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THE SILO GAME: A SIMULATION ON INTERDISCIPLINARY COLLABORATION

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ABSTRACT

Collaboration is a highly valued skill in construction, and it has become essential considering the advent of more collaborative delivery methods (e.g., design-build, integrated project delivery). This paper introduces the Silo Game which is a teaching simulation developed to mimic the trade-offs made during the design process to meet client's requirements while also meeting project goals. This simulation mimics the development of an environmentally conscious building using two phases: one illustrating disciplines isolated in teams mimicking silos and another with multi-disciplinary teams. The facilitator assumes the role of an owner and participants are assigned one of the four roles defined for the game: architect, civil engineer, mechanical engineer, and electrical engineer to meet the project's conditions of satisfaction defined early in the game. Initially, the professionals are grouped by role and later assigned to multi-disciplinary teams. The game has been played with three undergraduate classes and also with the Administering and Playing Lean Simulations Online (APLSO) community and the instructions are easy to relay. The lessons learned can be directly translated to construction settings sparking discussions about various Lean tenets and systems including integrated project delivery contracts, target value design, collaboration, and conditions of satisfaction.

KEYWORDS

Collaboration, sustainability, design, conditions of satisfaction, serious games, simulation

INTRODUCTION

This paper introduces the Silo Game as an additional teaching simulation to underscore the importance of collaboration in construction and how it is central to delivering value to environmentally conscious clients. In the early days of the International Group for Lean Construction (IGLC) community, topics related to waste reduction in construction projects were very prominent, and the focus was very much centered on reducing material waste and planning for more reliable flows of work, thus, reducing the waste of human effort (e.g., Alarcon 1997). The approaches used during the early days of the IGLC, expanded over the years as researchers and practitioners turned their attention to ways in which value is to be achieved for the clients, using only the resources necessary to achieve the clients' needs and considering broader solutions to achieve these goals from design, through production planning, supply chain initiatives, operations, and maintenance of projects (Alves and Tsao 2007). As this shift took place over the years, increased attention

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was placed on a Lean Project Delivery System (Ballard 2008) which considers multiple disciplines working in different areas from design, through production planning and control, work structuring, and supply chain management to name a few.

In this scenario, calls to promote interdisciplinary work, while addressing value maximization for the client and promoting a smooth flow of work, gained more popularity and contracts also became a relevant element in the discussion. Contracts incorporating more collaborative forms of work (e.g., design-build, integrated project delivery) became a necessity to promote environments where interdisciplinary work across trades and specialties was not only required but also rewarded (Alves et al. 2021). Comparisons between project performance using the traditional design-bid-build (DBB) delivery method versus design-build (DB), and integrated project delivery (IPD) methods showed the marked differences between these approaches (ElAsmar et al. 2015). Markedly, the development of projects using DBB in a siloed fashion revealed shortcomings that were addressed by the collaborative nature of DB and IPD projects.

In order to illustrate how traditional versus collaborative delivery methods play out in delivering projects and satisfying the client's conditions of satisfaction, the author developed a simulation to mimic the design process in both methods in a classroom setting. This simulation was developed to support activities related to an undergraduate course on environmentally conscious construction in California, where building codes are markedly progressive and unique (e.g., Calgreen 2022) and tend to push environmental standards much higher than other codes in the United States. In many cases, California building codes are stricter than requirements defined by rating systems like Leadership in Energy and Environmental Design (LEED), and this puts projects in California on a more streamlined path to certification, considering that many prerequisites and credits are standard practice in the state (USGBC 2022a, b). Considering these factors, the simulation was developed to mimic the design process and underscore the importance of collaboration in the development of environmentally conscious buildings.

