ICCEPM 2022
The 9th International Conference on Construction Engineering and Project Management
Jun. 20-23, 2022, Las Vegas, NV, USA

Hands-on Education Module for Modular Construction, 3D Design, and 4D Schedule

Kyle A. Kithas, AIA[1]*, Jin Ouk Choi, Ph.D.[2]

[1] *Department of Civil and Environmental Engineering and Construction, University of Nevada, Las Vegas, 4505 S. Maryland Pkwy., Las Vegas, NV 89154, USA,* E-mail address: *kyle.kithas@unlv.edu*
[2] *Project Management and Construction Engineering Lab (PMCEL), Department of Civil and Environmental Engineering and Construction, University of Nevada, Las Vegas, 4505 S. Maryland Pkwy., Las Vegas, NV 89154, USA,* E-mail address: jinouk.choi@unlv.edu

Abstract: A paradigm shift in teaching modular construction in higher education and K-12 is proposed as a means to increase the future adoption of the modular construction technique. To this effect, a new education module is presented to STEM educators. This education module is based on LEGOs and directed towards educators in the architecture, engineering, and construction (AEC) industry. The main objectives of the education module are to increase interest and knowledge of modular construction, acknowledge the benefits of using 3D design with 4D scheduling, and create a simulating hands-on educational opportunity. The education module is designed to allow participants to experience a hands-on simulation of modular construction and stick-built construction through building a LEGO project. Participants are challenged to find the advantages and disadvantages in both construction systems first-hand and record their findings. Results are presented from the preliminary testing of this education model on a group of construction management students at the University of Nevada, Las Vegas. Overall, the survey results showed that the LEGO education module was successful at achieving the project's three main objectives: 1) increasing the participants' interest and knowledge of modular construction through an interactive project; 2) increasing the participants' understanding of the benefits of 3D design with 4D scheduling over the use of 2D drawings; and 3) creating a simulating hands-on educational opportunity to help participants compare modular construction to stick-built construction. In the end, this proposed a new LEGO education module addressing the problems identified from this study with more participants.

Key words: LEGO, industrialized construction, modularization, STEM education, 4D scheduling

1. INTRODUCTION

Increasing productivity and efficiency is paramount as the architectural, engineering, and construction (AEC) industry faces the future challenges of labor shortages and climate crises. A majority of the current construction industry still relies on a stick-built construction technique that treats the project site as the location of all construction activities. The stick-built method is familiar, yet arguably, not the best construction technique to implement on all project typologies. An alternative to the stick-built construction technique is modular construction. Modular construction is quickly gaining market share [1] as it offers hope for increasing the AEC industry's production and efficiency. Modular Construction is defined as exporting a portion of site-based construction work to an off-site fabrication yard or modular assembly shop [2]. Modular construction offers many advantages over traditional stick-built construction, such as offering compressed project schedules, fewer job-site environmental impacts, increased worker safety, and increased construction quality [2], [3].

Although the major benefits of the modular construction technique are known, a major challenge still lies in increasing the adoption of modular construction [4]. To this effect, modularization maximization enablers [5] have been identified that can accelerate the adoption of modularization. The authors explored one of these modularization maximization enablers: modifying how the design process is taught in school [5]. Additionally, the authors also explored how technology, specifically, 3D design and 4D scheduling [6], [7], can benefit modular construction.

In an effort to increase modular construction's future industry adoption and acceptance, an additional curriculum must be developed for higher education and K-12 to introduce students to this concept while embracing the STEM values at the core of architecture, engineering, and construction management education. While there are advanced graduate course curriculum offerings developed for modular construction [8], a limited introductory curriculum exists to introduce students to this concept. Thus, a LEGO education module was conceived that would expose participants to this complex real-world building technique in a fun, familiar, and interactive way. Specifically, the LEGO education module is designed to allow participants to experience a hands-on simulation of modular construction and stick-built construction through building a LEGO project. Participants are challenged to find the advantages and disadvantages in both construction systems first-hand and record their findings.

