DESIGN SCIENCE RESEARCH IN LEAN CONSTRUCTION: PROCESS AND OUTCOMES

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ABSTRACT

Design science (or constructive) research is a mode of producing scientific knowledge. It differs from explanatory research whose goal is to describe, understand and eventually predict phenomena of a particular field. Alternatively, the goal of design science research is to develop scientifically grounded solutions that are able to solve real-world problems. In this way, it establishes an appropriate link between theory and practice, strengthening the relevance of academic research. This paper discusses the design science research approach and illustrates through the analysis of two Ph.D investigations how it can be adopted in lean construction. In this paper, the outcomes and the research process adopted in these investigations are presented. At the end, some conclusions concerning the outcomes achieved and the activities involved in conducting design science in lean construction are discussed.

KEYWORDS

Theory, design science, constructive research.

INTRODUCTION

Scientific disciplines can be organised in three groups (i.e. formal sciences, explanatory sciences, and design sciences) depending on the mode of producing scientific knowledge (Van Aken 2004). In formal sciences such as mathematics knowledge is build by creating systems of abstract propositions and testing their logical consistency (Van Aken 2004). Differently, in explanatory sciences, knowledge is related to descriptions, explanations, or predictions of observable phenomena (Van Aken 2004). In these sciences, phenomena are described and explained by proposing scientific claims and empirically testing their validity (March and Smith, 1995). Alternatively, in design sciences knowledge is produced through the creation and implementation of a solution that is able to manipulate or alter a particular phenomenon (Vaishnavi and Kuechler 2007).

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Design science research (DSR) or constructive research is an approach for conducting research in lean construction, and more specifically in construction management. According to AlSehaimi et al. (2012), such approach can assist in the development and implementation of innovative managerial tools, tackling different managerial problems of construction. The same authors further argue that in so doing, constructive research will better connect research and practice, and thus strengthen the relevance of academic construction management. Koskela (2008) argues that repositioning construction management as a design science rather than an explanatory science will help to solve problems affecting this discipline such as the problem of relevance.

In fact, several studies carried out by the Lean Construction Community can be classified as DSR since they develop solutions that aim to solve practical problems while also providing a theoretical contribution. The Last Planner System of Production Control is an example of a solution. However, most studies that have contributed to its development were not positioned as DSR. A few recent research initiatives (e.g. Bonatto et al. 2011) have explicitly adopted DSR as a research approach. However, it is necessary to further explore how this approach can be explicitly adopted in Lean Construction research.

This paper discusses the research process and outcomes involved in developing DSR in construction management. In order to demonstrate the suitability of this approach two recently completed Ph.D. investigations strongly related to Lean Construction are presented (Tezel 2011 and Rocha 2011). The first investigation focuses on visual management (VM) and the second one on mass customisation (MC), which are themes closely related to lean construction. MC seeks to provide customised products, which meet clients' specific requirements, while striving to maintain cost and delivery time similar to mass-produced products. It emphasises production efficiency and generation of value, which are also goals of lean construction. VM is concerned with the employ of visual (sensory) tools and aids at workplaces to increase the self-management ability of the workforce. VM is one of the founding blocks of the Toyota Production System and supports process transparency, which is a lean construction principle.

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THE RESEARCH PROCESS

Several authors such as March and Smith (1995), Kasanen (1993), Lukka (2003), Vaishnavi and Kuechler (2007), and Holmstrom et al. (2009) propose steps for conducting DSR. March and Smith (1995) state that the constructive research process has two fundamental activities: creating things that serve human purposes and evaluating their performance in use. Kasanen (1993), Vaishnavi and Kuechler (2007) and Lukka (2003) propose more detailed research steps, as depicted in Figure 1.