SIMULATIONS TO TEACH LEAN CONSTRUCTION

This simulation builds on a long-standing tradition of teaching Lean Construction principles using simulations shared with the IGLC community and beyond (Tsao et al. 2012). The author is also part of a group of Professor Iris Tommelein's former graduate students at UC Berkeley, who have spearheaded the development and use of lean simulations (Rybkowski et al. 2020). From a production planning standpoint, these simulations have illustrated the effects of production system design using pull techniques to plan assembly (Tommelein 1998), the effects of uncertainty in production performance (Tommelein et al. 1999), how customization can be managed using lean principles (Sacks et al. 2007), and how site organization and communication using 5S can support better performance (Pollesch et al. 2017) to name a few. Additionally, simulations illustrating the importance of collaboration in general (Bavelas 1973) and use of lean principles in design to achieve targets (Rybkowski et al. 2016) and support architectural programing (Solhjou Khah et al. 2019) have also been used in the IGLC community to underscore the dynamics of the design process and trade-offs involved.

While most simulations developed until 2019 relied mostly on in-person interaction, with some exceptions including those using computer simulations (e.g., Tommelein et al.'s (1999) parade game), during 2020 and beyond, academics and practitioners had to pivot and translate face-to-face simulations to online environments to continue teaching during the Covid-19 pandemic. This effort is well documented in the description of the

Administering and Playing Lean Simulations Online (APLSO) community by Rybkowski et al. (2021). The APLSO is a virtual community of academics and practitioners, which started in March of 2020 during the Covid-19 pandemic, and was led by Dr. Zofia Rybkowski. The community, which was still active at the time this paper was written, meets once a month to play a simulation developed by one of its members or invited guests illustrating lean concepts. It was in this environment that the Silo Game was developed: virtual instruction using Zoom, breakout rooms, and Google Drive documents to support instruction. The author was involved with the early days of the APLSO and at the time the community started, she had already adapted the Architectural Programing (AP) simulation (Solhjou Khah et al. 2019) to the virtual environment and worked on a version of the Silent Squares simulation (Bavelas 1973) to teach a graduate course and, finally, the development of the Silo Game to support the teaching of design of an environmentally conscious building in an upper division undergraduate course. The common thread in simulations used in the APLSO community is the simplicity of the play and the clarity of instructions and concepts involved, which are relayed on an environment that needs to be inclusive and free of jargons, or regional expressions, to facilitate understanding (Rybkowski et al. 2021).

INTERDISCIPLINARY TEAMS, SUSTAINABLE DESIGN, AND LEED

Sustainable and high-performance buildings rely on the work of interdisciplinary teams to come to life (Kibert 2016). Solving problems from a multi-disciplinary standpoint helps teams reap synergistic benefits that cannot be achieved by any single specialization. For instance, addressing water consumption reduction and/or recycling in a building relies on the work of architects, landscape architects, civil engineers, and mechanical engineers, to name a few, so that the building and its systems are designed to use the minimum amount of water possible and recycle it whenever possible, in addition to capturing rainwater. An example of this extraordinary effort can be seen in net zero buildings, those that produce what they consume, in which water, energy, and/or trash are reduced, recycled, and reused. The Kendeda Building is an example of a high-performing building where the design approach allows the building not only to be net zero, but also give back to the environment and regenerate it (Georgia Institute of Technology 2022).

Environmentally conscious buildings can be attained by meeting and exceeding existing codes like the California Green Building Standards (Calgreen 2022), a recognized leading code in the United States (USGBC 2022a). However, the Leadership in Energy and Environmental Design (LEED) is arguably one of the most recognizable rating systems in the world (USGBC 2022b) and very educational in how it defines areas of concern and focuses the attention of teams on its main categories: Location and Transportation (LT), Sustainable Sites (SS), Water Efficiency (WE), Energy Efficiency (EE), Materials and Resources (MR), Indoor Environmental Quality (EQ), and additional areas of interest in Regional Priority (RP) and Innovation (IN) (USGBC 2022b). Considering the widespread popularity of LEED and its implementation in over 100,000 projects around the world (USGBC 2022c), this rating system was used to inform the development of the different categories used in the Silo Game.

