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Design Science Method and Theory in a Construction and Engineering Context: "A Phronetic Tale of Research"

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DESIGN SCIENCE METHOD AND THEORY IN A CONSTRUCTION AND ENGINEERING CONTEXT: "A PHRONETIC TALE OF RESEARCH"

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ABSTRACT

Design Science as a research method offers the researcher a viable way of improving the outcome of research for both the researcher and the researched. In Construction and Engineering there is almost always the intention to better understand and then improve processes, materials or outcomes. Using two case studies of research adopting Design Science, one in Engineering and one in Construction, the advantages of the use of Design Science as the research method are highlighted. The desire to improve construction and engineering through a better understanding of 'practical wisdom' or domain expertise through use of the concept of phronesis enables the researcher to build solutions that reflect the practices and processes practitioners actually need, enhancing their own knowledge through the collaborative research process and enabling the researcher to better reflect on what the research produced.

KEYWORDS: Design Science, Design Thinking, Phronesis, Co-Design Theory and Novel Research Method

INTRODUCTION

Technical research such as in Construction and Engineering where research projects aim to produce tangible outcomes such as artefacts, products, new processes, models and software solutions to solve specific problems, often requires collaboration between researcher and practitioners (users) (Maslach et al. 2012; Sohaib & Khan 2010). The development of solutions to practice problems, as a research process, requires not only design thinking, but also design theory and a systematic design process approach within a recognised research paradigm, like Design Science. Although the strengths of Design Science, design thinking and co-design theory have been acknowledged in the literature over decades, the common problems faced in the development of many solutions is that the researcher(s), who come to design such solutions, and the domain expert (who the solutions are built for) often focus on different sides of practice. We argue here that they can be brought together advantageously in a research framework.

In seminal articles about Design Science, Gregor and Hevner (2013) and Gregor and Hevner (2015) focus on the 'what' and the 'how' of projects using Design Science as a means to understand researchers engagement with practitioners. There is, however, also a growing critical voice demanding a more reflective account of engagement with practitioners (Bensimon 2007). Specifically, authors like Flyvbjerg (2006); Flyvbjerg et al. (2012); Kinsella and Pitman (2012) have highlighted the importance of "phronesis" (practical wisdom/domain expertise), and the need to dismantle the divide between the researcher and the researched (practitioners), so that the practitioners can critically become co-researchers in the field. This demand of research reflects on asking 'why' what was observed or learned happened, why this knowledge is/was important and therefore why the research was undertaken. Traditionally Design Science addressed only the 'what' and 'how' and rarely the 'why'.

Two research projects which demonstrate 'where the action is', what needed to be improved and why, how that was achieved and how effective it was when adopted, are used here

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to show what can be achieved through a phronetic approach to research using a novel combination of design thinking, co-design theory and Design Science research methodology. The focus here is not on the outcomes of the research but on the research process itself as a novel method to embed the researcher into engaging with the practical wisdom of the practitioner either directly or indirectly. In the first case study project Design Science and co-design theory framed the development of a collaborative solution to knowledge loss in a company constructing engineering products to resolve two problems, (1) loss of expert knowledge and experience through personnel leaving the company; and (2) to improve the make-span, time-to-market, element of the product design and production process; the other project/case study used Design Science to develop and then evaluate a BIM-Enabled Code Checking System within the building design process for architects and building certifiers to improve the efficiency of a building design compliance checking process.

DESIGN AND PHRONESIS - THE RESEARCH CONTEXT

Design thinking is “a discipline that uses the designer’s sensibility and methods to match people’s needs with what is technologically feasible and with what a viable business strategy can convert into customer value and market opportunity.” (Brown 2008, p. 2). Design thinking practice is not limited to only practice where objects are produced that reflect design outcomes. Design thinking is for all designers to share a place of invention and reconsideration of problems and solutions, which can be symbolic and visual communication, material objects, activities and organised services and complex systems (Buchanan 1992). Design thinking is also defined as “an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback, and redesign” (Razzouk & Shute 2012, p. 330). Design thinking is still expanding in terms of meanings and connections in practice and understanding (Cross 2011; Dorst 2011; Kimbell 2011). Design thinking has grown from “a trade activity to a segmented profession to a field for technical research and to what now should be recognised as a liberal art of technological culture” (Buchanan 1992, p. 5). Brown (2009) and Rowe (1987) argue that design collaboration informs researchers’ desires to improve the outcomes and relevance of their research (Norman & Verganti 2014), including engineering (Dym et al. 2005).

