DEVELOPMENT AND TESTING OF AN INNOVATIVE ARCHITECTURAL PROGRAMMING SIMULATION AS A PRECURSOR TO TARGET VALUE DESIGN

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ABSTRACT

More than half of international construction projects are underperforming. Poorly defined scope of work has been ranked as the one of the highest reasons for poor performance over which owners and construction stakeholders have control. An owner's requirements and expectations are specified during the programming phase of a project and these define a design's scope of work. One focus of Target Value Design (TVD) is making owner's value a primary driver of design by improving project definition during programming—thus optimizing the design phase. While the number of published research articles praising TVD has been increasing, there is a dearth of information regarding the application of architectural programming (AP) to Target Value Design exercises, which engage stakeholders in a design decision making process called Choosing by Advantages (CBA). CBA first requires identification of attributes that are of value to an owner. The purpose of this research was to explore the importance of architectural programming in helping to identify key attributes of value to an owner, and to report on a lean game designed and preliminarily validated by the authors to investigate the accuracy and perception of attribute identification through AP as represented by the game.

KEYWORDS

Target value design, value, design science, architectural programming, serious games and simulations

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INTRODUCTION

Many reasons have been attributed to construction project cost overruns worldwide (**Figure 1**). The pre-eminent reason known as "material price escalation" refers to insecurity of an economy and inflation over which construction stakeholders have no control. However, poorly defined scope has been identified to be the second most influential reason for cost overruns in the construction industry, but the first over which the Owner, Architect, Engineer, and Contractor (OAEC) stakeholder team has control.

Architectural Programming (AP) is defined as the research and decision-making process that identifies the scope of work to be designed (WDBG 2016). It has been cited as a poorly implemented phase in the construction industry (Morêda Neto et al. 2016).
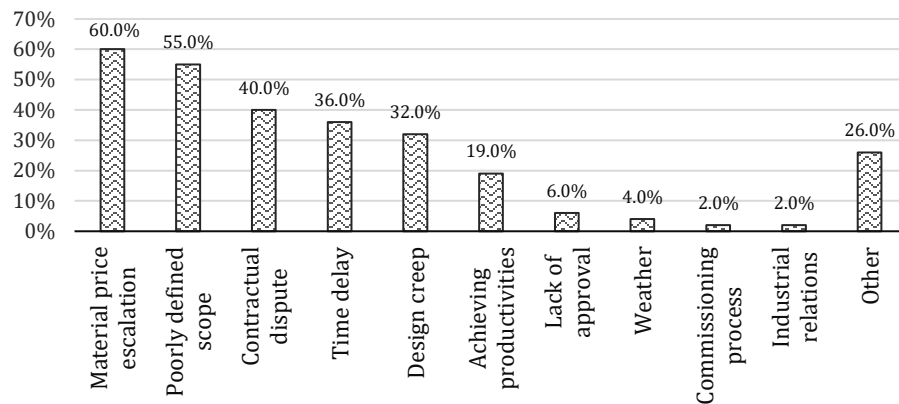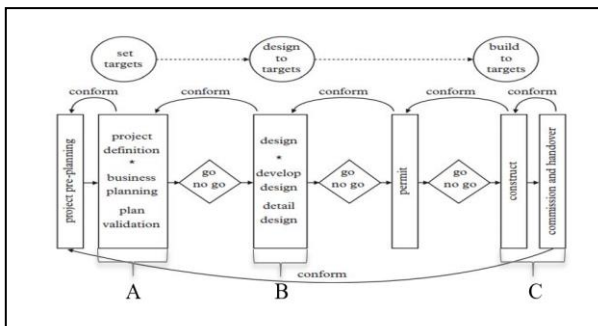

Figure 1. Reasons for cost overrun in construction projects worldwide, as of 2008. Adapted from PMI and KPMG (2013).

LITERATURE REVIEW

"Target Value Design (TVD) is a management strategy and known as a complex system, with stages including: Project definition (A), Design (B), and Construction (C) (**Figure 2**). It correlates closely with Lean thinking in design and construction" (p. 2, Zimina et al. 2012). TVD tools help stakeholders meet an allowable cost, while enhancing value, for a project owner, often saving a project as much as 15-20% on first cost (Ballard and Rybkowski 2009; Denerolle, S. 2013, Rybkowski et al. 2016).