2. RESEARCH OBJECTIVES

Three research objectives were identified before developing the LEGO education module: 1) increasing the participants' interest and knowledge of modular construction through an interactive project; 2) increasing the participants' understanding of the benefits of 3D design with 4D scheduling over the use of 2D drawings; and 3) creating a simulating hands-on educational opportunity to help participants compare modular construction to stick-built construction.

3. RESEARCH METHOD

The LEGO education module was comprised of two parts defined as method 1 and method II, see figure 1 and figure 2. Method 1 simulated stick-built construction and method II simulated modular construction. The goal of the research was to have the same group of participants complete both methods and make comparisons between the advantages and disadvantages of each method and how these advantages and disadvantages could be applicable to real construction. The LEGO education modules were administered by a team of 3 facilitators. Participants were divided into teams of 3-4 individuals. The education module involved real-world problems that typically arise on the construction job site, such as material delays and construction trade coordination. Participants were not prompted to study anything in advance of completing the LEGO education module. A written survey was collected at the end to measure what the participants learned from the LEGO education module.

3.1. Preliminary Testing of the LEGO Education Module

The LEGO education module was administered on November 18, 2021, at the University of Nevada, Las Vegas (UNLV). Six tables were used, and each table was provided with 1 grey LEGO baseplate representing the project site, as shown in figure 3. Participants arrived and seated themselves at the tables. The tables were limited to 4 occupants. Each table formed a team. Teams were assigned to begin with method 1 or method II based on which side of the room their table was on.

A brief introduction was provided to explain that the LEGO education module would consist of two methods that represent different construction techniques. The introduction was purposely vague as the written instructions would explain each method. The goal was to reduce the amount of cross-over information between the teams working on method 1 and method II since both methods would be running concurrently. The 3D design of the final LEGO project both teams would be attempting to construct was shown in Navisworks. The 3D design model was orbited. Individual modules were hidden while showing the Navisworks model to avoid giving ideas about modular construction to the teams beginning with method 1.

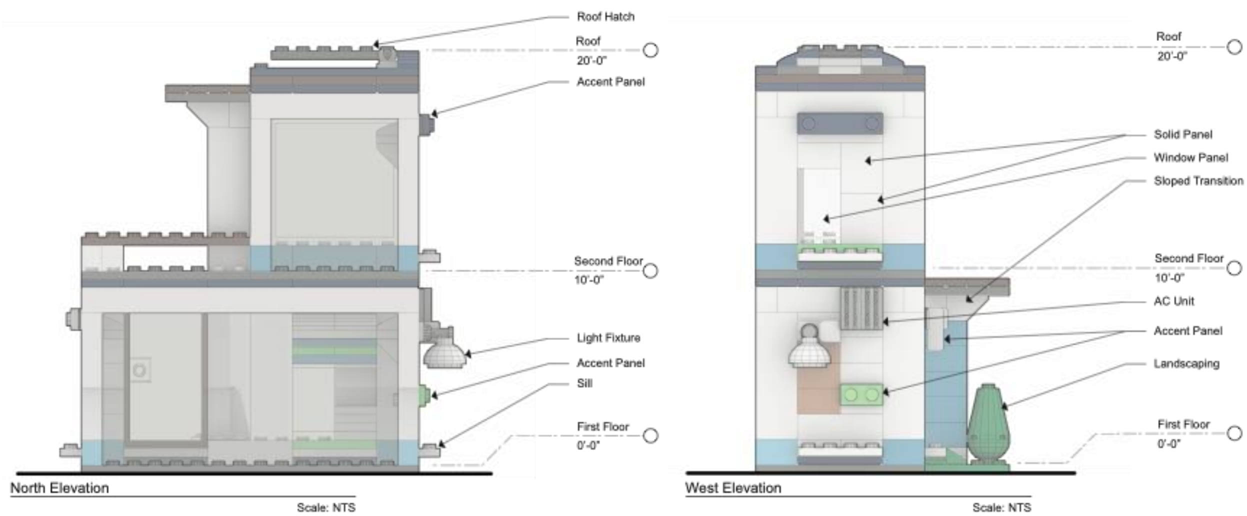

Figure 1. Method 1 required each team to build a LEGO project utilizing traditional stick-built construction with 2D plans, 2D elevations, and a construction schedule