Phronesis is embedded in the Aristotlian view of practical wisdom. Frank (2012, p. 57) calls for practitioners to “reflect enough that maybe, eventually, a kind of practical wisdom will develop that can never be fully articulated … but can be felt as a guiding force.” Hibbert (2013) is concerned with the increasing routinized and instrumentalised contexts of professional practice where educators disseminate information, reproduce the routines and instrumentality and practitioners receive training. What is apparent in the arguments of Flyvbjerg (2006); Flyvbjerg et al. (2012), Kinsella and Pitman (2012), Frank (2012), Hibbert (2013) and Antonacopoulou (2010a, 2010b) Antonacopoulou (2010a and 2010b) is the need for there to be opportunities for reflection so that practice can be evaluated and then shared so that knowledge grows and collaboration of knowledge emerge. This is their practiced wisdom. Flyvbjerg (2006, p. 370) argues we need this phronesis or practical wisdom by engaging in an interaction between the researcher and practitioner, “sometimes to clarify, sometimes to intervene, and sometimes to generate new perspectives …” These authors all argue that without the attainment of practical wisdom through engagement of the researcher with the practitioner, we achieve too little and don’t arrive at research that matters.

In a similar way Co-design theory posits that a traditional research method of the researcher remaining outside of practice and being ‘the observer’ is replaced by co-design, collaboration and iterative evaluation of solutions to problems identified by practitioners (Sanders & Stappers 2008) with the intent that those who the solutions are developed for or who have been the focus of research will use the outcomes in their practice (Payne et al. 2008). However, such co-designed solutions and outcomes are difficult because they need to include all stakeholders and their various roles and their respective knowledge domains. Construction and Engineering projects are very complex and involved both extended time frames, multiple and changing stakeholder influences, changing attention to different professional knowledge domains and complex interactions in and with the built and social environments in which they are situated. The more complex a design problem, the more knowledge that is needed to create the solution and this is more than one person can process (Fisher 2004). Therefore, collaboration is essential. There is a clear need for the development of 'practical wisdom' and shared development of practice and research.

Practitioners being researchers need to be more than informants (Sanders & Stappers 2008). Practitioners can create or increase value of the solutions being created (Spohrer & Maglio 2008; Vargo et al. 2008) as the solutions are specifically articulated and developed to suit the real needs of those practitioners (Szebeko & Tan 2010). So et al. (2010) and Svihla (2010) argue that such a knowledge-building environment, or what others above term phronesis, requires both that the knowledge exists and is clearly understood. We argue here, then, that significant value (business, practice, research) can be created when collaborations of design and practice between researchers and practitioners happen. Since practitioners are an integral part of the research they can benefit from the knowledge created and the researcher emerges with better understanding of real practices and it becomes part of their own practice of research as part of the collaboration. However, theory and philosophy alone, and a desire to engage in collaboration and phronesis are insufficient for research. There is a need for an accepted formal structure or paradigm in which to situate the research itself, and give an acceptable frame of reference through theory to the research outcomes. One way this can be done is within the Design Science research paradigm.

Design-science is a formal research method developed to incorporate the rigor of research as science, with contemporaneous design thinking. Design Science is "a body of intellectually tough, analytic, partly formalisable, partly empirical, teachable doctrine about the design process" (Simon 1988, p. 68) which Gregor and Hevner (2015) argue enables research to become the 'front-end of innovation'. Construction is driven by both scientific and design principles and therefore is a relevant research domain for Design Science application (Dave & Koskela 2009; Voordijk 2009). Design Science is a research paradigm that enables the researcher to engage the researched and build models, solutions and artefacts applicable in the research context (Arnott & Pervan 2010; Bichler 2014; Gregor & Jones 2007; Heusinger 2014; Hevner et al. 2004; Markus et al. 2002; McKay et al. 2010; Myers & Venable 2014; Richey & Klein 2014; Venable et al. 2014). 'The fundamental principle of Design Science research is that knowledge and understanding of a design problem and its solution are acquired in the building and application of an artefact' (Hevner & Chatterjee 2010, p. 5) and, we would argue, also in development of solutions, processes and models.

