Developing a Systematic Framework to Enhance Construction Procedure Design

Ali Shafaat
Lyles School of Civil Engineering
Purdue University
West Lafayette, IN
ashafaat@purdue.edu

Hossein Ebrahiminejad
School of Engineering Education
Purdue University
West Lafayette, IN
hebrahimi@purdue.edu

Farshid Marbouti
Charles W. Davidson College of Engineering
San Jose State University
San Jose, CA
farshid.marbouti@sjsu.edu

Monica Cardella
School of Engineering Education
Purdue University
West Lafayette, IN
cardella@purdue.edu

Amr Kandil
Lyles School of Civil Engineering
Purdue University
West Lafayette, IN
akandil@purdue.edu

***Abstract*— Construction projects approach design in different ways. While many consider design as the final built elements, the building process itself is often neglected. Construction projects contain intermittent operations that should be designed as well. This design is considerably different from conventional product design since the operation, without construction, is not tangible for students. Construction projects typically consist of many different activities occurring at different stages. In addition, uncertainty is an inseparable attribute of any construction project, which may result in project failure. These complex problems require a systematic solutions, which is a difficult task for novice designers. This study aims to develop a framework based on systems thinking, which not only helps students to understand components of the construction process, but also assists them in dealing with uncertainty, its sources, and its impacts. We suggest that the systemic problem framing of a project enhances the undergraduate construction students' understanding of construction activities and persuades them to take into account different factors which may cause variations in the project.**

Keywords— Construction engineering; Process design; Protocol analysis; Systems Thinking

I. Introduction

The Accreditation Board for Engineering and Technology (ABET) [1] defined engineering design as " the process of devising a system, component, or process to meet desired needs" (p. 3). Whereas Dym, Agogino, Eris, Frey, & Leifer [2] defined engineering design as "a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints." It is a complex cognitive process with multiple solutions, which involves divergence–convergence questioning, systems, decision making, and teamwork approaches [2].

Although distinguishing between design and engineering as distinct concepts is challenging [3], "engineering design" is currently considered as one concept [4]. Design is a human activity with a complex, temporal working system trajectory toward objectives; therefore, design processes can be considered as projects [5]. A working system is a socio-technical system, including social and machines using information, technology and other resources that serves customers' needs [6].

Systems thinking is an essential aspect of engineering design cognition [2, 7-9]. Systems thinking in engineering is supported by researchers, practitioners, and preeminent national organizations. It is even more critical in engineering design, given that engineering designers are challenged by interconnected, wide-ranging, and non-linear variables [10].

Based on Vincenti's classification [11], construction design is categorized as incremental and normal rather than a radical concept. Moreover, Friedman [12] looked at available design definitions and found three shared attributes: i) the word design refers to a process, ii) this process is goal-oriented, and iii) the set of goals consists of solving problems, meeting specific needs, improving situations, or creating something new or useful.

II. Construction Design

Construction can be very difficult to design as a system because it should accommodate many different constraints, such as the availability of in-house technology, safety, and budget. There are other factors that make construction design even more challenging. Another problem with designing construction projects is the lack of repetition. The designers also have to deal with the duality of the objectives when responding to the client's needs and maximizing their company's gains.

Several outcomes can be listed for construction design. These outcomes may include: developing a clear scope of work, statement of work, plan of activities, logistics, traffic control, budget, schedule, writing procedures and specifications, drawings, design details for temporary structures, and bills of quantity. Architects, field engineers, consulting engineers, quantity surveyors, and interior designers can contribute to the construction design process.

Although the process and product are very interrelated, designs are typically complete by different agencies without much communication [13]. The product, or final built outcome, is often designed by consultancy companies (or individuals), while the contractors are in charge of the design of the construction process. Unfortunately, process design does not receive enough attention from the construction researchers and it is almost absent from construction literature. On the other hand, process design is very well defined in chemical engineering as central to the field. Process design is the design of processes for desired physical and/or chemical transformation of inputs [14]. In the field of operation management, designing processes [13] include: i) process mapping (using symbols), ii) improve Processes, iii) define process performance, and iv), determine process throughput, cycle time, and work in process.