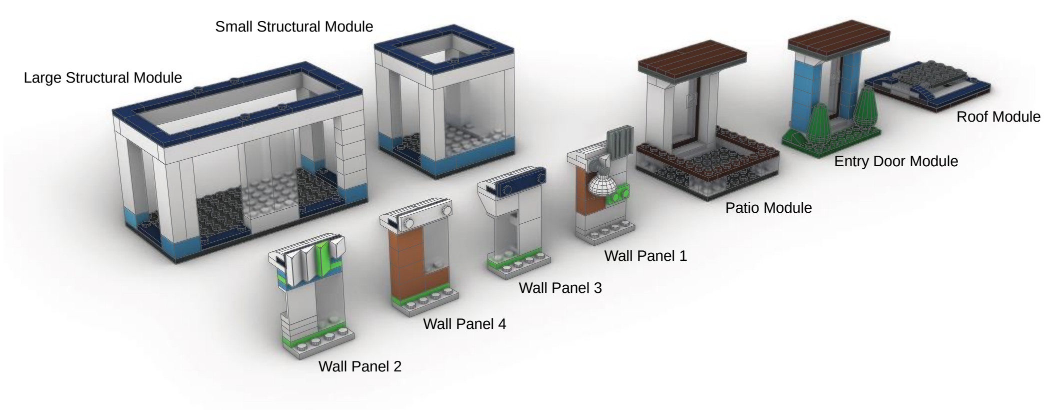

Figure 2. Method II required each team to build a LEGO project utilizing modular construction with a 3D design and a 4D project schedule

Initially, participants were going to have 30 minutes to complete method II and 55 minutes to complete method 1. The specific timing was as follows; method II: 10 minutes for participants to complete the submittal form and obtain LEGO pieces and approximately 20 mins for the participants to build the project; method 1: 10 minutes for participants to complete the submittal form and obtain LEGO pieces and approximately 45 mins for the participants to build the project.

Figure 3. Participants during the LEGO education modules

During the first part of the LEGO education module, teams 1, 2, and 3 were assigned method II, and teams 4, 5, and 6 were assigned method 1. Participants began reading the instruction and completing the submittal forms. Participants brought the submittal forms to the facilitators in exchange for LEGO pieces. First floor and second floor LEGO pieces were given to method II teams, and only first floor LEGO pieces were given to method 1 teams. Once the teams completed their respective method or ran out of time, they would disassemble their LEGO set and switch methods. During the second part of the LEGO education module, teams 1, 2, and 3 were assigned method 1, and teams 4, 5, and 6 were assigned method II. A written survey was collected at the end to measure what the participants learned from the LEGO education module.

4. RESEARCH RESULTS

4.1. Observations

During the first part of the LEGO education module, some teams took significantly longer than others to complete their submittals. The submittal times ranged from 5 mins to 10+ mins. Although it was not expected that teams would be able to fully complete method 1, teams proceeded much slower than expected with method II. At 30 minutes, all the teams working on method II were only approximately halfway complete. Therefore, the time was extended until the teams completed method II.

During the second part of the LEGO education module, some participants from team 2 who were working on the method I were overhead, saying that they were able to build from memory since they had already completed method II. It was noted that team 2 was very efficient - one participant was selecting the correct piece and handing them to another teammate who was constructing the

LEGO model. Similarly, Team 3, who had completed method II during part one, was attempting to build modular and had to be instructed by the facilitators to build stick-built. And, likewise, team 4, who had completed method I during part one, was attempting to build stick-built and had to be reminded by the facilitators to build modular.

4.2. Completion Times

During part one, team 2, who was working on method II, finished first at 60 minutes and team 3, who was working on method II, finished approximately 2 minutes later due to missing a LEGO piece. Team 1 did not finish method II. No team finished method 1. Only team 4 finished the first floor of method 1. Teams 5 and 6 only partially completed the first floor of method 1.

During part two, the first team to finish was team 2, who was working on method 1 at 39 minutes. Team 2 would have finished faster but had issues with their final inspection and had to complete a lot of rework. Team 2 was able to correct all the issues with their final inspection and had a fully complete and correct LEGO model. The next team to finish was team 3, who was working on method 1 at 49 minutes. Team 3 had issues with the final inspection and had to complete significant rework. Upon re-inspection, there were still items that were incorrect, but many things were improved. It was decided that the team's model was close enough to end the exercise. Team 1 did not finish method I.