The notion that the research process is not linear but involves loops is underlined in the steps presented on the literature. These loops are defined by Vaishnavi and Kuechler (2007) as circumscriptions and involve gaining an understanding that is only achieved by the specific act of construction. Circumscriptions can occur at the development and evaluation steps and lead to a revision of the problem awareness, creating a new cycle of design construction (Vaishnavi and Kuechler 2007). Another loop can also happen at the conclusion stage, feeding back into the problem awareness step and creating a new research cycle. The construction step also involves loops. It is inherently iterative and incremental (Hevner et al. 2004): the testing step provides essential feedback for the construction step in terms of the quality of the development process and the solution itself. In fact, the application and test of a solution precede its complete development because only through its study and use it is possible to formalize the models, constructs, and methods on which it is based (March and Smith 1995). Furthermore, prior and after the construction, hypothesis on how the solution will behave are created and deviations from the expected behaviour will lead to questioning, search for explanations, and ultimately to a modification of the solution (Manson 2006).

The development (or construction) of a solution and its evaluation are at the heart of the design science approach and are highlighted in all sequences of steps analysed (Figure 1). Nonetheless, a challenge lies in defining whether a solution is complete and the iterative activities of constructing and evaluating a solution should be terminated. Hevner et al. (2004) shed some light on this. They state that a solution is complete and effective when it satisfies the requirements and constraints of the problem it was meant to solve. Hevner et al. (2004) point out that utility, quality, and efficacy are parameters for evaluating a solution.

<table>
<tr><th></th><th>March and Smith (1995)</th><th>Kasanen (1993)</th><th>Vaishnavi and Kuechler (2007)</th><th>Lukka (2003)</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2"></td><td rowspan="2">Find a problem with practical relevance and that also has research potential</td><td rowspan="2">Awareness of the problem</td><td>Find a practically relevant problem with potential for theoretical contribution</td></tr>
<tr><td>Assess the likelihood for long-standing research collaboration with the target organizations</td></tr>
<tr><td>2</td><td></td><td>Obtain an understanding of the topic</td><td></td><td>Obtain an understanding of the problem from a practical and theoretical perspective</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Create things that serve human purposes</td><td rowspan="2">Innovate, namely construct a solution</td><td>Suggestion of a tentative design</td><td rowspan="2">Innovate a solution idea and develop a solution that solve the problem at hand</td></tr>
<tr><td rowspan="2">Further development of the tentative design and implementation</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Evaluate the performance of things in use</td><td rowspan="2">Demonstrate that the solution works</td><td rowspan="2">Implement the solution and test how it works</td></tr>
<tr><td>Evaluation of the design against a previously defined criteria</td></tr>
<tr><td rowspan="2">5</td><td></td><td>Present its connection to theory and the research contribution</td><td rowspan="2">Conclusion</td><td>Identify and analyse its theoretical contribution</td></tr>
<tr><td></td><td>Assess the scope of application of the solution</td><td></td></tr>
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Figure 1: Design science research steps according to the literature (Rocha, 2011)

OUTCOMES

Several outcomes for DSR (Figure 2) have been proposed. March and Smith (1995) propose four outcomes in the information technology arena: (i) constructs, which form the vocabulary of a specific domain and constitute the conceptualisations for describing a problem and specifying its possible solutions; (ii) model, i.e. a group of premises that express relationships among constructs; (iii) method, that is a set of steps for executing a task; and (iv) instantiations, which are implementation(s) of constructs, models, and methods, demonstrating the feasibility of the conceptual elements that the solution contains.

Hevner et al. (2004) described three outcomes of design science: the design artefact, its construction and evaluation processes. Design artefacts are here taken to include the constructs, models or methods, which are designed or constructed during the research process. Hevner et al. (2004) further argue that there may be a need for a combination of different types of artefacts to be produced to enable implementation of innovation in organisations, describing from an IT perspective a combination of technology-based artefacts (e.g., system conceptualizations and representations, practices, technical capabilities, interfaces, etc) organisation-based artefacts (e.g., structures, compensation, reporting relationships, social systems, etc), and people-based artefacts (e.g., training, consensus building, etc).