THE SILO GAME SIMULATION

This section describes the process to develop the Silo Game. It starts by introducing why the simulation was developed and the approach taken to design its different elements.

DESIGNING THE SIMULATION

This simulation was developed with the intention of illustrating the importance of interdisciplinary collaboration in the design of sustainable buildings. The author teaches a course on environmentally conscious construction to students in civil and construction engineering majors and had the goal of showing that the traditional way of designing buildings, where specialty designers in different fields work separately, is not an appropriate option to design sustainable buildings.

For this game to effectively mimic the traditional versus a more collaborative approach to design buildings, and solve problems in general, the simulation was designed considering a few areas of interest (e.g., siloed vs. interdisciplinary discussions; trade-offs related to solutions; synergies between environmentally conscious solutions), which are discussed in the following sections.

THE PROBLEM: DESIGN AN ENVIRONMENTALLY CONSCIOUS PROJECT

Considering the main topic of the course for which this simulation was developed, the focus of the design would have to be related to the design of environmentally conscious buildings. A fictitious project also had to be defined so that participants could be held to the value proposition that they would need to deliver.

In this simulation, the project's vision comprises "*an environmentally conscious building that appeals to the market and has a low maintenance cost over the long run*" (Figure 1). The owner has a budget of “10 units of currency” (target value) to spend on the project. Please notice that a fictitious currency was used to remove the focus on the real cost of such a project, given that other characteristics are not precisely defined. Considering where the game was developed, the project was loosely defined as a multi-family development in Northern California. The target market was defined as environmentally conscious, young professionals living by themselves or sharing a unit, couples with one or two children. The allowed cost was set as medium to high for these small units, and because of the small square footage of the units, there should be open areas and amenities to provide additional space beyond the small private unit. Additionally, parking should also be provided. Finally, the units need to have individual meters for water and energy (sub-metering).

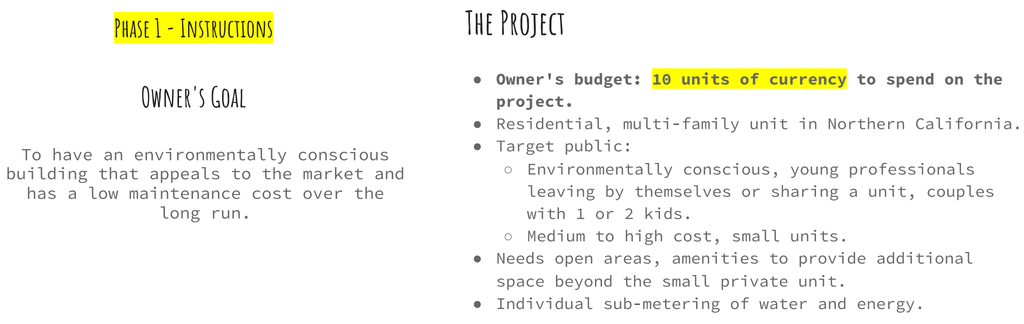

Figure 1: Examples of slides used to share information about the project and the owner.

STAKEHOLDERS/ROLES

The definition of stakeholders for this simulation should also mimic those involved in the design process and how they would interact or not during the simulation, and help in the evaluation of how the conditions of satisfaction for the design were met. Participants were assigned one of the four different roles, namely: Architects, Civil Engineers, Electrical Engineers, and Mechanical Engineers, whose specific responsibilities are outlined in Table 1. An example of the slides shared with participants representing one of the roles (e.g., Architect) is shown in Figure 2.