The first team to finish method 2 was team 6 at 56 minutes, followed by team 5 and then team 4. Team 4 and 6 passed inspection and successfully completed method 2. Team 5 completed the project but did not pass the final inspection. It was decided that team 5's model was close enough to end the exercise.

4.3. Issues

During part one, once teams 2 and 3 finished method 2, and team 4 completed the first floor of method 1, all teams were asked to begin disassembling the LEGO sets and re-sort the LEGO pieces by floor. One issue encountered was that since team 1 did not complete method 2, and had all the LEGO pieces out on the table, they could not re-sort them by floor. Thus, they had to have all the pieces given to their group at once when working on method 1.

During part two, participants did not bring their LEGO bags back to the facilitator table. The facilitators ensured the proper LEGO sets were at each table after switching methods. The only exception to this was with team 1, as they were unable to re-sort their pieces and had to retain both the first and second floor during method 1. Since teams had their LEGO pieces at the same time as their submittal forms, teams were able to complete their submittals simultaneously as they began constructing.

4.4. Survey Results

Participants were surveyed at the end of the LEGO education module to gain an understanding of the background of those who participated and the outcome of the LEGO education module. The main goal of the survey was to understand who participated, what the participants learned, and if the participants enjoyed the LEGO education module. Participants were offered multiple ways to report their feedback through different question types. Multiple-choice questions, short answer questions, and scale rating questions were included in the 2-page survey. In total, 21 surveys were collected. There were 22 participants, but one participant left early, and a survey response was not collected. Of the 21 participants surveyed, 13 were Senior Undergraduate, 2 were Junior Undergraduate, 3 were Master's Graduate, 2 were Ph.D. Graduate, and 1 had no response. The participant's years of industry experience were also collected.

The survey asked a series of multiple-choice questions to probe if the LEGO education module achieved one of its main objectives: **increasing the participants' interest and knowledge of modular construction through an interactive project.** Participants were asked to consider if method 1 or method II would produce better quality construction, was faster to complete, caused less rework, cost less, had more RFIs, had better quality control, and was safer. An option was also given to participants to rate method 1 and method II as the same with respect to any of the above items. These results are shown in figure 4.

Survery Responses			
Question	Option 1	Option 2	Option 3
	Method 1: Stick-built construction with 2D plans, 2D elevations, and construction	**Method 2:** Modular construction with 3D design and 4D project schedule.	The same
Which method would be more effective in real construction?	2	18	1
Which method would produce better quality construction?	1	18	2
Which method was faster to complete?	2	19	0
Which method caused less rework?	2	19	0
Which method will cost less?	3	17	1
Which method had more RFIs?	20	1	0
Considering the QC plan your team submitted, which method is better to control quality?	3	16	2
Considering the safety plan your team submitted, which method is safer?	0	18	3

Figure 4. Survey responses to multiple-choice questions

Additionally, the survey asked a series of short answer questions to probe if the LEGO education module achieved another one of its main objectives: <u>increasing the participants' understanding of the benefits of 3D design with 4D scheduling over the use of 2D drawings.</u>

A few advantages of using a 4D schedule participants identified in their short answer responses were: showing project progression, visualization over time, coordination and clarity, and better tracking. A few advantages of using a 3D design that participants identified in their short answer responses were: easier to notice mistakes, easily identify what the final project will look like, better control the quality, clears answers to RFIs, and visualization.

Lastly, the survey asked a series of scale rating questions to probe if the LEGO education module achieved its final main objective: <u>creating a simulating hands-on educational opportunity to help students compare modular construction to stick-built construction.</u>

Participants were asked to rate if they liked the LEGO education module, if it fostered participation, and if it fostered teamwork on a scale of 1 to 10, with 10 being the highest rating. The average participant ratings were 9.1 for liking the education module, 9.4 for it fostering participation, and 9.4 for it fostering teamwork. Participants were also asked to rate how closely they felt the LEGO education module simulated, or allowed them to experience both stick-built and modular construction. The average participant rating for the education module's ability to simulate stick-built construction was 7.6, and the average participant rating for its ability to simulate modular construction was 9.6. These results are shown in figure 5.