Design Science is built on a set of principles (Arnott & Pervan 2010; Baskerville et al. 2015; Hevner et al. 2004) which provide the formal framework that validates the Design Science method for research:

- a viable artefact/process/model/solution/process has to be developed (this artefact can be a construct, a model, a method, or an the operational realization of an artefact;
- the problem has to be relevant with the production of new knowledge from design-and-development;
- the design has to be evaluated for utility, quality and efficacy through use of formal methods, ethnographies (Baskerville & Myers 2015), statistical analysis, or narrative analysis; and
- the research has to make a significant contribution and be rigorous, based on an iterative research process, to enable the product to be readily understood and able to be used by both technicians or practitioners or professionals and management.

These principles have been developed further by the same authors (Arnott & Pervan 2010; Baskerville et al. 2015; Hevner et al. 2004) into a research framework designed to offer a unified approach to the use of Design Science as a research methodology (Table 1).

Table 1 Design Science Research Framework

Guiding principles	**Description**
Design as an artifact, process, method, model	Design-science research must produce a viable product in the form of a construct, a model, a method, or an instantiation.
Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant problems.
Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, models and/or design methodologies.
Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the research product.
Design as a Search Process	The search for an effective product requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Source: Adapted from (Hevner et al. 2004, p. 83)

Design Science then can also be viewed as a collaboration between the researcher and the researched; and as one perspective of co-design and one possible way of constructing phronesis, when the research process also addresses the issue of why. The researcher(s) and the practitioners co-operate and co-design the solutions to the identified problem, whether artefact, solution, process model etc. (Payne et al. 2008), but in Design Science within the methodological framework accepted as Design Science. The Design Science method of research offers continuity in knowledge generation and a dynamic process of research collaboration as an alternative to conventional quantitative research analyzing specific relationships or understanding explanations of those relationships at a point in time. The process of qualitative research often is restricted to a particular period and is reflective of the participants' positions at that time. Design Science goes beyond that context. It reflects change over time in ways similar to Action Research (Baskerville & Wood-Harper 1996) but differs fundamentally as Design Science incorporates elements of qualitative and quantitative research as part of data collection and data analysis and can incorporate the reflective outcomes that emerge from Action Research as well. However Design Science alone cannot always address all elements in knowledge production. Phronesis is more about asking 'why', and not just the 'what' and 'how' embedded in Design Science. These three aspects together, it can be argued, align with the Aristotelian intellectual virtues of *techne* (more WHAT), *episteme* (more HOW), and *phronesis* (more WHY), and offer researchers a means of addressing the needs of both practitioners and the researcher in the research act of co-designing new products, new solutions, new processes or new designs.

None of these concepts, Design Thinking, Design Theory, Co-Design Theory or Design Science research, is in themselves novel in Construction or Engineering research. However, taking the opportunity to bring them together as phronesis offers both the researcher another means of enriching their own knowledge and practice and extending the capabilities of their research to seek better solutions, but it also offers the practitioner the opportunity to reflect on their practice and engage in a broader, and deeper practiced wisdom, as both Hibbert (2013) and Frank (2012) have argued, improving practice and impacting on construction projects as Flyvbjerg (2006, p. 370) suggest "sometimes to clarify, sometimes to intervene, and sometimes to generate new perspectives".

CASE STUDIES

The viability of using design thinking co-design theory within the framework of Design Science research methodology was tested in two case studies, one where phronesis was deliberately used and one where the focus was more one-sided oriented to the researcher, with elements of collaboration included through the researcher checking outcomes and conclusions with practitioners. The case studies were chosen simply as exemplars of research using Design Science where the author was either the researcher or the research supervisor so that intimacy of knowledge and review being second-hand was avoided. Chan (2013) and Ellis and Haugan (1997) have similarly used known contacts in undertaking research in construction and engineering. Each case study frames an engineering and/or construction context and addresses solutions to specific problems identified in the real world through research, each developed in a theoretical context. Both projects were developed on similar elements of design thinking, that good solutions lie in good design and that design must be solution based. Frank Lloyd Wright said 'I believe that in the search for the answer lies the answer' (1950). In Case Study 1 the problem is identified with engineering professional practices co-created between the researcher and the researched, on a 'problem' identified by the researched. In Case Study 2 the problem originated from the academic researcher and a practitioner. The two case studies offer examples of different uses of design science research and its contextualization to frame a discussion about the nature of Design Science research and the ways it can be used to improve both the research output and the nature of professional practice in construction and engineering.