Better theories are also an outcome. DSR creates better theories by building solutions that test a particular body of knowledge, having a similar role to experiments in natural sciences (Vaishnavi and Kuechler 2007). The relationships among the solution' elements usually become more visible during either the construction or evaluation steps, contributing in refuting or elaborating elements of existing theories (Vaishnavi and Kuechler 2007). The testing discussed by Vaishnavi and Kuechler (2007) does not seem to involve a whole theory, but a part of it (e.g. a set of concepts, a taxonomy) that are specifically used in a solution. In this way, such outcome contributes in refining or improving part of an existing body of knowledge.

Technological rules are another type of outcome. Technological rules are prescriptions for a class of problems, linking a solution to a particular goal in a certain field of application (Van Aken 2004). They usually involve the statement of a goal and the prescription for accomplishing it. For example, if X is to be achieved (goal), than Z should have parameters X and Y (prescription). A technological rule needs to be grounded on scientific knowledge (Van Aken 2004), i.e. it is necessary to justify from a logical viewpoint why a rule is able to achieve a particular goal. Furthermore, it should also be thoroughly study and tested in a series of contexts of its intended application to be as sure as possible of its effectiveness (Van Aken 2004).

Substantive theories and formal theories, discussed by Holmstrom et al. (2009) are other possible outcomes. For defining these two types of theory, Holmstrom et al. (2009) build upon Glaser and Strauss (1967) who discusses theories in sociology. According to the latter authors, a substantive theory is that developed for a substantive or empirical area such as patient care, and delinquency, whereas a formal theory is that developed for a formal or conceptual area such as stigma, authority, power, and reward systems. Substantive theories are usually needed for generating formal theories (Glaser and Strauss 1967). This is necessary because formal theories involve abstract elements that are usually inferred from substantive theories. In design science, creating a substantive (or mid-range) theory involves a thorough theoretical understanding of the solution and its contribution, usually requiring the application of the solution in multiple contexts (Holmstrom et al. 2009). This is similar to the comparative analysis (Glaser and Strauss 1967) in sociology, in which a comparison among groups within the same substantive area helps to elicit the underlying substantive theory.

PH.D INVESTIGATION 1 – TEZEL (2011)

THE RESEARCH PROCESS

Since VM has emerged in the manufacturing sector, it is necessary to investigate how it can be adopted in construction and which functions. This is important to enable enable its wider adoption by construction companies. Aiming to address this problem, Tezel (2011) proposed a conceptual model that defines the different functions that VM can have in construction. The research reported in Tezel (2011) was presented as a case study. In this paper a re-interpretation of the research process is presented, discussing how this research fits better DSR, instead of an explanatory research.

The research process was divided in two sequential stages as shown in Figure 2, and involved fourteen construction sites: nine construction sites in Brazil and five sites in Finland. The first and second steps of the constructive research method were carried out in stage A. They involved the definition and understanding of the research problem based on an in-depth literature review in both manufacturing and construction. The problem was better understood from both a theoretical and practical perspective after the first set of case studies was developed.

