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A CASE STUDY ON DESIGN SCIENCE RESEARCH AS A METHODOLOGY FOR DEVELOPING TOOLS TO SUPPORT LEAN CONSTRUCTION EFFORTS

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ABSTRACT

Effective application of lean theory in construction generally requires tools and/or processes to facilitate implementation. Last Planner System®, A 3 problem solving, plus/delta and pull scheduling sessions are a few examples. These kinds of tools assist construction participants in making the shift from abstract theories to project application. As innovation in this area is constantly occurring in the lean community, methodologies for developing new tools warrant consideration and testing.

Design Science Research (DSR) is a methodology that was strongly recommended by facilitators during the 2012 International Group for Lean Construction Summer School program in San Diego, CA. This paper uses a project that attempted to develop a trust-building tool as a case study to analyze the effectiveness of DSR as a methodology. The results of the project show support for the continued application of DSR methodology in the development of tools and processes supporting lean construction efforts. It was determined that the flexibility and iterative evaluation loop inherent to DSR were effective at providing a framework for the tool created in the case study project. However, the comparative need for time associated with iteration may limit interested researchers' ability to apply DSR to future projects.

KEYWORDS

Lean construction, action learning, process, design science research, constructive research.

INTRODUCTION

The continued dissemination of lean theory in the construction industry isheavily dependent on the ability of potential adopters to overcome implementation barriers and effectively apply lean principles to their projects and teams. According to Alarcon, et al. (2005), a variety of implementation barriers exist such as lack of training, lack of self-criticism and weak communication among participants, among others. In order to overcome these barriers, adopters need tools, techniques and/or

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processes to help bridge the gap between an understanding of the theory itself, and what the application of that theory actually looks like on a job site.

There have been many tools, techniques and processes (hereafter referred to collectively as tools) developed that aim to assist participants in making the transition from theory to application. Some tools, such as Last Planner System®, A3 problem solving, plus/delta and pull scheduling sessions are regular components of many project teams' efforts. Other tools like the airplane game, Parade of Trades (a.k.a., the dice game) and the Red Bead Experiment are geared towards introducing and teaching lean theory to those considering implementation. Many lean construction pioneers first "ah-ha" moments came as a result of tools such as these.

As innovation in this area is constantly occurring in the lean community, with new tools emerging regularly, methodologies supporting tool development warrant consideration and testing. This paper uses a research project that attempted to develop a trust-building tool as a case study to analyze the effectiveness of one particular methodology – Design Science Research (DSR). The use of DSR as a research methodology was strongly encouraged by the facilitators, Dr. Lauri Koskela and Dr. Carlos Formoso, during the 2012 International Group for Lean Construction Summer School program in San Diego, CA.Similar to Rocha, et al. (2012), this paper provides a review of DSR methodology followed by details about how DSR was implemented in a particular case study including feedback regarding the strengths and weaknesses of this methodology for the continued development and innovation of tools to support lean construction efforts.

DESIGN SCIENCE RESEARCH

Design Science Research methodology, also called Constructive Research in accounting literature (Lukka, 2003), has received attention and support in fields such as business administration, information systems and technology, medicine, and engineering research (Kasanen and Lukka, 1993; Lukka, 2003; Van Aken, 2004; Hevner, et al., 2004). This wide-spread adoption is likely due to DSR's apparent ability to align the academic side of a given field with its industry counterpart.

It has been suggested that DSR is capable of assisting with the relevance or utilization problem that exists in many academic fields (e.g.Van Aken, 2004; Kaplan and Johnson, 1987). In management research, this issue has been called the "rigor-relevance dilemma" (Whyte, 1991). Van Aken explains that this dilemma occurs when "theory is either scientifically proven, but then too reductionistic and hence too broad or too trivial to be of much practical relevance, or relevant to practice, but then lacking sufficient rigorous justification" (Van Aken, 2004, pp. 221). The goal of DSR is to "produce innovative construction, intended to solve problems faced by the real world and, by that means, to make a contribution to the theory of the discipline in which it is applied" (Lukka, 2003, pp. 1).

