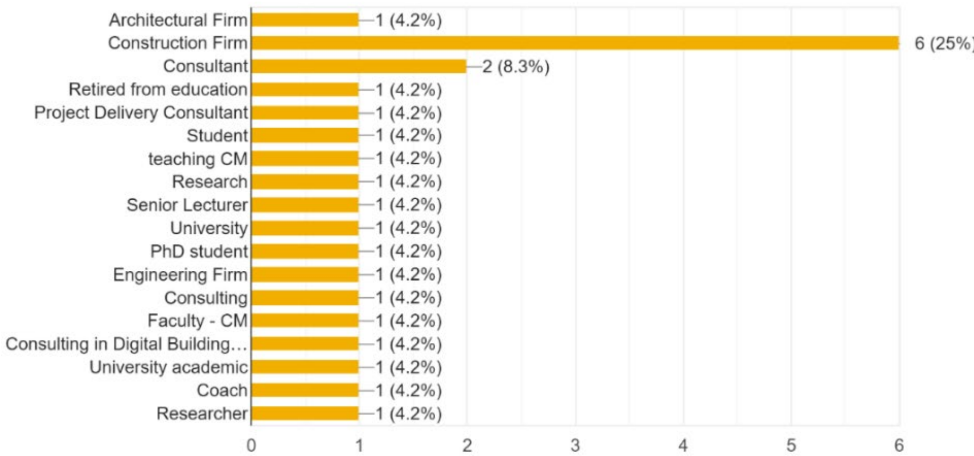

Figure 27. Participant's current occupation

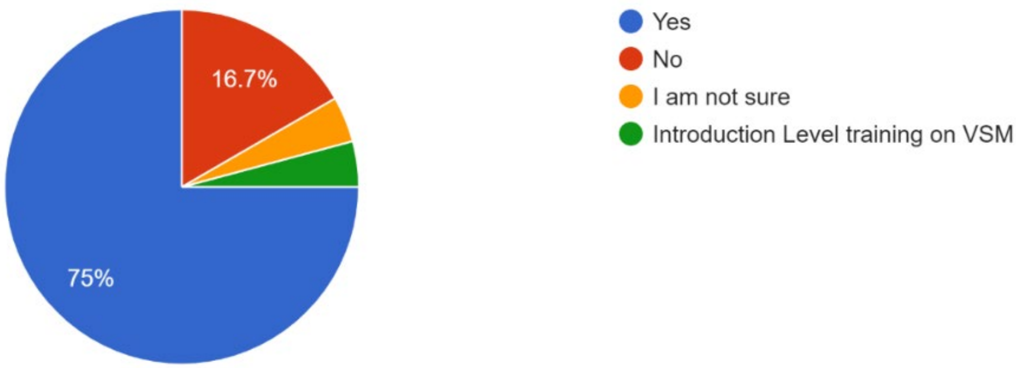

Figure 28. Participant's past VSM training

In addition, the first run study, which included 48 graduate students, the students discussed whether they would be persuaded by the chosen tool or graphic if they were the manager of a construction company and an analyst presented the visual to them to improve their decision-making. The students mostly agreed that they could not immediately understand the data presented in the flow charts of conventional VSMs since they require a substantial understanding or prior training in VSM symbols. Students also stated that they preferred the proposed VSM formats (Figure 6, 7, & 8) over the conventional form of VSMs (Figure 5). This is likely because constructors have more experience with Gantt charts.

Ultimately, they were asked about what they liked about the given exercise (plus) and what they thought could be improved (delta). Table 3 shows the collected feedback from the students.