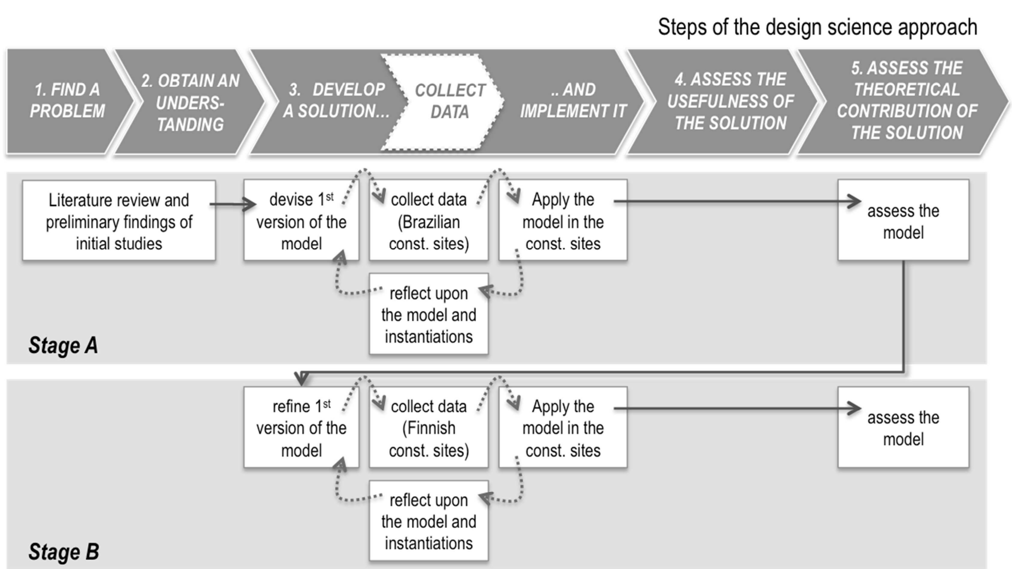

Figure 2: The research process

The third step involved the solution development and implementation, being divided into four activities. First, a preliminary version of the model was devised, mainly based on the literature and on the preliminary understanding of the problem. The preliminary model proposed the functions of VM. Following, case studies were developed to identify and better understand how VM was being applied in practice on construction sites with the most advanced use/practical application of the concept. The data collected on the case studies were then used to validate and refine the functions proposed on the VM model originally developed. The data were also useful in refining the model in terms of identifying which VM tools were used to support different VM functions. The results of these analyses can be classified as instantiations, as these contributed to assess the effectiveness of the conceptual elements that the solution contains. The model was then refined based on the analyses, with some functions refined and new functions added. After that, an assessment of the theoretical contribution of the model was carried out. The results of such assessment were then further tested and refined through a second round of case studies, carried out in Finland (Figure 2). The data gathered in the Finnish case studies were used for further testing the solution on stage B.

OUTCOMES

The main outcome of the research is the conceptual model. This model can help companies to apply visual management since it outlines the different functions that VM can support. Mainstream practices that are replaced by each of these functions are also highlighted in the model. For example, VM can be used to increase transparency, improving the ability of a production process (or its) parts to communicate with people. In this way, the information concerning such process that is usually held in people's mind and on the shelves (mainstream practice) becomes available through VM tools. Each function of the model is defined by a set of constructs. The relationship among these functions is also outlined, converting this set of constructs into a model. The analysis of different construction sites using the model has created instantiations. For example, the incidence of the functions in the Brazilian construction sites were outlined. Another outcome of this investigation is a refining of the theoretical background on VM, particularly regarding the functions that VM can fulfill. In this sense, the instantiations have an important role since they establish a link between the existing theories on VM and the functions that are indeed fulfilled by VM in the construction sites.

PH.D INVESTIGATION 2 – ROCHA (2011)

THE RESEARCH PROCESS

This investigation was focused on mass customisation (MC) and how it can be pursued in the house-building sector. Since MC and related principles were devised considering manufactured products and, hence, it is necessary to adapt this theoretical background to address the specific characteristics of the construction industry. The small number of studies that adapt such background also creates a practical problem since MC cannot be readily used by organisations in developing and producing residential buildings. Seeking to address this problem, the investigation proposed a conceptual model for defining customisation strategies in the house-building sector.

The research process was divided in tree stages (Figure 3) and involved four case studies (CS1, CS2, CS3, and CS4), carried out in different companies. The first and second steps were carried out in stage A. They involved the definition and understanding of the research problem based on a literature review and initial findings of case study 1 (CS1). Following that, data were collected to support the development of the solution. The solution development step involved three activities. First, a preliminary version of the model was devised, mainly based on concepts from the literature. This was then applied, i.e. used to describe and analyse the customisation strategies in the case studies. The application of the model in each of the case studies created an instantiation, or implementation of the model. The preliminary version of the model was then refined, taking into account a reflection based on the instantiations, and initiating a new cycle of solution (re)development (Figure 3).

Therefore, several cycles of development, testing and refining of the solution were carried out until a suitable version of the model was produced, and then discussed with the representatives of the companies. The usefulness of the model was assessed (fourth step) through discussions on the instantiations with those companies. Actions that the companies realised or planned to undertake based on those discussions were registered and analysed as they provided evidence for the model usefulness. The fifth and final step encompassed an assessment of the model from a theoretical viewpoint.