Generally speaking, DSR appears to be a good fit for research in lean construction because of the field's "applied" nature. Researchers have suggested that industry players, namely architects, engineers and urban planners, deal with problems that can be appropriately resolved using DSR (Van Aken, 2004). By selecting a methodology that supports real-world application, researchers might be able to avoid what Meredith, et al. (1989) decried as research that is high in "academic prestige" at the expense of relevancy to real-life problems.

DSR GUIDELINES

The guidelines for DSR, as published by Hevner, et al. (2004), are provided in Table 1 to create the framework for the discussion regarding the differences between DSR and more "traditional" research methods.

Table 1: Design Science Research Guidelines (Hevner, et al., 2004)

	Guideline	Description
1	Design as an artifact	DSR must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
2	Problem relevance	The objective of DSR is to develop technology-based solutions to important and relevant business problems.
3	Design evaluation	The utility, quality and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
4	Research contributions	Effective DSR must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
5	Research rigor	DSR relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
6	Design as a research process	The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
7	Communication of research	DSR must be presented effectively both to technology-oriented as well as management-oriented audiences.

A Model for DSR

DSR's model shows similarities to the general structure of Van Strien's (1997) "regulative cycle". Van Strien's cycle is made up of five main steps:

1. Identification of a problem
2. Diagnosis of the problem situation
3. Creation of a plan of action
4. Intervention aimed at affecting change
5. Evaluation of the new situation

The various components of this cycle are included in a model for DSR implementation, see Figure 1, created by Vaishnavi and Kuechler (2007). In addition to Van Strien's steps, the model includes representations of the knowledge transfer or flow occurring between the steps and also the outputs associated with each of the steps.

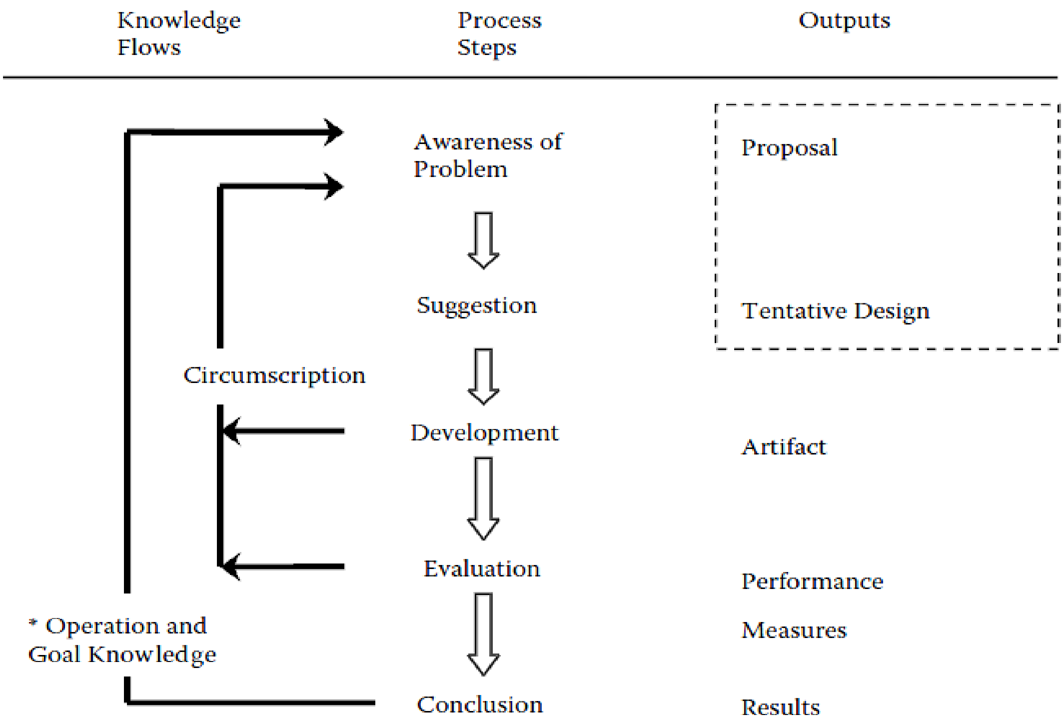

Figure 1: A Model for Design Science Research (Vaishnavi and Kuechler, 2007)

One of the key features of DSR is the iterative nature it requires. The development and evaluation stages provide feedback for an improved awareness of the problem and more effective suggestions for its solution until satisfactory results are achieved. This model is similar to those proposed by various quality management theorists. The Deming Cycle consists of four similarly simple steps: Plan-Do-Check-Act (PDCA) (Deming, 2000). Each of these approaches to improvement could be considered forms of action learning.