To help educate participants about TVD, Rybkowski et al. (2016) developed a two-phase estimating simulation to illustrate to participants the "Design/Develop Design/Detail Design" process (**Figure 2**, phase B) of TVD. However, "Project Definition/Business Planning/Plan Validation" (**Figure 2**, phase A) must precede the design process as it informs designers of what an owner values. A simulation to introduce participants to stage A was needed and did not yet exist. Filling this gap was the basis for this paper.

Figure 2. Target Value Design process scheme (Figure 4 in Zimina et al. 2012).

For this study, seven architectural programming methods were identified including: Davis's Programming, Farbestian's Programming, McLaughlin's Programming, Kurtz's Programming, Moleski's Programming, White's Programming, and Peña's Programming (Sanoff 1992). For example, Peña's programming method addresses four primary elements including Function, Form, Economy, and Time. Peña's programming requires work sessions that gather all stakeholders involved in the project to explore 132 considerations covering many aspects of a project (Peña and Parshall 2001, Sanoff 2016).

In the construction industry, training and its advantages are underestimated, which leads to inadequate formal training activities (Kuykendall 2007). In a study conducted by Cox et al. (1998), it was found that companies, which invested in training practices, increased their productivity by 42%. As with other skills, lean training is vital in establishing an advanced mindset and culture, which is critical to successful lean implementation (McGraw-Hill 2012). This training leads to the foundation for successful changes in an organization (Wan et al. 2008). Lean training is applicable in many forms, including lectures, presentations, hands-on games and activities, videos, and case studies. These approaches are effective when used separately, but they can also be adopted together for better overall performance. Serious games and simulations are some of the most efficient methods to demonstrate the advantages of lean tools and concepts (Kuriger et al. 2010). They differ from simple "gaming" in that the primary aim is educational—i.e. to learn through entertainment (Wouters et al 2007).

PROBLEM STATEMENT

This study seeks to address the need for construction stakeholders to develop an appreciation for systematic architectural programming at the start of a construction project during the early stages of TVD. The amount of information regarding the application of architectural programming to TVD is insufficient. In TVD, project definition is included as a separate upfront design step that should involve architectural programming. Therefore, the focus of this study is to design and test via proof of concept an innovative and functional Lean simulation in order to communicate the importance of architectural programming on value creation for the owner.

RESEARCH OBJECTIVES

The overall goal of this study is to develop and test a new lean simulation that introduces systematic architectural programming as a way to determine value for a building owner at the start of TVD. The objective of this specific research is to collect feedback after testing the simulation, and to use that feedback as a guide to improve future versions of the simulation. The ultimate aim is to help increase value of the built environment.

PROPOSED METHODOLOGY

This paper documents the exploratory, quantitative and qualitative development and testing of a lean architectural programming simulation at Texas A&M University, Virginia Tech University, and Brigham Young University. In addition, a questionnaire was distributed to participants to evaluate the simulation's effectiveness. To the best of the

authors' knowledge, there is no previous lean simulation which explores the impact of architectural programming. In this research, the authors developed a simulation to evaluate the importance of architectural programming (AP) by using an algorithmic manipulation of three floor plans to yield a compilation of 144 possibilities. By conducting a subsequent evaluation, research tested how systematic architectural programming (AP) might benefit the participants, who are about to embark on TVD exercises.

The Architectural Programming lean simulation was designed to investigate perceptions about the importance of AP. It was originally designed and tested at the College of Architecture at Texas A&M University. It was pilot tested on graduate and undergraduate students, who were being prepared to enter construction related industries within the next one to five years. Students were affiliated with the departments of Construction Science, Architecture, and Civil Engineering. The Institution Review Board permitted testing to be performed in classrooms by the facilitators in the aforementioned departments at Texas A&M University, and exact dates and times were set to conduct the simulation in classes. To administer the simulation, the facilitator read aloud instructions. At various points the facilitator clarified aspects of the game as needed, based on verbal questions from the participants, and provided written questionnaires to secure feedback from the students following play.