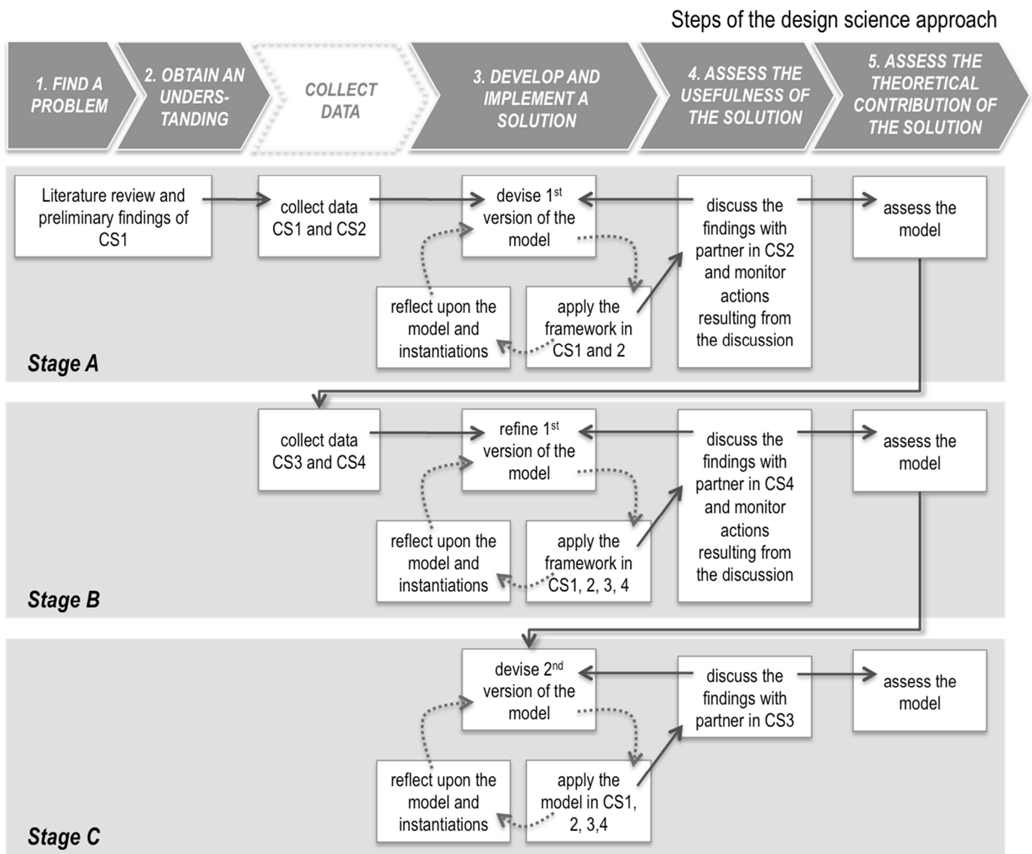

Figure 3: The research process (Rocha, 2011)

OUTCOMES

The main outcome of this investigation is the conceptual model, which contains ten decision categories organised in four groups (core categories, product design, client interface, and production). In defining a customisation strategy, an organisation should make decisions for each of those categories. Each category entails one or more constructs. The set of decision categories forms a model because the relationships among them are clearly established, enabling the implications of a decision over the others to be identified. An overall sequence in defining the categories needs to be followed, i.e. the core categories need to be defined prior to the others. Consequently, the solution also involves a method. Another outcome is the instantiations, which were created in the solution development step in stages A, B, and C (Figure 3). They were necessary for testing the applicability of the model and also for assessing the usefulness of the model by discussing the findings with the study partners.

CONCLUSIONS

This paper presented two Ph.D investigations with the goal of showing how DSR can be adopted in lean construction research initiatives. These investigations indicate that such approach can strengthen the relevance of academic research by better connecting research and practice. However, this approach involves a different research process and outcomes, which are discussed in this paper. Understanding these differences is the starting point for its wider adoption of DSR by the lean construction academic community. The analysis of the Ph.D. investigations also sheds some light on aspects of DSR that have not been discussed by previous literature.