Although the final product characteristics usually determine construction procedure, the construction process dictates some characteristics of the final design for some projects, such as marine structure. The reason is the loads during construction, shipping, and installation are beyond the operational conditions. In many projects, designing the construction takes more effort than designing the fabricated structure. For example, construction in the presence of high water is challenging and necessitates significant planning. In relatively small projects—when the contractors are in charge of designing the whole project product and process—the design process also involves both the construction and what will be built.

III. Research Questions

A number of research studies are available on product design and engineering design stages. However, very few scholars studied the design of the construction process. Since construction projects are complex, with multiple activities and configuration, it is very challenging for novice designers to come up with clear solutions. To help them discover and realize the outcomes and assist them in problem scoping and framing, a structure will be provided for the teams. This structure is based on system engineering models. This study aims to answer the following research question: To what extent does a systemic structure improve the design of construction projects for novice designers?

IV. Study Design

Engineering design is a complex, cognitive activity. One of the highly accepted ways for investigating engineering design is protocol analysis, which results in a relatively accurate understanding of designers' practices. Protocol analysis is a well-established empirical research tool for studying design processes [15]. A protocol is designed to capture the content of the statements rather than the rationale of their occurrence [16].

In addition to protocol analysis, students' design techniques using other methodologies—including interviews, feedback analysis, and observation— will be used for a better understanding of construction engineering. These techniques are categorized differently in the research method classification. Although observation and interviews are qualitative, feedback and protocol analysis are mixed research methods. "Mixed Methods" are methods that have the potential to combine methodologies, especially qualitative and quantitative methodologies [17]. Cardella successfully [18] used these techniques in a framework called triangulation to study engineering students' use of mathematical thinking.

In order to answer the research question of this study, we combined three methodologies: 1) a verbal protocol study of Construction Engineering and Management (CEM) students' detecting potential variations in construction design practices; 2) a study of CEM students' evaluation of the new method using interview questions; and 3) assessing the quality of communication by observing the students' feedback and evaluations.

The interview questions provide characterizations of what engineering students experience and learn from the systemic structure applications and allow students to describe their experiences in their own words. The observations provide an opportunity to evaluate the students' reports on using construction design, their feedback, and an opportunity to identify additional factors that students witness. The verbal protocol analysis of student teams' think-aloud data while working on design problems provides additional insights into engineering students' cognitive processes while engaged in construction design. These studies also allow an opportunity to identify differences between the two designs and assess the effectiveness of the new method in persuading the students to detect more details and perceive potential variations. The findings from this project can also be used to investigate CEM student systems thinking in future research.

V. Plan of Study

To conduct the study, first we focused on CEM students as novice designers. Then, we developed a design workshop for a class of sophomore CEM students.

A. Participants

This study was designed as a workshop for students registered in CEM 280, Construction Engineering Professional Development I in the CEM Division of the College of Engineering at Purdue University. CEM students' degree plan requires three internships. For the first internship, students typically find a sponsor firm or are placed by the division, and then either continue with the sponsor company for the other two summers or find another company that is a better fit. Thus, a senior student in CEM division, for instance, has already spent three summers in construction companies, while a sophomore has experienced one internship.

All engineering students at Purdue are required to take two first-year engineering courses, in which they learn about engineering design processes. Therefore, the students are exposed to design process and they are expected to be familiar with the engineering design process concepts.

CEM 280 is a required course for CEM students; this course prepares students for professional practice in construction engineering, including information on Careers and Issues in Construction, History and Culture of the U.S. Construction Industry, Engineering Ethics, and Preparation for Leadership. Also, students receive help with their plan of study and become more familiar with the division and the program. This course enhances students' written and oral communication skills. CEM 280 is typically offered during the spring semester and followed by Construction Engineering Professional Development II, CEM 380, in the following fall semester.