Simulation Process:

Before starting the game, instructions were delivered orally by the facilitator. Participants were divided into pairs of two members: one as an owner, and the other as an architect. Required material for this simulation included: Template for Scenarios (**Figure 5**), six Architectural Programming Scenarios which portrayed scenarios to define owner's expectations and requirements (**Figure 6**), Two 11" X 17" landscape format photocopies with 144 apartment layouts were provided for each pair with five variables including: Number of bedrooms, Ability/Disability, Solar Orientation, Open vs. Closed Kitchen, and Quality of Finishes (**Figure 8**). Each plan was given an identifier and three assigned potential quality of finishes (Low, Medium, High). The purpose of this lean game is for architect players to understand the difference of impact between *not* listening and listening carefully to an owner's needs before recommending to the owner appropriate diagrammatic apartment plan layouts with associated quality of finishes. The lean simulation was administrated in two rounds.

Round I:

Selected plan identifiers with associated quality of finishes were written on slips of paper and shuffled in a bowl for owners to draw (**Figure 4**). Owners memorized the drawn plan identifier with quality of finishes, and the architect was instructed to guess the plan identifier with quality of finishes. Architects were allowed to ask two yes or no questions pertinent to the given criteria on the blank "Template for Scenarios" in four minutes and owners were permitted respond to their questions based on the given information in the related Scenarios. At the end of the first round the architects were asked to guess what they believed was the owner's desired plan identifier and its quality of finishes. The facilitator then asked each architect to announce his or her guess. The results of the guess were collected onto a table drawn onto the room's white board.

Round II:

In the second round, owners read their scenarios slowly to their architects. Architects were not allowed to ask any questions. But they were permitted to ask their owners to read their scenario again. Within six minutes, the architect players guessed the plan number and its quality of finishes. Participants' guesses were again recorded by the facilitator on the whiteboard table. The results for the two stages were compared. At the end of the game, Peña's Programming table was projected onto a screen in order to demonstrate how the lessons of the game can be applied to actual projects. In addition, a questionnaire was distributed to participants to collect feedback regarding their perceptions of the game (**Figure 7**).

This simulation is an effort to help the participants understand the importance of systematic architectural programming in meeting owner's requirements and expectations—i.e. what an owner deems to be of a greatest value. Moreover, the simulation indicates adverse effects of lack of communication between owners and architectural programmers on the outcomes of construction projects. An example of data collected on a whiteboard by the facilitator is shown (**Table 1**). All white board tables were photographed. These data, along with data from questionnaires completed by participants and all players were cumulatively inputted into excel and evaluated.

Table 1. Example of "Guess Table" drawn by facilitator on whiteboard

	Team #				
RND I	1	2	3	4	5
Guessed DWG # and Quality of Finishes	E1-2 Low	D4-2 Medium	A4-2 High	D2-1 Medium	B4-1 Medium
	Y Ⓝ	Ⓨ N	Y Ⓝ	Y Ⓝ	Y Ⓝ
RND II					
Guessed DWG # and Quality of Finishes	A2-2 Medium	D4-2 Medium	B3-2 Low	C4-1 Low	D4-1 Medium
	Ⓨ N	Ⓨ N	Ⓨ N	Ⓨ N	Y Ⓝ

RESEARCH LIMITATIONS

While the outcome from these initial tests were promising, it must be acknowledged that the sample size was relatively small (N=136, combining results from three universities); thus, the conclusions might not convincingly reflect the attributes of players from practice or industry. Also, the simulation does not take into consideration cultural differences among participants.

RESULTS AND DATA ANALYSIS

Results from the Architectural Programming (AP) Lean experiment from three universities (Texas A&M, Virginia Tech, and Brigham Young; **Table 2**) indicate there was a marked decrease in the percentage of incorrect guesses from Round 1 (95.38%) and
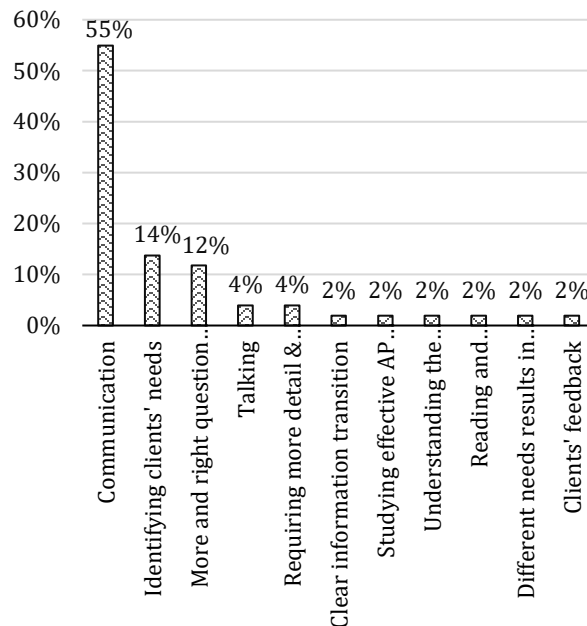
Round 2 (21.5%)—a decrease of 77.5%. In other words, owner's requirements and expectations were not met during the first round but were largely met during the second round.