What was the Research Problem?

Case 1 (Kanjanabootra 2011)

This research involved problem resolution in an Australian company that manufactures customized commercial refrigerators. The small team of engineers was taking too long to get new products to market and the expertise and knowledge of the design engineers was never captured. As a consequence the Company was vulnerable to employees being poached by competitors and the Company's competitive position was at risk. Additionally, their costs were too high as design and development took too long. The Company had been competing in the refrigeration industry for more than two decades and collected significant amounts of data, information and accumulated significant unique knowledge. However, the Company had no knowledge management strategy in place. Knowledge in the Company was kept in a disorganized, almost chaotic form and knowledge was rarely shared. The Company realised that this was an important problem because they believed it was affecting both their competitiveness and business continuity. The solution agreed between the company, represented by the engineers (the researched) and the researcher was to utilize a co-design process of knowledge design and classification, and building of a Knowledge Management System in collaboration.

Case 2 (Shih 2016)

This research project aimed to create an Information System tool to facilitate the building certification process. In every construction project, the project team needs to acquire approval from the relevant authorities prior to the construction work starting. This approval process included building design compliance checking against various building codes. In Australia this process has often been carried out by building certifiers. The problems identified were: 1) that the designers (architects and engineers) usually have only a superficial level of knowledge of building codes and regulations, and 2) that the building certifiers and certifying authorities are not involved in the project during the design process but rather late in the construction stage. These practices make it difficult for compliant building designs to be generated during the design process. If building designs do not comply, it has to be rectified until the design is complied. These limitations make the compliance checking process troublesome for all stakeholders, designers, engineers and owners. The aim of this research project was to develop a BIM-enabled code checking system where building designs can be checked for compliance again the building codes and regulations.

What theory was the research grounded in?

Case 1 (Kanjanabootra 2011)

The research framework adopted for this research used the Zack (1999) model, Nonaka's (1994) Dynamic Theory of Organizational Knowledge Creation and the knowledge-based theory of the firm (Grant 1996) to examine what happens when addressing knowledge and strategy gaps. Traditional strategic management theory focuses essentially on transaction, cost analysis (Liebeskind 1996; Porter 1991). This approach to knowledge argues that investment in innovation creates new knowledge and the risk associated with it is reflected in the return on that investment. However, such theory offers no understanding of what particular strategies needed to be put in place to assure this return. The knowledge-based theory of the firm (Grant 1996) was an attempt to do this. This theory builds of the Resource-based Theory of the Firm (Conner 1991; Conner & Prahalad 1996; Wernerfelt 1984), which argues that the basis for competitive advantage results from the extent and application of the resources the firm can use. Conner and Prahalad (1996) extend that argument to include knowledge as a key resource.

Case 2 (Shih 2016)

This research was framed in understanding of how construction professionals deal with complexity and compliance (Eastman et al. 2009; Khemlani 2011). Theoretically the research assessed how a regulatory framework affected and was affected by the design process, grounded in practitioner's use of design theory.

What was the design thinking involved in each research project?

Case 1 (Kanjanabootra 2011)

The purpose of the system development for the Company was to co-produce an outcome that could help the Company capture their employee's knowledge for reuse to meet company strategic goals and resolve operational weaknesses in product development. The artefact developed was a knowledge-based management system.

The design thinking involved the application of four ideas. First, the design system had to be able to capture relevant specific domain knowledge from the engineers and from their prototype testing process during day-to-day tasks. The design of the system had to mimic their methods of working and their visualisations of the data they collected each day. Co-design bringing the technical competence of the researcher together with the domain competencies of the practitioners were then essential in the design idea and its application. Second, the develop structure of the KMS had to also reflect the "phronesis" of the engineers. In other words, the design thinking was that the system structure should not change the context of domain knowledge of the practitioner just to suit computational language. A middle-out approach was adopted because the structure started with the known information established in collaborations with the engineers and expanded to cover new information and knowledge throughout the study. Using the data, information and knowledge derived from this approach cannot enable the structure to be predicted. The design thinking was that this process is organic and grows. The third element of design thinking was that the developed system also had to be designed in a way that facilitated the engineers ability to capture their day-to-day work knowledge at the same time as work was done, not adding additional tasks to their work process. Their practiced wisdom was being captured as the KMS was being simultaneously co-designed and populated. Fourth, data captured had to enable process mining (van der Aalst et al. 2007; Weijters & van der Aalst 2003) of work activities, both relevant and irrelevant, to identify and evaluate their effects on the design and testing processes. The intent was to develop process models enabling the practitioners to make better decisions about their work efficiency. The reflections of both the researcher and the researched as part of this process are to assess not only what and how they undertook their job, but also why.