In terms of the outcomes, both investigations involve the refinement and further development of an existing theoretical background, the development of a solution, and instantiations. The refinement of an existing theoretical background is here considered as a 'better theories' outcome. This is due to the fact that during the process of developing the solution, the theoretical background on CM and VM were refined and new conceptualizations were proposed at each investigation. On both investigations, instantiations also had an important role in creating better theories as they enabled the theoretical elements of the solution to be applied in an empirical context. By implementing the solution, existing theories can be refined and new conceptualisations grounded on empirical data can emerge, as demonstrated in the studied investigations. The solution on both cases is a conceptual model, which entail a set of constructs. Nonetheless, the model in investigation 2 seems to be more readily applicable in solving real world problems since its usefulness was assessed and there is evidence that it can support decision-making.

None of the investigations proposed technological rules or substantive (mid-range) theories. Further implementations/applications of the solutions in different contexts would be necessary for the development of mid-range theories. However, some possible technological rules could be identified. For example, in investigation 2, companies that had the scope of customisation clearly defined (i.e. a clear definition of what could and could not be customised in a product) were benefiting from MC more than companies that had the customisation scope ill defined. A potential technological rule underlined in this finding could be: "*In order to fully benefit from MC (goal), the scope of customisation should be clearly defined (prescription)*". The model developed in investigation 2 can be used to define the scope of customisation. In this way, a solution is a means to implement a technological rule (i.e. a prescription to attain a particular goal).

In terms of the research process, the investigations here described provide details on the activities involved in constructing a solution that had not been previously discussed in the literature. Inductive reasoning (i.e. inferring from the specific to the general) had an important role in constructing the solution in both investigations. Indeed, the models proposed were devised by abstracting from particular cases. In Tezel's work, the functions of VM were partially abstracted from existing VM tools and practices previously adopted by construction companies. In Rocha's work, the decision categories were also partially abstracted from existing decisions made by companies concerning their customisation strategies.

However, a solution is not constructed only through abstraction from empirical data. The existing theoretical background also provides an important input to this process. In Tezel's work, the theoretical background on VM provided indications of some functions of VM. Later, functions that were abstracted from existing VM tools and practices were also identified. Therefore, the theoretical background was useful for preparing a preliminary version of the model and guiding the data collection. In Rocha's work, the theoretical background had a slightly different role. Key concepts that support MC (e.g. modular architecture, postponement) were used for identifying underlying decisions within the empirical data previously gathered. Hence, the theoretical background was particularly important for data analysis. Also, the form of the solution (i.e. a model with decision categories) was not outlined from the outset but emerged throughout the data analysis.

The analysis of the two investigations provided a better understanding of the cycles involved in DSR. The literature seems to suggest that there is only one type of cycle, which happens between the construction and evaluation steps. However, the investigations indicate that there are, at least, two types of cycles. The first one, termed here as internal testing, happens during construction when the solution is applied in an empirical context, creating an instantiation, and the researcher reflects upon the solution and the instantiation. Such testing is necessary for verifying the applicability of the solution, resembling pattern matching (Yin 1994). Yet, in design science, this testing does not involve only a comparison of an empirically based pattern with a predicted one, as in pattern matching. It also entails refining the predicted pattern, which may require the development of new conceptualisations, that are better able to reflect what is being observed in the empirical context. Internal testing is not a straightforward process as indicated by investigations 1 and 2 and seems to involve several loops until reaching a suitable version of the solution.

The second type of cycle occurs when the usefulness of the solution and instantiations are assessed. This is termed here as external testing, since it relies on third parties and is not only an internal process of the designer/researcher. Such cycle was only carried out in Rocha's investigation. As depicted in Figure 3, the results of this testing can lead to a redevelopment of the solution. A major difference between these two types of cycle is their frequency: internal testing seems to be thoroughly repeated whereas external testing is more intermittent. Also, internal testing should precede the external testing as an intelligible version of the solution needs to be devised prior to its presentation to third parties.

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