Table 1: Roles and responsibilities (each participant receives instructions for their role only)

Professional Role	Responsibilities
Architect (A)	• Orient the building to incorporate environmentally conscious values. • Promote the health and well-being of the building occupants. • Select the materials of the façade to support the goals of the client. • Define open areas and amenities in the project to support the goal of having open spaces/community areas in the project. • Your goal: address the owner's needs for this project.
Civil Engineer (CE)	• Address site water runoff. • Propose alternatives to support water conservation and reuse. • Promote the health and well-being of the building occupants. • Advise on solutions related to the parking lot.
Electrical Engineer (EE)	• Design the electrical system to be environmentally friendly. • Promote the health and well-being of the building occupants. • Propose alternatives to support energy conservation/generation. • Reduce maintenance costs for the owner of the building over the long run.
Mechanical Engineer (ME)	• Design the HVAC and plumbing systems to be environmentally friendly. • Promote the health and well-being of the building occupants. • Propose alternatives to support water conservation and reuse. • Propose alternatives to support energy conservation/generation. • Reduce maintenance costs for the owner of the building over the long run.

Architect

- You are the architect.

  Your tasks are:
- Orient the building to incorporate environmentally conscious values.
- Promote the health and well-being of the building occupants.
- Select the materials of the façade to support goals of the client.
- Define open areas and amenities in the project to support the goal of having open spaces/community areas in the project.
- Your goal: address the owner's needs for this project.

Architect - Design Solutions and related cost in units of budget

Solutions	Cost (unit)
Orient the building to take advantage of passive light and ventilation, include a small garden/playground for outdoor activities, include a parking garage building.	3
Orient the building to have the best views, moderate use of passive light and ventilation, include a small garden/playground for outdoor activities, include a parking garage building.	1
Orient the building to take advantage of passive light and ventilation, include a small park for outdoor activities, add the parking garage under the building.	4
Orient the building to have the best views, moderate use of passive light and ventilation, include a small park for outdoor activities, add the parking garage under the building	2

Figure 2: Examples of slides showing the roles and responsibilities of the Architect as well as the design solutions

The slides repeat the combined information shown in Tables 1 and 2 for each of the roles. These slides can be printed and shared with participants in face-to-face settings or shared via Google Slides in a virtual setting. For example, in a virtual setting, all architects receive the same link to a Google Slide deck with their roles and responsibilities and the solutions available to them. Other links are generated for additional slide decks for each of the roles as each participant receives information about their role only.

CATEGORIES TO FOCUS DURING THE DESIGN EXERCISE

Predefined solutions for each professional role (Table 2) were developed as part of the simulation to meet the owner's conditions of satisfaction.

Table 2: Predefined solutions (each participant receives the solutions for their role only)

Professional Role	Design Solutions	Cost (unit)
Architect (A)	Orient the building to have the best views, moderate use of passive light and ventilation, include a small garden/playground for outdoor activities, include a parking garage building.	1
	Orient the building to have the best views, moderate use of passive light and ventilation, include a small park for outdoor activities, add the parking garage under the building.	2
	Orient the building to take advantage of passive light and ventilation, include a small garden/playground for outdoor activities, include a parking garage building.	3
	Orient the building to take advantage of passive light and ventilation, include a small park for outdoor activities, add the parking garage under the building.	4
Civil Engineer (CE)	Parking lot under the building + BMPs for site water runoff.	1
	Parking garage building next to the building + best management practices (BMPs) for site water runoff and conservation on the surrounding landscape.	2
	Parking lot under the building + Retention basin in a small park + BMPs.	3
	Parking garage building + coordinated system to catch and recycle water as part of a small park + BMPs throughout the project.	4
Electrical Engineer (EE)	Use sensors to turn off lights when areas are not used and adjust light intensity depending on the incidence of natural light in different areas. Use efficient lighting systems.	1
	Use sensors to turn off lights when areas are not used and adjust light intensity depending on the incidence of natural light in different areas. Add photovoltaic panels to the project.	2
	Use sensors to turn off lights when areas are not used and adjust light intensity depending on the incidence of natural light in different areas. Use efficient lighting systems. Add photovoltaic panels to the project.	3
	Use sensors to turn off lights when areas are not used and adjust light intensity depending on the incidence of natural light in different areas. Use sensors to communicate with the HVAC system to open/close windows to achieve desired temperature. Use efficient lighting systems. Add photovoltaic panels to the project.	4
Mechanical Engineer (ME)	No HVAC system or individual heaters, design only the plumbing system.	1
	Use of individual heaters in each unit, design the plumbing system.	2
	Fully mechanically ventilated system with controls/sensors in individual units + design the plumbing system.	3
	Mixed: partial use of a HVAC system + operable windows with sensors to communicate changes to the operating system of the building + design the plumbing system	4