Table 3. Plus/Delta from students

Plus
Simple & easy to understand
Good graphical representation
Helps in critical thinking and raising a broader perspective
Helps in coming up with new and creative ideas
Attention to details
Helps in deep understanding and identifying of value-added & non-value-added activities
Lucid and effective way to show continuous improvement
Shows the application of Leaning in real life
To the point video (Short video while delivering the concept)
Helps to brainstorm ideas
Helps to identify different ways for performance measurement
It was engaging and encourages student involvement in the class
Clearly depicts the importance of knowing the customer’s need
Establishes an ideology for the Lean concept
It was an interesting way to teach the concept of VSM
Helps to represent ideas graphically and in an effective and quantifiable manner
Helps to think out of the box
Explains how a simple task can be efficiently done in the other way
Straightforward exercise, understandable by multiple parties
Explains the basics of Lean using a simple example
It is a fun and innovative exercise for learning VSM
Encourages to learn more about how to better qualify, quantify specific metrics
Delta
Commercial setting instead of a private setting
Create a third animation with the ideal scenario with all the lesson learned
Rearrange the kitchen (Putting an island in the middle) for the optimized scenario
Use construction-oriented example instead of making spaghetti
Calculate distance in both scenarios

The plus/delta feedback collected from the Lean experts following play is shown in Table 4.

Table 4. Plus/Delta from Lean experts

Plus
Hands on, great for classroom application
Fun visuals. Quick and easy to complete
The graphical presentation
The wastes were obvious (waiting, motion, etc.)
The time spent was appropriate. It was short but enough to understand the concept of VSM
The visualization, especially the animations, was easy to follow
A good way for illustrating wastes in the class
Simple, understandable, and attractive video
A very powerful to folks who are not familiar with Lean tools & principles
Animation was simple and quite pleasing to watch
Nice animation, difference between first two scenario is clear, easy to identify Muda
It is very practical to see in a single video the changes that occur in the process
It represents a relatable and simple example
Delta
A more construction-oriented example may be advantageous
An introduction to VSM prior to the simulation could have helped set the stage for what the simulation is about
The actions were too fast for to record
A little labeling to identify the items, like the hot plate, to clarify
Try to use OR algorithms to find optimized solutions
Integrate metrics (time, number of trips, travel distance…) into each round so can show measurable improvement

The simulation game is intended to transfer understanding about a critical concept to people who are new to identification of waste and VSM. Based on initial feedback, the developed simulation appears to be an effective tool to help participants recognize, diagram, and eliminate waste, which is a foundational concept of Lean. Preliminary tests also demonstrated that Value Stream Mapping could help streamline practices in concrete construction activities, material delivery to the job site, logistics, area-based scheduling, manufacturing, process document management in the trailer, jobsite information management, and any other repetitive tasks in construction.

6.2. Analysis the Data Collected from the Online Game (Part II)

The information related to the online game participants is depicted in Table 5. Students played the online game during the in-person sessions. The facilitator explained the rules and instructions and was available for the duration of the class to help participants with any questions they might have. The participants were divided randomly into two groups (i.e., control and experimental) by the researcher. For the APLSO test session, participants were invited into two separate breakout rooms (i.e., also control and experimental) using Zoom. The facilitator explained the rules and instructions and divided them into two study groups using the breakout room option in Zoom. Links to the game were sent to them, and they were asked to play.

Table 5. Online Game Participants and Dates

1	Students	37 graduate students taking COSC 663 (Sustainable Construction) course at Texas A&M University.	09/22/2022
		15 masters and PhD students from the Department of Construction Science at Texas A&M University	9/28/2022
2	Lean experts	8 Lean Experts from APLSO	10/03/2022

Data collected from group A (control group) is illustrated in Table 6. This group played a version of the online game in which the spaghetti diagram was not given to them. They were only able to see their travel distance after each round.