Case 2 (Shih 2016)

The purpose of this research was to develop a BIM-Code Checking System (BIM-CCS) which enables designers to automatically check their designs against the existing Building Code prior to submission for approval by authorities. Design thinking aspects in BIM-CCS included:

First, the design thinking was for a simple, easy to use solution in that 1): the BIM-CCS had to be developed in a way that the existing tools (BIM) that domain experts (designers) use can be utilized to carry out the code checking process without creating excessive additional tasks (burdens) to the users; and 2) the BIM-CCS had to be developed in a "plug-in" format so that the domain expert users did not have to acquire new knowledge just to operate. The second element of design thinking in this project was to design a system that facilitated consistent interpretation of the Building Codes (specifically in the Fire Code section) and then transformed into computational codes language to enable design-checking consistency. The back-end algorithm of the BIM-CCS was developed so that the relevant design elements and parameters in the BIM building model could be captured and compared consistently to the interpreted Building Codes for design compliance. The design thinking within this project also addressed the means of communications needed for the system to be useful to the users and again that there was consistency and simplicity. The BIM-CCS was designed to generate design compliance reports which would be similar to the traditional design compliance report that have been generated in the past by building certifiers in the industry and which also could be understood by the relevant authorities. The system was demonstrated to both building certifiers and architects, potential users of the system, seeking reflections on what the system was able to achieve. The focus was on the 'what' and 'how' from the practitioners perspective. However, the feedback enabled the researcher to better understand why compliance happened the way it did and enabled changes to the system to better meet those needs.

What and how were the findings, solutions or products developed?

Case 1 (Kanjanabootra 2011)

The collaborative research activities of the researcher and the company engineers (researched) involved knowledge capture, knowledge modeling, and iterative building and testing of a KMS. The data collected included both the engineers' explicit and tacit knowledge. The explicit knowledge of the Company existed in the Company products catalogues, testing log sheets, product plans and images, design drawings, and testing reports. The recorded knowledge was significant in the design process of the knowledge-based system because it was a physical reflection of the tacit knowledge/expert knowledge that the engineers had previously and were still using on a daily basis in their design and build of each refrigeration cabinet (company products). This knowledge, in collaboration with the engineers involved, was then classified using an ontology and designed into the process of building the knowledge-based system, utilizing the design thinking that had already occurred prior.

The collection of tacit knowledge was undertaken by the researcher who went to the factory every day in the first 4 months, and then participated in the various activities with the engineers including 1) attending the engineers product development daily meetings every morning; 2) group or individual shadowing processes to allow the researcher to fully understand and participate in the engineer's work processes; 3) documentation of the data and information collected and discussions with the engineers whilst at work. Scenario simulation and interview with the engineers on a daily basis were also deployed during the KMS development and evaluation processes. This research process enabled the researcher to ask 'why' the process was as it was and enabled the engineers to state what they needed to make the process better.

After the initial data collection the researcher started to develop a prototype knowledge based system structure based on the information from collected data, using discussions with and active observations of work done with the engineers. During this stage the researcher was still attending the factory on a regular basis seeking feedback from the engineers about the design and operational elements of the system being developed. The factory visits during this stage were to iteratively evaluate the structure of the KMS and also acquire additional data if required. This occurred over a 6-month period to ensure system functionality, quality, efficacy, consistency, performance, effectiveness and accuracy were designed into the system in ways that were useable and effective and which met the needs of the engineers in their work on a daily basis. The researcher then mapped the testing process in detail and applied Heuristic Process Mining

(HPM) to identify activity redundancy. The outcomes of this analysis were then evaluated by the engineers for accuracy and efficacy as part of their practice.