Considering that the course for which the simulation was originally developed addresses environmentally conscious construction, the LEED scorecard (USGBC 2022b) was used as a guideline to define the main categories addressed in the game and the main characteristics considered during the design exercise. Participants are led to discuss elements of passive design to save energy by orienting the building for best light and ventilation, open spaces for recreational use, parking location, use of best management practices (BMPs) to address the Civil side of the project and the need to retain and slowly release water out of the site per California code, and use of sensors in combination with windows and the heating, ventilation, and air-conditioning (HVAC) system to address occupant comfort and energy consumption. While decisions are made by each professional during the simulation, they have to remember that the owner has defined a budget of "10 units of currency" for this project. The cost of each predefined solution is defined in Table 2, which attempts to mimic costs associated with each solution. The cost for each solution increases as they become more encompassing and start having synergistic relationships with solutions presented by other professionals. Later in the description of the phases, the reader will notice that the best solution is not necessarily the most expensive when considered from an interdisciplinary standpoint.

LOGISTICS AND APPROACH TO RUNNING THE SIMULATION

Considering that this simulation was developed during the Covid-19 pandemic, when classes were still online, the simulation was initially played via Zoom and later in-person. In order to accommodate multiple participants in different teams, while the simulation was played on Zoom, breakout rooms were used. Finally, in the virtual environment, documents were shared with participants online via Google Drive links, with different links defined for each of the four professional roles previously described. When the game is played in person, paper copies of the roles and the design solutions are distributed to participants. Each participant only receives information about their role in Phase 1.

PHASES

Figure 3 gives an overview of how participants are assigned to groups in two phases to help the reader visualize how the phases are structured.