Table 2. Summarized pilot test results for AP lean simulation from three universities

Round I	Percent of Correct Guesses	Percent of Incorrect Guesses
TAMU	4.54%	95.65%
VTech	12.50%	87.50%
BYU	2.94%	97.06%
Round I Total	**4.62%**	**95.38%**
Round II	**Percent of Correct Guesses**	**Percent of Incorrect Guesses**
TAMU	78.26%	21.74%
VTech	37.50%	62.50%*
BYU	88.23%	11.77%
Round II Total	**78.50%**	**21.50%**

* Deviation in game implementation during Round II may be responsible for this number.

Various purposes for the AP lean simulation experiment were identified by participants. As **Figure 3** shows, approximately 55% of players believed that "Communication" is the primary purpose of the simulation. Players perceived this simulation to be a useful tool to indicate the importance of communication and identifying owner's expectations, which ultimately outlines the importance of utilizing a comprehensive AP tool in the construction industry. Other evaluations were conducted to assess difficulty and levels of enjoyment while playing the Architectural Programming lean simulation. Approximately 77% of players believed that this simulation was "moderately easy" or "easy to understand", and 61% of players agreed

Figure 3. Results from questionnaire following play by Texas A&M participants

that this simulation was "very fun" or "extremely fun to play." These scores outline the convenience of this innovative lean simulation with respect to being played at organizations for the purpose of teaching the importance of AP in construction and other related fields. Participants' demographic data indicates that 86% of participants were male players, and 14% of them were female players. Approximately 87.5% of the players were undergraduate students, and 12.5% were graduate students. Players' academic majors were

classified based on the degree they planned to earn within five years: 77.2% of participants were studying construction science, 10.3% architecture, 3.7% business, 2.2% civil engineering, 3.7% facilities management, 2.2% technology and engineering studies, and 0.7% product design. Typical feedback on how the AP lean simulation can be improved included: this simulation is a good game, provide more clear instruction, make it more challenging, provide more time, and permit more questions and guesses during Round I[*]. Outcomes of the AP lean simulation suggest that there was substantial alignment between an owner's expressed needs and an architect's design after the AP method was implemented e.g. 3 correct guesses in Round I vs. 51 correct guesses in Round II.

DISCUSSION

Although an in-depth discussion of Choosing by Advantages exercises (CBA; Suhr 1999) is beyond the scope of this paper, it is important to clarify that this simulation simply helps identify basic attributes that are critical to an owner. Target Value Design typically engages participants in CBA, which encourages stakeholders to brainstorm and then subject to criterion analysis multiple alternatives embodying these attributes (Arroyo et al. 2013; Schöttle et al. 2007). In other words, while there are many ways to design a two-bedroom home, the designer needs to first recognize an owner wants a two-bedroom home, for example. Architectural programming helps identify critical attributes of value to an owner.

The AP lean simulation was developed as an attempt to communicate to OAEC (Owner, Architecture, Engineering, and Construction) stakeholders the importance of reliable architectural programming methods (AP) on OAEC projects. Preliminary feedback from simulation participants indicates that this simulation can be applied to real-world scenarios. While studies have been conducted on TVD in the fields of Lean Construction and Architectural Programming individually, there are few publications that address both simultaneously. The aim of this research is to integrate lean strategies and AP components to fill this gap. Indeed, these methods can both coexist and complement one other.