Table 6. Data collected from control group

Type	No.	1-Layout	1-TD	2-Layout	2-TD	3-Layout	3-TD	4-Layout	4-TD
NoSD	Player 1	A	59.00	B	55.84	A	61.22	C	47.76
NoSD	Player 2	A	77.52	C	52.91	C	46.73	B	51.69
NoSD	Player 3	A	75.86	C	42.25	B	66.20	A	53.39
NoSD	Player 4	A	72.85	C	67.82	A	68.99	C	49.77
NoSD	Player 5	A	71.01	C	53.39	A	68.84	B	53.15
NoSD	Player 6	A	69.31	A	53.76	C	52.03	B	61.84
NoSD	Player 7	A	68.31	C	65.88	A	67.26	C	61.84
NoSD	Player 8	A	67.70	C	51.09	B	51.86	C	42.98
NoSD	Player 9	A	67.30	B	54.42	C	56.15	A	55.94
NoSD	Player 10	A	67.09	C	52.58	B	57.01	A	51.83
NoSD	Player 11	A	63.56	C	56.57	C	54.56	A	66.93
NoSD	Player 12	A	63.45	C	66.49	B	50.58	B	63.66
NoSD	Player 13	A	63.31	B	52.26	A	61.07	B	56.65
NoSD	Player 14	A	62.81	C	54.71	A	61.13	B	61.83
NoSD	Player 15	A	62.74	C	49.35	B	52.16	C	47.14
NoSD	Player 16	A	61.70	C	56.41	C	48.22	C	48.88
NoSD	Player 17	A	60.12	C	43.24	B	53.52	A	54.88
NoSD	Player 18	A	59.57	C	49.61	C	48.79	B	54.09
NoSD	Player 19	A	59.27	B	68.90	C	56.07	C	75.56
NoSD	Player 20	A	58.62	A	46.18	B	73.28	C	54.07
NoSD	Player 21	A	57.61	A	52.12	B	54.01	C	57.90
NoSD	Player 22	A	57.18	C	52.55	B	47.99	B	55.41
NoSD	Player 23	A	57.10	C	60.45	B	51.53	B	62.93
NoSD	Player 24	A	57.09	C	47.65	C	47.81	A	57.52
NoSD	Player 25	A	56.89	C	53.43	B	53.53	A	79.73
NoSD	Player 26	A	56.59	C	61.93	B	57.80	A	55.47
NoSD	Player 27	A	52.27	B	55.16	C	51.53	A	51.82
NoSD	Player 28	A	52.09	C	44.19	B	46.00	A	43.21
NoSD	Player 29	A	49.49	B	48.76	B	54.56	A	55.39
NoSD	Player 30	A	49.00	C	65.41	B	54.40	A	66.36
Mean		**-**	**61.88**	**-**	**54.51**	**-**	**55.83**	**-**	**56.65**
SD		-	7.24	-	7.18	-	7.22	-	8.34

The researcher compared the participant's performances for only rounds 1 and 4. The difference of the average distances between rounds 1 and 4 shows improved performance. The mean of the enhanced performance for the control group was calculated (-5.23), as shown in Table 7. The negative value implies that the distance was shortened (i.e., improved) in the later round.

Table 7. Traveled distance difference in rounds 1& 4 (control group)

No.	1-Layout	1-TD	4-Layout	4-TD	Performance Improvement (TD4-TD1)
Player 1	A	59.00	C	47.76	-11.24
Player 2	A	77.52	B	51.69	-25.83
Player 3	A	75.86	A	53.39	-22.46
Player 4	A	72.85	C	49.77	-23.08
Player 5	A	71.01	B	53.15	-17.86
Player 6	A	69.31	B	61.84	-7.47
Player 7	A	68.31	C	61.84	-6.47
Player 8	A	67.70	C	42.98	-24.72
Player 9	A	67.30	A	55.94	-11.36
Player 10	A	67.09	A	51.83	-15.26
Player 11	A	63.56	A	66.93	3.37
Player 12	A	63.45	B	63.66	0.21
Player 13	A	63.31	B	56.65	-6.66
Player 14	A	62.81	B	61.83	-0.98
Player 15	A	62.74	C	47.14	-15.60
Player 16	A	61.70	C	48.88	-12.82
Player 17	A	60.12	A	54.88	-5.24
Player 18	A	59.57	B	54.09	-5.47
Player 19	A	59.27	C	75.56	16.29
Player 20	A	58.62	C	54.07	-4.54
Player 21	A	57.61	C	57.90	0.29
Player 22	A	57.18	B	55.41	-1.77
Player 23	A	57.10	B	62.93	5.83
Player 24	A	57.09	A	57.52	0.43
Player 25	A	56.89	A	79.73	22.84
Player 26	A	56.59	A	55.47	-1.12
Player 27	A	52.27	A	51.82	-0.45
Player 28	A	52.09	A	43.21	-8.88
Player 29	A	49.49	A	55.39	5.90
Player 30	A	49.00	A	66.36	17.36
		Mean			**-5.23**

Data collected from group B (experimental group) is summarized in Table 8. This group played a version of the online game in which the spaghetti diagram was depicted at the end of play. The travel distance and selected layout for each round was collected.