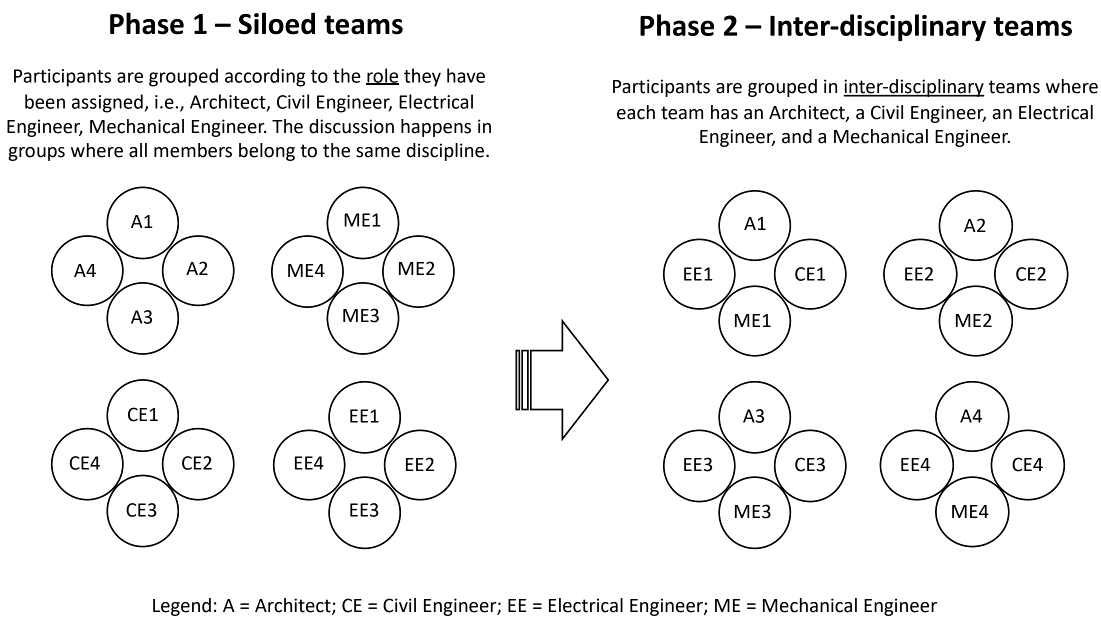

Figure 3: Structure of the teams in both phases of the Silo Game

The two phases to deliver the project previously described were defined illustrating different approaches used in this simulation. Each phase lasts for eight minutes and is described as follows.

Phase 1 – Siloed teams

Similar to the Design-Bid-Build (DBB) environment, the first phase illustrates isolation, lack of interaction and information exchange between participants of a project. During the first phase, participants are assigned a project team number (e.g., 1, 2, 3, etc.) and a specific professional role (e.g., Architect, Civil Engineer, Mechanical Engineer, or Electrical Engineer), and are put into groups with professionals with their same assigned role (e.g., EE1, EE2, EE3, EE4) to define which of the four predefined solutions indicated for their role in Table 2 will be chosen to address the owner's needs. The four professional roles should be equally split among participants to four project teams, in the case presented in Figure 3, which are separated as described in the first phase, but will be together later during the simulation.

For instance, all architects (e.g., A1, A2, A3, A4) are put into a group with other architects to mimic their interaction with peers from the same company, with whom they can exchange ideas for this particular project. The same is done for the other three professional roles. However, professionals with different roles can only communicate with their own group of professionals, as shown in Figure 3, but cannot communicate with peers assigned different professional roles and placed into separate groups. This phase also illustrates the lack of interaction with professionals from other disciplines and the lack of knowledge about what other professionals might be selecting to meet the conditions of satisfaction defined by the owner for a single project team. The professionals in Phase 1 select solutions without much, or any, regard to the cost of their own solutions and how this will impact the final project cost or how the solutions could benefit from synergistic effects obtained if solutions were coordinated among disciplines. In a real project, this would also impact the conditions of satisfaction (COS) defined by the owner and how well trade-offs could be made considering the value of each solution and their associated cost.

Phase 2 – Interdisciplinary teams:

The second phase illustrates a collaborative and interdisciplinary environment where different professionals work together to achieve the project's COS. This is similar to the environment in Design-Build (DB) and Integrated Project Delivery (IPD) projects where value is maximized through collaborative work and exchange of ideas. During this phase, participants are put together with their respective teams (e.g., 1, 2, 3, etc. as shown in Figure 3), and each team has a representative of all four professional roles to represent an interdisciplinary team. For instance, team 1 will have one Architect (A1), one Civil Engineer (CE1), one Mechanical Engineer (ME1), and one Electrical Engineer (EE1), who will all work together to meet the client's goals. Participants are instructed to discuss how their solutions help achieve the goals of the project and meet the cost defined by the owner.

Moreover, considering that some of the solutions have synergistic relationships, participants are rewarded for that with cost reductions for their design. For instance, the facilitator might remind participants that if the architect properly orients the building to take advantage of passive light and ventilation, less energy will be consumed; this is one example that can be shared during the simulation. During this phase, participants should have some basic understanding of how the categories considered in all four professional roles are related to one another. The author also played this simulation with freshmen students in an introductory seminar to the field of Construction Management and all students were well aware of these relationships.