B. Data Collection and Analysis

The class met Tuesdays and Thursdays for one-hour class sessions. The whole study takes two weeks (four sessions). The students, in teams of four, will be asked to design two similar real life construction projects that have previously been built. Before the second design practice, the class will begin with a twenty-minute lecture on the new systematic method. This new method is designed to model the project based on systems engineering. Having a short lecture before the design helps the students practice the material more effectively. The teams will have half an hour to design the projects and they will be asked to think aloud and audio record all the conversations and design processes during the two 30-minute design sessions. Later they will be asked to individually evaluate their team's design process in each session. They will also provide peer feedback on another team's design work. This peer evaluation will be double blind in order to reduce the pressure of criticizing classmates' work.

Students also will be asked to modify their design based on their peers' feedback. At the end the students will be asked to compare the advantages and disadvantages of the new method based on their experience during the design and when giving feedback to other teams. To avoid being influenced by the lectures, students will provide feedback on both design works during session 3. The design works, feedback, and individual evaluations will be graded by one of the researchers. The feedback and design outcomes have been slightly structured in order to help students in communication and articulation. This structure also helps the students to compare the two design outcomes.

In addition to the soundness of the solutions and plans, the ability of the designers to recognize possible variations will be evaluated to compare the design outcomes. To address this issue, the robust design protocol developed by Cummings, Shafaat, and Oaks [19] will be used.

VI. Next Steps

The first phase of this study has been started. The two problems have been defined and some preliminary data has been collected. The next steps will be collecting more data and transcribing the audio recordings. The data analysis and comparison are the next steps and will be completed during summer 2016.

REFERENCES

[1] ABET, Criteria for Accrediting Engineeering Programs, Engineering Accreditation Commission: Baltimore, MD 2007. PP. 3.

[2] Dym, C.L., et al., *Engineering design thinking, teaching, and learning.* Journal of Engineering Education, 2005. 94(1): p. 103-120.

[3] Moody, S., *The role of industrial design in technological innovation.* Design Studies, 1980. **1**(6): p. 329-339.

[4] Petroski, H., *Design paradigms: Case histories of error and judgment in engineering*. 1994: Cambridge University Press.

[5] Ralph, P. and Y. Wand, *A proposal for a formal definition of the design concept*, in *Design requirements engineering: A ten-year perspective*. 2009, Springer. p. 103-136.

[6] Alter, S., *Metamodel for service design and service innovation: Integrating service activities, service systems, and value constellations.* 2011.

[7] Katehi, L., G. Pearson, and M. Feder, *Engineering in K-12 education.* Committee on K-12 Engineering Education, National Academy of Engineering and National Research Council of the National Academies, 2009.

[8] Ottino, J.M., *Engineering complex systems.* Nature, 2004. 427(6973): p. 399-399.

[9] Schunn, C.D., *Engineering educational design.* Educational Designer, 2008.

[10] Lammi, M. and K. Becker, *Engineering design thinking.* 2013.

[11] Vincenti, W.G., *What Engineers Know and How They Know It Analytical Studies From Aeronautical History.* 1990.

[12] Friedman, K., *Theory construction in design research: criteria: approaches, and methods.* Design studies, 2003. 24(6): p. 507-522.

[13] Slack, N., S. Chambers, and R. Johnston, *Operations management*. 2010: Pearson education.

[14] Munir, M. T., Yu, W., & Young, B. R.,Recycle effect on the relative exergy array. Chemical Engineering Research and Design, 2012, 90(1), 110-118.

[15] Cross, N., K. Dorst, and H. Christiaans, *Analysing design activity*. 1996: Wiley.

[16] d'Astous, P., et al., *A Coding Scheme to Analyze Activities in Technical Review Meetings.* Psychology of Programming Interest Group, 1998: p. 5-7.

[17] Johnson, R.B. and A.J. Onwuegbuzie, *Mixed methods research: A research paradigm whose time has come.* Educational researcher, 2004. **33**(7): p. 14-26.

[18] Cardella, M.E., *Engineering mathematics: an investigation of students' mathematical thinking from a cognitive engineering perspective*. 2006: University of Washington.

[19] Cummings, A. T., Shafaat, A., & Oakes, W. C. , Using robust design as a conceptual framework to understand expertise. In *Frontiers in Education Conference (FIE), 2015. 32614 2015. IEEE* (pp. 1-6). IEEE.