Table 8. Data collected from the experimental group

Type	No.	1-Layout	1-TD	2-Layout	2-TD	3-Layout	3-TD	4-Layout	4-TD
SD	Player 1	A	125.90	C	54.13	B	73.99	C	49.13
SD	Player 2	A	95.41	C	82.34	A	65.66	B	59.43
SD	Player 3	A	89.68	C	53.24	B	65.14	C	53.88
SD	Player 4	A	76.41	C	78.47	C	67.62	C	55.30
SD	Player 5	A	71.95	B	57.18	B	59.88	C	49.52
SD	Player 6	A	70.22	C	64.83	B	51.29	C	59.70
SD	Player 7	A	68.71	B	58.94	C	45.79	A	62.67
SD	Player 8	A	67.66	C	57.47	B	57.60	A	66.16
SD	Player 9	A	67.41	C	56.50	B	54.68	A	56.32
SD	Player 10	A	66.00	B	61.05	C	65.44	C	62.99
SD	Player 11	A	62.66	A	59.70	B	57.29	C	60.22
SD	Player 12	A	61.11	B	51.60	C	55.39	C	44.24
SD	Player 13	A	60.19	B	49.09	C	45.76	C	41.12
SD	Player 14	A	60.16	C	51.07	B	69.27	C	60.15
SD	Player 15	A	59.59	C	48.05	B	63.08	C	52.81
SD	Player 16	A	59.26	C	62.68	B	50.75	B	56.64
SD	Player 17	A	59.05	B	52.52	C	43.42	C	51.65
SD	Player 18	A	58.76	C	44.99	C	45.73	C	55.80
SD	Player 19	A	58.62	C	56.55	B	54.18	A	59.93
SD	Player 20	A	57.69	C	54.67	A	61.77	B	52.17
SD	Player 21	A	56.88	C	47.74	B	48.62	A	58.48
SD	Player 22	A	56.65	A	56.20	B	55.00	C	49.89
SD	Player 23	A	56.49	C	78.43	B	71.87	C	53.21
SD	Player 24	A	56.33	A	55.34	B	45.23	C	47.00
SD	Player 25	A	56.25	C	57.65	C	52.92	C	61.07
SD	Player 26	A	55.09	C	49.23	B	50.66	C	52.28
SD	Player 27	A	54.68	C	54.95	C	47.28	B	50.72
SD	Player 28	A	53.98	C	51.17	C	53.06	C	47.86
SD	Player 29	A	51.08	C	50.10	B	48.16	C	42.66
SD	Player 30	A	50.43	C	38.99	C	36.06	C	45.46
Mean		**-**	**64.81**	**-**	**56.50**	**-**	**55.42**	**-**	**53.95**
SD		-	15.38	-	9.53	-	9.33	-	6.43

According to Table 9, the difference of the average distances between rounds 1 and 4 shows improved performance.

The mean of the enhanced performance for the experimental group was -10.86. The negative mean suggests the cook's path in round 4 versus round 1 was shorted by 10.86 units, which is greater than that found for the control group.