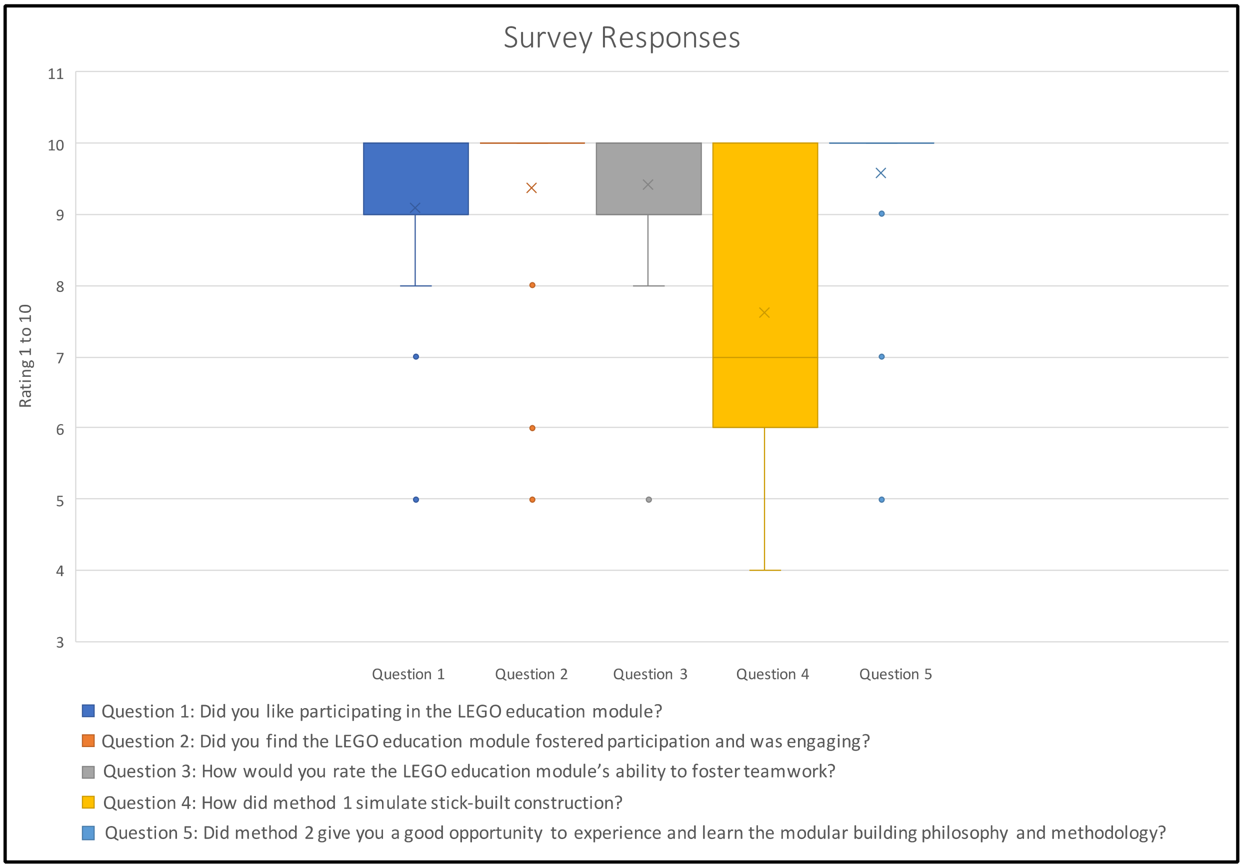

Figure 5. Survey responses to scale rating questions

5. CONCLUSION

The survey revealed that the LEGO education module was well received by the trial participants, as shown in figure 5. An unexpected result of the survey was that the participants did not find that method 1 did a good job of simulating stick-built construction, with an average score of 7.6 out of 10. Some participants also commented in the survey that the LEGO education module could be improved if more time was allotted to method 1, if method 1 was simplified, or if method 1 had better 2D plans and 2D elevations.