Descriptive vs. Prescriptive Research

Early work and conceptual support for DSR were provided by Simon's (1996) seminal book, The Sciences of the Artificial. In his work, Simon describes a difference between naturally occurring and artificially occurring phenomenon. March and Smith (1995) point out that scientists can contribute to not only the study of these artificial phenomena, but also the creation of them. This dual capacity allows for scientific involvement in both sides, as opposed to natural phenomena which by definition occur without intervention and can merely be described or explained.

According to the work of March and Smith, natural science, or more traditional research in the "hard sciences," is generally aimed at understanding and explaining reality, and can thus be classified as descriptive research. Alternatively, DSR attempts to *create* things that serve specific purposes or needs (Denning, 1997). Products from design science are tested against the value or utility they bring, generally based on the value-determining question – "does it work?" (March and Smith, 1995, pp. 253) This type of work is classified as prescriptive research. In other words, where "natural sciences are descriptive and explanatory in intent, design science offers prescriptions and creates artifacts that embody those prescriptions"

(March and Smith, 1995, pp. 254). Hevner, et al. (2004) described the difference and association between the two as follows:

"The goal of [natural] science research is truth. The goal of design science research is utility… Our position is that truth and utility are inseparable. Truth informs design and utility informs theory." (Hevner, et al., 2004, pp. 80)

Table 2, adapted from Van Aken (2004), describes the main differences between the two approaches.

Table 2: Main Differences between Descriptive and Prescriptive Research (Van Aken, 2004)

Characteristic	Descriptive Research	Prescriptive Research
Dominant paradigm	Explanatory sciences	Design sciences
Focus	Problem focused	Solution focused
Perspective	Observer	Player
Logic	Hindsight	Intervention-outcome
Typical research question	Explanation	Alternative solutions for a class of problems
Typical research product	Causal model; quantitative law	Tested and grounded technological rule
Nature of research product	Algorithm	Heuristic (hands-on)
Justification	Proof	Saturated evidence

For additional analysis and exploration on the differences between descriptive and prescriptive research, please refer to Holmström, Ketokivi and Hameri(2009).

The "applied" nature inherent to lean construction research can be viewed as being highly prescriptive in nature. We use innovative tools to create or suggest an intervention and affect the resultant outcome. The focus is on a solution that is created, tested, evaluated and iterated in an effort to achieve a desired outcome. The success of the tool is measured by its ability to achieve the prescribed goal. It is heuristic in nature in that it provides an alternative set of possible solutions for a problem and is then evaluated on a trial and error basis.

POTENTIAL BENEFITS AND RISKS

Testing tools in the context of their anticipated application introduces additional variables to the research design that may be difficult to manage. Similar to some clinical research, the heuristic approach can make it difficult, if not impossible, to draw conclusions about causation. However, the ability to test tools in the context of their designed use also provides validity that can arguably be lacking in true laboratory experiments. Van Aken (2004) suggests that despite its weaknesses, sufficient supporting evidence can be obtained using this method, in addition to improved assurances of effectiveness in the intended context of application. In this way, the solution can be tested without being overly reduced by the need for quantification, possibly giving more holistic results. The starting point is what

Pawson and Tilly (1997) called the basic realist formula: *mechanism* + *context* = *outcome*.

Table 3 summarizes known potential benefits and risks of constructive research, or DSR, as listed in Lukka's (2003) analysis of the methodology.