Table 9. Traveled distance difference in rounds 1& 4 (experimental group)

No.	1-Layout	1-TD	4-Layout	4-TD	Performance Improvement (TD4-TD1)
Player 1	A	125.90	C	49.13	-76.77
Player 2	A	95.41	B	59.43	-35.98
Player 3	A	89.68	C	53.88	-35.80
Player 4	A	76.41	C	55.30	-21.12
Player 5	A	71.95	C	49.52	-22.43
Player 6	A	70.22	C	59.70	-10.51
Player 7	A	68.71	A	62.67	-6.04
Player 8	A	67.66	A	66.16	-1.50
Player 9	A	67.41	A	56.32	-11.09
Player 10	A	66.00	C	62.99	-3.01
Player 11	A	62.66	C	60.22	-2.44
Player 12	A	61.11	C	44.24	-16.87
Player 13	A	60.19	C	41.12	-19.07
Player 14	A	60.16	C	60.15	-0.01
Player 15	A	59.59	C	52.81	-6.78
Player 16	A	59.26	B	56.64	-2.61
Player 17	A	59.05	C	51.65	-7.40
Player 18	A	58.76	C	55.80	-2.96
Player 19	A	58.62	A	59.93	1.30
Player 20	A	57.69	B	52.17	-5.52
Player 21	A	56.88	A	58.48	1.60
Player 22	A	56.65	C	49.89	-6.76
Player 23	A	56.49	C	53.21	-3.28
Player 24	A	56.33	C	47.00	-9.33
Player 25	A	56.25	C	61.07	4.82
Player 26	A	55.09	C	52.28	-2.81
Player 27	A	54.68	B	50.72	-3.97
Player 28	A	53.98	C	47.86	-6.12
Player 29	A	51.08	C	42.66	-8.42
Player 30	A	50.43	C	45.46	-4.97
		Mean			**-10.86**

Comparing the averages of the improved performances between the two groups states that the participants who played the version with a spaghetti diagram had a better performance overall. The review of the results can be found in Table 10. In addition, the results of the paired t-test results are as follows:

- The two-tailed P value equals 0.1261. By conventional criteria, this difference is considered *not* to be statistically significant. Therefore, the null hypothesis cannot be rejected.
- The mean of Group One minus Group Two equals 5.6363.
- 95% confidence interval of this difference: From -1.6331 to 12.9058
- Intermediate values used in calculations:

t = 1.5520

df = 58

Standard error of difference = 3.632

Table 10. Data Review

Group	Group A (Control Group)	Group B (Experimental Group)
N	30	30
Mean	-5.2253	-10.8617
Standard Deviation	12.0122	15.8546
Standard Error of the Mean	2.1931	2.8946

In addition, data analysis showed that those in the experimental group were more successful in identifying an optimized layout for the kitchen since 70% of the experimental group participants chose layout C, while only 30% of the control group participants chose

C. The spaghetti diagram appears to have helped them understand that layout C (placing the sink and stovetop closer together) would reduce wasted motion.

The data collected showed that layout C was the only layout where participants could minimize their travel movements (Figures 29 & 30). Furthermore, the best performance among participants belonged to a participant from the experimental group.

To validate the above statement, a Chi-Square test was used. The chi-square statistic is 9.6 and p-value is 0.001946. The result is significant at $p < 0.01$. This means that there was a significant difference between the experimental group and the control group for choosing layout C as shown in Table 11.

Table 11. Observed layout C chosen by the participants

Type	Layout C	Other Layouts	Row total
Experimental Group	21	9	30
Control Group	9	21	30
Totals	30	30	60