Overall, the survey results showed that the LEGO education module was successful at achieving the project's three main objectives: 1) increasing the participants' interest and knowledge of modular construction through an interactive project; 2) increasing the participants' understanding of the benefits of 3D design with 4D scheduling over the use of 2D drawings; and 3) creating a simulating hands-on educational opportunity to help participants compare modular construction to stick-built construction. As shown in figure 4, *there was a strong correlation of participants being able to identify the advantages of modular construction after completing the education module.*

The authors also acknowledge the limitation of this module. The current module has a complex 3D design with too many pieces, making it impossible for the participants to complete the module within a given time. The authors propose revising and upgrading the LEGO education module, addressing the issues and comments raised by the participants with more participants to properly validate the module. In particular, 1) method 1 should be significantly improved to simulate the stick-built method properly; and 2) both methods should be simplified or provided with better instructions and resources to help the participants complete the module on time. Also, AR/VR features can be added to enhance the visualization of a 3D model and to educate the benefits of BIM and AR/VR.

6. ACKNOWLEDGMENTS

The authors would like to give credit to Kreider and Crosby's LEGO Project Management Exercise for inspiring the idea for this research. The authors would like to acknowledge the UNLV Project Management and Construction Engineering Lab (PMCEL) members, Seung Song and Seungtaek Lee, for their help preparing for the LEGO education module's preliminary test. The authors would also like to acknowledge Bandana Shrestha for her support in beta testing the LEGO education module and for helping facilitate the LEGO education module on November 18, 2021. Also, the authors thank Autodesk for offering free licenses for academic use. The 3D model and 4D schedule were developed and presented to the participants using Autodesk software and suites. In addition, the authors acknowledge and give credit to LEGO as the authors used "Modular Modern Home" [31068] LEGO kits partially and adopted the main design/idea of the modular building.

7. REFERENCES

[1] McGraw Hill Construction. *Prefabrication and Modularization: Increasing Productivity in the Construction Industry.* Bedford, MA: McGraw-Hill Construction, 2011. [White paper].

[2] J. O. Choi, X. B. Chen, and T. W. Kim, "Opportunities and challenges of modular methods in dense urban environment," *International Journal of Construction Management*, vol. 19, no. 2, pp. 93–105, 2019.

[3] MBI Modular Building Institute, *Improving Construction Efficiency & Productivity with Modular Construction.* Charlottesville, VA: Modular Building Institute, 2010. [White paper].

[4] J. T. O'Connor, W. J. O'Brien, and J. O. Choi, "Industrial Project Execution Planning: Modularization versus Stick-Built," *ASCE Practice Periodical on Structural Design and Construction*, vol. 21, no. 1, 2016, doi: 10.1061/(ASCE)SC.1943-5576.0000270.

[5] J. T. O'Connor, W. J. O'Brien, and J. O. Choi, "Industry-wide Maximization Enablers for Higher Levels of Modularization," in *Proceedings of The First International Conference on Maintenance and Rehabilitation of Constructed Infrastructure Facilities (MAIREINFRA1),* Hosin "David" Lee, ed. International Society for Maintenance and Rehabilitation of Transport Infrastructures, pp. 1–6, 2017.

[6] R. Ghimire, S. Lee, J. O. Choi, J. Y. Lee, and Y. Lee, "Combined Application of 4D BIM Schedule and an Immersive Virtual Reality on a Modular Project: UNLV Solar Decathlon Case", *Int. J. Industrialized Constr.*, vol. 2, no. 1, pp. 1–14, 2021.

[7] J. O. Choi, B. K. Shrestha, Y. H. Kwak, and J. S. Shane, "Innovative Technologies and Management Approaches for Facility Design Standardization and Modularization of Capital Projects," *ASCE Journal of Management in Engineering*, vol. 36, no. 5, 2020, doi: 10.1061/(ASCE)ME.1943-5479.0000805.

[8] J. O. Choi, "A New Graduate Course on Modular Construction: University of Nevada, Las Vegas," in *Proceedings of 2018 Modular and Offsite Construction (MOC) Summit,* M. Al-Hussein, ed. University of Alberta Libraries, pp. 125–132, 2018.