Table 3: Potential Benefits and Risks of Design Science Research (Lukka, 2003)

Benefits	Risks
Access to new interesting research sites	High relevance of study results can be perceived by the participants as being "too delicate" to be published (Lukka, 2003, p. 13)
Participants get critical analysis of relevant problems	Cannot maintain the commitment of the target organization or participant
Gap between research and practice is narrowed	Participants fear losing control of business secrets
Practitioner has interest in providing honest and relevant data	Anticipating and managing side-effects or confounding variable (March and Smith, 1995)
Demands thorough prior knowledge in order to be implemented	Neutrality of the researcher
	May be viewed by journal editors and peer reviewers as an un-established methodology

As with any risks, these potential risks need to be analyzed in the context of the specific project and managed to avoid any negative impacts. Similarly, these potential benefits should be highlighted to maximize their positive impacts.

THE CASE STUDY – DEVELOPMENT OF A TRUST-BUILDING TOOL

As previously mentioned, this paper is a case study on a project that used DSR in order to develop a trust-building tool for the construction industry (Smith, et al., 2014). The remainder of this paper provides detailed results, analysis and discussion regarding how DSR was implemented and its strengths and weaknessesin this particular case study.

CONTEXT

The case study project was conducted by multiple researchers over the course of approximately 2 years as part of a graduate degree. The goal of the project was to create a tool that assisted users in their efforts to build interpersonal trust with construction project participants. Trust was viewed as a key attribute necessary for the collaboration inherent to lean project delivery. The project used a mixed methods design within the phased framework suggested by DSR (see Figure 1). Table 4 describes the overall project approach including specific embedded methodologies used by the researchers. Some details regarding implementation of each specific methodology within the DSR framework are included in Smith, et al. (2014) and others are forthcoming in pending publications.

Table 4: Case Study Schedule of Events and Methodologies

Project Phase		Description	Approximate Duration
I		Awareness of the Problem	1 year
	A	Semi-structured Interviews	1 month
	B	Project/Site Observations	1 month
	C	Iterated Questionnaire	10 months
II		Suggestion of a Solution	Milestone
III		Development	9 months
	D	α-Testing: internal analysis	3 months
	E	β-Testing Stage I: first –run study with student participants	3 months
	F	β-Testing Stage II: case study application with industry participants	3 months
IV		Evaluation – conducted following each stage of development phase	7 months
V		Conclusion	Milestone

Using the same designations included in Table 4, Figure 2 graphically describes the sequencing adopted for various components of the project.

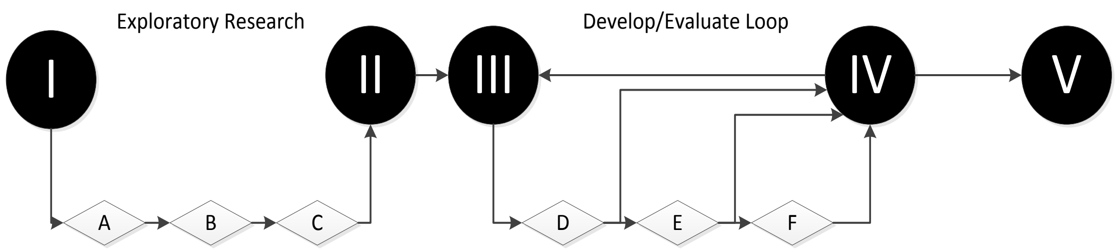

Figure 2: Sequencing of Events and Methodologies

As described in Table 4 and Figure 2, the case study's research teamexplored the topic of trust in construction using semi-structured interviews and observations to inform an iterative questionnaire. These exploratory methods were used to confirm relevance of the proposed research topic to industry participants. This process also allowed for the team to narrow down potential research directions and research questions. The interviews were comprised mainly of open-ended questions designed to avoid limiting participants' responses. The combination of these methods effectively provided an awareness of a general problem that exists in the construction industry relating to low levels of interpersonal trust between key project personnel.

The research team in the case study then suggested a possible solution for the low level of trust – in this case a tool to assist project participants in their efforts to build trust. This suggestion was immediately followed by three levels of development, the evaluation, assessment and feedback collected at each level informing the next iteration of the trust-building tool. After the initial development stage (α-Testing) which consisted of internal analysis and basic pilot testing, an updated version of the tool was tested in a quasi-experimental design using students as subjects, followed by a series of case studies using industry practitioners as subjects. Details on the artifact/tool created in this case study can be found in Smith, et al. (2014). This approach provided support for some of the known risks associated with DSR while at the same time capitalizing on the known benefits (see Table 3).