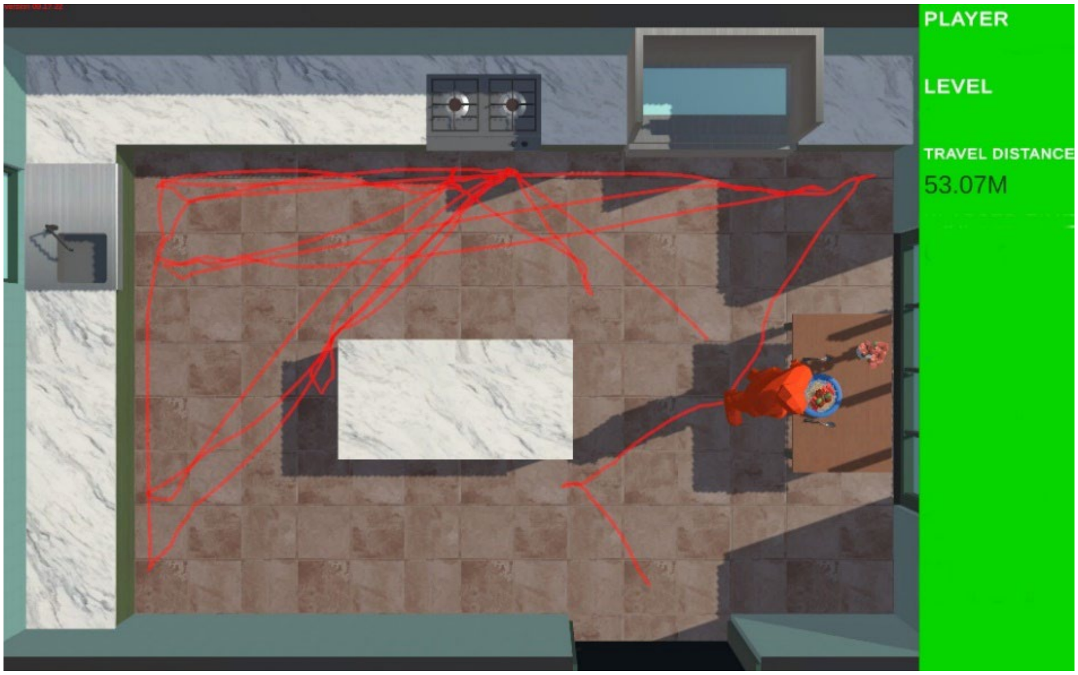

Figure 29. Example of Spaghetti Diagram in Layout A

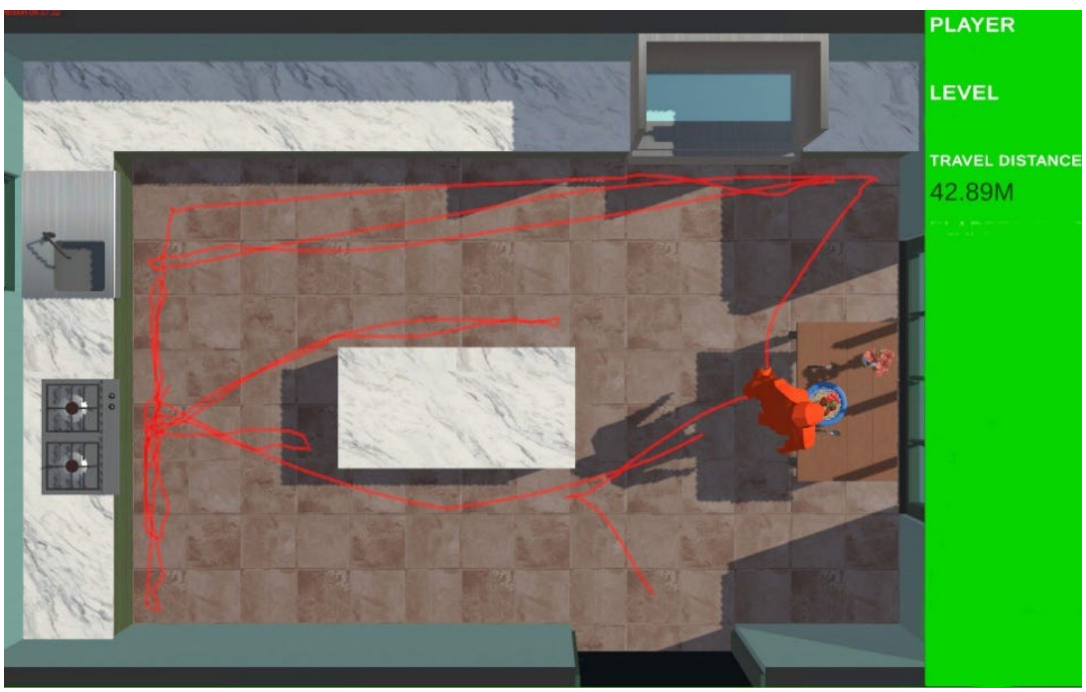

Figure 30. Example of Spaghetti Diagram in Layout C

The experimental group participants were asked how they used their spaghetti diagram to identify a strategy to improve their performance. According to participant responses, the spaghetti diagram helped them to:

- focus on long travel distances;
- visualize their movement through the diagram's trace;
- realize that utensils, stove, and sink should be close to each other to reduce unnecessary time and space;
- find an optimized layout by placing the stove close to the sink.
- grab items in a logical order in terms of distance travelled.
- realize that they should always carry something when moving between locations.
- understand their displacement and movements (i.e., the geometry of the spaghetti diagram and the repetitive lines showed where is needed to focus more and change the layout);
- design a better path;
- figure out wasteful movement, as well as time;
- decide the best position for the stove;
- figure out wasteful movement and workflow; and
- remove inefficient pathways and create new scenarios.

Finally, the results of plus/delta of the online game are summarized in Table 12 and 13.

Table 12. Experimental group' Plus/Delta for the online game

Plus
Interactive and fun game
Creative Game
User Friendly
Very innovative
The graphic is nice and engaging
Game is simple to understand and hence easy to contribute
liked the interface of the game. The movement of avatar looks great.
The spaghetti diagram was useful
The spaghetti diagram was intuitive
Delta
show the procedure of cooking so that some time could be saved not trying to figure out
Design a game in a construction context
Change the rules to provide more creativity in deciding work order

Table 13. Control group' Plus/Delta for the online game

Plus
The game really helps with understanding how planning of activities can help with saving time and how the work can be done more effectively
User Friendly
Fun to play
Helps to better understand importance of time management and proactive planning
Very innovative
Easy to understand and simple
Great case for simulation / first run studies
Delta
Display distance traveled during the game session instead of afterward
Add more options to place the stove
Include the option of relocating the ingredients
The location of the stove was not intuitive
It required a few rounds to get used to the controls
Include the movement's trace in the game

7. DISCUSSION

7.1. Contribution

Value Stream Mapping is a tool used to capture a current state process, identify waste, and suggest an improved future state process. The ultimate intended value of this work is to help users improve workflows.

A user can adapt and integrate the designed application into a more comprehensive system of methods and tools for Lean construction and assembly for process mapping. By capturing images or videos of the ongoing processes in the field, movement by a worker or equipment can be tracked, recorded, and projected onto the ground as a spaghetti diagram. This will help to capture current process time and travel distance, as well as facilitate analysis of possibilities for improvement.

Results of this pilot study suggest that the designed video and on-line simulation are relatively easy to understand, and offer graphically interesting tools that can be used for teaching the foundations of Lean to those who are new to VSM, waste recognition, and productivity analysis. Furthermore, according to the participant feedback, the developed video and online game are innovative, fun and easy to play. The latter tool is also interactive.

The video and simulation game can be used as a training tool to teach participants how to identify waste and heighten self-awareness of opportunities for productivity improvement. Because they are automated and internet-accessible, both the video and online simulation game offer the possibility of expanded geographic reach that exceeds what physical, in-seat simulations can do. This can offer a substantial benefit to multinational companies seeking to train personnel in different parts of the globe simultaneously.

7.2. Limitations

Value Stream Mapping traditionally requires studying the inputs of an entire system. One limitation of this simulation game is that the exercise is designed to only depict processes and wastes graphically in one part of the VSM. Additionally, the designed online game cannot be played until the rules and instructions are explained to players. This game needs a facilitator to teach the players how to move and interact with the objects. The application of the designed concept in the actual construction scenario using object tracking and Spatial Augmented Reality is intended to be applicable to a small-scale construction site layout and for tracking one object (worker or equipment).

8. CONCLUSION

This research reports on the development and testing of a video (Part I) and novel simulation and online game (Part II). The intent has been to expose participants to the utility of Value Stream Mapping (VSM) as a mean to identify and remove wastes from construction processes. As part of the simulation, a graphic video was created to depict the process of a familiar activity—i.e. making spaghetti. As a first run study, the video simulation was tested on (i) 48 graduate students taking an advanced productivity and lean course in the Department of Construction Science at Texas A&M University; (ii) 9 experts from San Diego Community of Practice; and (iii) 14 participants at a meeting of the Administering and Playing Lean Simulations Online (APLSO) community.