For each solution selected by the project team that addresses an additional category (i.e., by displaying synergistic relationships as previously described) the cost of the solution is reduced by 2 units. For example, if a design solution selected by the electrical engineer (EE) helps the mechanical engineer (ME), the solution from the EE and the ME each get a 1 unit cost reduction lowering the cost of the combined solution. This aims to illustrate the fact that sustainable solutions are not more expensive than traditional solutions when they are considered from an interdisciplinary standpoint. This activity also mimics the work of cross-functional design teams, or clusters, tasked with developing solutions for specific systems in a project considering interdisciplinarity (Lostuvali et al. 2014).

Report out and debrief

The time limit was defined for this task considering the time allocated for the entire simulation which ideally should fit within a class period of 50 minutes. Ultimately, the time given to the teams was eight minutes in each phase, followed by 10-15 minutes of discussion after each phase so that participants can share lessons learned and observations. During the reporting breaks, after each phase, participants are asked to share:

- What is the final cost of their project?
- Each breakout room enters the cost of the solution adopted by their respective discipline either in a spreadsheet shared online or report to the facilitator who enters the cost of each solution defined for each group on a board or shared computer screen.
- What are your impressions of the phase being discussed (1 or 2)?
- Could the team meet the budget and the client's requirements?
    - Yes/No?
    - What happened?
    - What worked and what didn't work?

DISCUSSION

So far, the Silo Game has been played with freshmen, junior, and senior students at San Diego State University and also with the APLSO community. Feedback has been gathered but the simulation has not been changed from its original version by the author. However, those interested in playing this simulation are free to make adaptations while making proper attributions to the author considering the Creative Commons attribution CC BY-NC-SA 4.0 (Creative Commons 2022).

During the game plays, feedback gathered so far indicates that participants learn during Phase 1 (siloed) that they are prone to fail as decisions are made based on the information from a single discipline who might choose what is best for their specialty area but might not meet the budget requirements defined for the project. Results have been tabulated live during the simulation, however, they have not been kept for reporting purposes after each play. In Phase 1, participants invariably do not meet the cost defined by the client as each siloed group picks the best option for their discipline without much regard to the solutions and related costs chosen by other disciplines. After this phase, participants share their frustration regarding not knowing what other disciplines have selected.

During Phase 2, participants meet the conditions of satisfaction rather quickly after having become familiar with the design solutions they have. During the APLSO play, participants (who were in general more experienced in the construction industry) noted that while synergies can be taken advantage of, the trade-offs made regarding each design solution selection do not have the same cost, and that the focus should be on value for the client not on cost. Participants also pointed out to the need to have teams develop their own conclusions about the lessons learned within their group, and later share them with the broader group to avoid groupthink. During the discussion in each phase, special attention can be given to topics related to collaborative versus siloed delivery methods and construction contracts, the level of understanding achieved by the teams during the collaborative phase, and the definition and achievement of a target value and conditions of satisfaction for the project as illustrated by what the owner wants given the project monetary constraints. Finally, thanks to the suggestion of one of the anonymous reviewers of this paper, this simulation could also address the role of rework that happens between Phases 1 and 2. Participants could be asked to document if and how their solutions changed between phases and a rework cost could be added to that change. Questions could be asked about who pays for the rework and how that impacts the final cost of the project, the time to resolve changes, and the potential impact on client satisfaction.

CONCLUSIONS

This paper described the development and related rules of the Silo Game, which was originally developed to mimic the development of an environmentally conscious project and teach important concepts related to interdisciplinary work, design synergies, collaboration, and sustainability. Participants with various levels of construction experience from undergraduate freshmen to academics and professionals played this simulation. The game has proven to be simple and easy to grasp and play, potentially adaptable to teach different subjects using its basic design, and to promote a rich discussion about the impacts of siloed decisions (e.g., in DBB projects) versus collaborative ones (e.g., DB and IPD projects). Various Lean tenets and systems including integrated project delivery contracts, target value design, collaboration, and conditions of satisfaction can be discussed during the game play and any or all of these topics can be illustrated by the process mimicked in this game.

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