DSR STRENGTHS

To assess the strengths of DSR, the final results of the case study project must be analyzed. Success, in this instance, is truly determined by whether or not the developed tool accomplishes what it was designed for (March and Smith, 1995). However, in an effort to provide an exhaustive review of the overall methodology, ancillary results from the various phases of the project will also be analyzed.

Complementary Phasing

There were two major work packages in the case study project. The first package consisted of Phases I and II which were primarily descriptive in nature. Results from the first package created the starting point for the second package consisting of Phases III and IV which were primarily prescriptive in nature. Many research projects consist of only one of these two work packages. The case study project team felt that in comparison to the many projects consisting of only one of these two, DSR's combination of the complementary approaches provided for improved development of useful tools by ensuring that the tools provided solutions to real problems.

This complementary phasing in DSR also supports a holistic approach to critical thinking and problem solving. One researcher recommended this model as appropriate for any graduate student that has interest in a specific topic but has yet to develop a specific research question. It was suggested that a focus on the identification of an actual real-world problem during the "awareness of the problem" phase, although time consuming, was very valuable in the overall creation of an effective tool.

Flexibility

Most data collection methodologies can fit within the DSR framework. This allows the researcher to select the most appropriate data collection techniques (e.g., simulation, observation, case study, surveys, etc.) for the various phases of the project. This flexibility allows for a wide range of data types and data sets which also can serve to strengthen the final results.

Additionally, an emphasis on becoming aware of the problem during Phase I can prevent problem solvers from becoming mistakenly focused on a problem or a question that is of little interest or value to the relevant industry. Maintaining flexibility during the problem definition supports more useful solutions in the end.

Respondent Engagement

Early engagement by respondents on the exploratory end of the project seemed to create increased interest and involvement on the development end. It also supported the idea that both the problem and the solution would be relevant to those in industry. This increased interest greatly assisted in the repetitive testing and data collection portions of Phase III/IV. These observations supported a number of Lukka's (2003) proclaimed benefits from Table 3.

Useful Tool Creation through Iteration

As mentioned, a successful resultant tool is the best indicator of how effective DSR methodology is. The results from Phase III/IV/V of the case study, both quantitative and qualitative, showed support for the project's hypothesis that interpersonal trust could be actively managed by using a tool like the one that was created. The effectiveness of the tool improved with each iteration of the develop/evaluate loop critical to DSR, and utilization of multiple groups and multiple methodologies allowed for triangulating support for the hypothesis. In the end, the final version of the tool successfully helped three different industry participants build trust with construction project counterparts.

Theory Development

Finally, the controlled but flexible DSR methodology allowed for concurrent theory development during the course of the project. In this case study, the theoretical development was a new model for trust-building. The model benefited from DSR iterations which allowed for specific components to be added or removed as dictated by the latest results.

DSR WEAKNESSES

Project Duration

The completion of a DSR project as modelled by the case study can be time consuming. Many practitioners and/or researchers (graduate students and otherwise) are not able to devote as much time to the iterative develop/evaluate loop as may be needed. Similarly, excessive requests on respondent time, particularly industry participants, may lead to a lack of commitment as described by Lukka (2003).

Confounding Variables

The project team found that testing a tool in the context of its anticipated application created potential confounding variables. The lack of experimental control consistent with construction jobsites and everyday interpersonal interactions makes it difficult to remove unanticipated variables that could potentially affect study results. The inability to draw specific conclusions is a weakness that was also identified by previous researchers.

CONCLUSIONS

The results of the project show support for the continued application of DSR methodology in the development of tools, techniques and processes supporting lean construction efforts. It was determined that the complementary phasing, flexibility and iterative evaluation loop inherent to DSR were effective at providing a framework for tool creation in the case study project. However, the comparative need for adequate time to allow for iteration may limit interested researchers' ability to apply DSR to future projects. Also the potential for confounding variables resulting from testing tools in their anticipated context necessitates preventative management (e.g., mixed methods data triangulation) on the part of the interested researcher.

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