Results from Part I showed that most participants liked the graphics of the video and found it easy to understand. Additionally, there seemed to be a consensus that the designed exercise encourages participants to generate innovative ways represent process flows to those in the construction industry. There also appeared to be general agreement among experts that the presented simulation is an excellent tool for teaching the fundamentals of lean and introducing the concept of VSM to individuals previously unfamiliar with the concept.

The authors of this paper observed that by sharing the simulation video and by implementing a Gantt chart to represent current and target conditions, students and practitioners trained in construction felt comfortable applying VSM to construction processes. While the conventional VSM format is perhaps well suited for many engineering and manufacturing applications—especially for those with prior VSM training—results from this research suggest there are additional and alternative ways to map construction processes that may be more aligned with the conventions of those trained in the construction industry.

In Part II, the researcher developed an online game called “Spaghetti Kitchen” to be easily accessible to the participants and encourage experiential learning and help them improve their performance awareness. The online game was tested on (i) 37 graduate students taking a sustainable construction course in the Department of Construction Science at Texas A&M University; (ii) 15 graduate students from the department of construction science at Texas A&M University; and (iii) 8 participants at a meeting of the Administering and Playing Lean Simulations Online (APLSO) community.

Two study groups played the online game. A control group played the version of the game that did not include a post-play spaghetti diagram. The experimental group could view the spaghetti diagram depicting their movements after each round of play. Among the participants, 30 were randomly selected to take part in the experimental group and 30 to take part in the control group.

Feedback from testing the developed online game showed that the game was interactive and enjoyable to play. Results suggest the online game increased participant awareness and facilitated participant ability to identify and reduce waste. In addition, the results showed that the post-action spaghetti diagram incorporated into the game helped players identify an improved stovetop location that reduces their travel distance in the kitchen.

This research suggests that additional and alternative ways to map construction processes, such as spaghetti diagrams, may be more aligned with the visual aptitudes of those trained in the construction industry and therefore helpful for increasing awareness of waste reduction and improved performance.

8.1. Opportunities for Future Work

Findings from this study point to opportunities for future research. These include investigations into applications of this simulation to actual construction scenarios. Movements of a worker or equipment can be tracked, recorded, and projected onto the ground in the shape of a spaghetti diagram so travel paths can be visually observed by the worker. Future experimentation using real-life scenarios will be able to confirm whether or not a visual spaghetti diagram is an effective tool for enhancing worker self-awareness and productivity.

Additionally, the online simulation game can be adapted to depict construction activities on an actual project, with locations for material delivery to the job site, logistics, and laydown areas, etc. In addition, the game can be designed and tested in 3D (perspectival) instead of a 2D view (plan view) to determine whether or not a 3D view is more intuitive and effective for those practicing in the construction industry.

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APPENDIX A

GOOGLE FORM SURVEY FOR THE PILOT STUDY

Spaghetti Kitchen

Please fill out this survey.
Your time, effort, and thoughtfulness are greatly appreciated!

* Required

1. What did you like about this simulation (Plus)?

2. What do you think could be improved (Delta)?

3. What is your field of education? *

Mark only one oval.

- ◯ Architecture
- ◯ Construction
- ◯ Engineering
- ◯ Other: ______________

4. What is your current profession? *

Check all that apply.

- [ ] Architectural Firm
- [ ] Construction Firm
- [ ] Other: ____________________

5. Did your past training include Value Stream Mapping? *

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) I am not sure
- ( ) Other: ____________________

6. For which activities on a construction jobsite do you think Value Stream Mapping could be helpful for streamlining practices? *

____
____
____
____
____

APPENDIX B

LINK TO "SPAGHETTI KITCHEN" THE ONLINE GAME

Link to the online version of the game with the Spaghetti Diagram (Experimental Group):

https://spaghetti-kitchen.itch.io/spaghetti-kitchen-sd

Link to the online version of the game without the Spaghetti Diagram (Control Group):

https://spaghetti-kitchen.itch.io/spaghetti-kitchen-nsd