CONCLUSION

Project success has been defined by two key factors including managing costs to achieve efficiencies, and creating and enhancing value (Venkataraman and Pinto 2011). Lean Construction strategies can be applied in order to create and improve values in construction projects. However, 53% of construction projects are underperforming overall (KPMG 2015). Poorly defined scope of work by OAEC stakeholders has been identified as the most frequent reason for project cost overruns. By improving the architectural programming stage of a project, stakeholders can improve scope of work related to owners, meet their expectations and requirements, and ultimately, increase the probability of project success. This paper suggests exploring ways to integrate lean strategies with architectural programming methods to fill a gap that synergistically addresses the needs of owners, architects, engineers, and contractors when embarking on TVD. The intent of this research

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[*] The authors believe this feedback may reflect a misunderstanding of some participants of the purpose of the simulation.

was to develop and test an innovative simulation to effectively highlight the value of architectural programming and its associated long-term benefits, thus helping to reduce cost overruns and increase project success among OAEC stakeholders. After playing the Architectural Programming simulation, participants indicated they understood the importance of architectural programming in the construction industry. Student participants in this study represented potential stakeholders in the construction industry, and it would be worthwhile for a future longitudinal research project to explore whether their understanding endures or is transformed as the student participants pursue careers following graduation.

C4-1 (Low)	E3-1(High)
D4-2 (Medium)	B3-2 (Low)
D3-1 (Medium)	A2-2 (Medium)

Figure 4 (above). Slips of paper
(To be drawn by owners out of the bowl).

Figure 5 (right). Template for Scenarios
(To be given to architects only).

Figure 6 (below left). Scenarios
(To be given to owners only).

Figure 7 (below right). Feedback Questionnaire
(To be given to all participants).

Template for scenarios

Variables	RND I (Pick 2 Variables to ask)	RND II
1 # of bedrooms		
2 Ability / Disability		
3 Solar Orientation		
4 Open vs. closed kitchen		
5 Cost of Finishes		

RNDI - Plan Number_____ Cost of Finishes_____

RNDII - Plan Number_____ Cost of Finishes_____

E3-1 (High)

1	My wife and I have a 17-year old teenage daughter and a 9-year old son. The children need to have their own bedrooms.
2	Everyone is healthy and my wife and I are very active.
3	We live in a part of New Zealand (i.e. southern hemisphere) which is so cold it has penguins. Give us sun in our bedrooms and living room please!
4	I am the cook in the family and like peace and quiet when I cook after work. The kids like watching TV in the living room which can be noisy, so I want some barrier between us.
5	I am a data scientist and make good money so cost is not a constraint.

B3-2 (Low)

1	My husband and I are retired and 65 and 60 years old, respectively.
2	We are currently in good health but want a place to live well into our 70s or even 80s, assuming we live that long.
3	We live in Arizona which is really hot. So we don't want to have direct sunlight in our bedroom at midday when we take naps. We also don't want sunlight in the afternoon in our bedroom.
4	We have young grandchildren and will be taking care of them during the day while their parents are at work. We want to be able to supervise them while they play in the living room, even while we cook.
5	We are living off of social security so need a modestly-priced home.

A2-2 (Medium)

1	I am a night security guard in New York City and prefer to live alone.
2	I lift weights when I can and am in tip-top shape.
3	Since I work at night and sleep during the day I don't want light coming into my bedroom.
4	I have a great film collection, and want to be able to see my plasma screen in the living room while I am cooking.
5	I am solidly middle-class. I'm not rich but I'm not poor either.

| 5 | We come from a middle-class family who saved money for our college education. We aren't rich, but we can afford a better place than the lowest cost apartments. |

An Innovative Architectural Programming Simulation

To help us assess the effectiveness of the simulation, we appreciate your help completing the following information:

1. What is your gender? ----------------------
2. Circle your role in AP simulation (Architect/Owner)
3. Circle your classification (Undergrad/ Grad/ Neither)
4. What is/was your undergraduate major (if applicable)? ----------------------
5. What is/was your graduate major (if applicable)? ----------------------
6. What is your job title? ----------------------
7. How many years do you have industry experience? ----------------------
8. What do you think was the purpose of this simulation?

9. Do you think the instructions were easy to understand? Please answer on a scale of 1 to 6.

Hard to understand | 1 | 2 | 3 | 4 | 5 | 6 | Easy to understand

10. Do you think the game was fun to play? Please answer on a scale of 1 to 6.

Not at all fun to play | 1 | 2 | 3 | 4 | 5 | 6 | Extremely fun to play

11. How do you think this simulation is applicable to an actual project?

Figure 8. AP Simulation Materials: Architects must guess which of 144 floor plans best fulfill the owner's values (to be given to both owners and architects).
Sheets were numbered in color to clarify to players that the two sheets differ.

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