One paradoxical issue of the results of the process mining analysis was that it was difficult to identify whether the improved testing process that the engineers had achieved as a result derived from this HPM or from the reflections of the engineers as part of the research process in the co-design of the previous 12 months that affected, either directly or indirectly, on the way that the engineers created, used, captured and reused their own knowledge. The collaborative discussions held during the three iterations of the KMS and its evaluation by both the researcher and the engineers concluded that the KMS enabled the engineers to reflexively alter the way that they worked as they better understood why they worked as they did.

Case 2 (Shih 2016)

The research was designed to reflect collected information where the focus of design and analysis lay with the researcher, rather than as a co-design process. The research process started with the researcher conducting interviews with construction designers and building certifiers. Documentation analysis was also conducted to identify relevant documents involved in the compliance checking process including design compliance reports and the Fire Code Section C of the Australian Building Codes. The purpose of the document analysis was to validate the building compliance checking processes and the elements involved in the process.

Then the researcher analyzed the Fire Code Section C by each small unit and clause. The aim was for the researcher to interpret the building code in an explicit manner so that the algorithm driving the system could be developed in a logical manner. There were two semantic analysis methods deployed to analyse and interpret the building codes. These included, Requirement, Applicability, Selection and Exception (RASE) (Hjelseth & Nisbet 2011) which dealt with Code requirements which related specifically to “Shall” or “Shall not” building code elements. This semantic approach allowed the interpreted codes rule to be applied to the IFC-based BIM model to compare specific building components to the building code following (Hjelseth & Nisbet 2011).

The other semantic used was Dialogue Language (DL). DL provides systematic structures that organize the hierarchical dialogue of codes. These structures contained eight primary items which included, Parent_id, Code_violation, Clause, Condition, Action, Comment and Dependency. These items were used to explain the semantic meaning of the clauses in the text (Omari & Roy 1993). During this stage the researcher was conducting a preliminary evaluation of the interpretation created by the semantics analysis in collaboration with two building certifiers.

The researcher compiled the collected data and semantic analysis into a development of an algorithm structure. The user’s interface of the BIM-CCS had also been developed at the same time, resulting in development of the first version of the BIM-CCS. The researcher subsequently conducted the first system evaluation by interviewing six accredited building certifiers. Using an evaluation framework which tested aspects such as system functionality, accuracy, efficacy and performance, the researcher revised the BIM-CCS. The researcher then conducted a second evaluation by using a focus group to demonstrate the usability of the BIM-CCS with a group of fifteen architects again the researcher then refined the BIM-CCS.

What were the challenges faced in the DS research processes?

Case 1 (Kanjanabootra 2011)

1) Tacit knowledge capture is a challenging and difficult process. In this research multiple techniques were used to collect the tacit knowledge of the engineers. These included a detailed study of existing artefacts, interviews, meetings, observation and shadowing.

2) The knowledge generation, transfer and sharing activities were often difficult to capture because of its dynamic nature.

3) One of the common problems in knowledge capture process is knowledge hoarding. The resistance to share knowledge often occurs. This might be due to the insecurity as the knower has seen their knowledge been taken away as threat. In this project the researcher had developed trust among the engineers in the company resulting from the researcher being immersed in the company for 4 months on a daily basis and then regularly over the remaining 12 months. The management level also had made it clear and transparent to the engineers that this research project was created to facilitate their work process.

4) The most important aspect that had made this research project successful was the importance of the researcher's own domain knowledge. The shared domain knowledge (mechanical/refrigeration engineering) enabled the researcher to fully understand the engineers work process and their tacit and explicit knowledge. As a result, the relevant knowledge had been captured, classified and structured into the company knowledge management system, consistent with the meaning and understanding of the engineers and their professional practice. The shared domain knowledge also enabled the researcher to co-design the KMS in a way that integrated it into the engineers' work processes without adding additional duties just to operate the KMS.

Case 2 (Shih 2016)

1) The researcher had an industrial design background. However, he had very limited experience in the construction industry. His industrial design experience had contributed the BIM-CCS in terms of user's interface design but because it was designed from the researcher's own perspective, it didn't always reflect knowledge and design principles that are part of the construction professional's practice.

2) The Building Code in Australia has been written in a way that leaves it open to the user's own interpretations. This often creates a conflict of interest between authorities and the building designers. As a consequence some of the clauses are very difficult to interpret through the use of semantic analysis. The expert's opinions though, collected from interviews and the Focus Group, played an important role in solving this problem in this research project and in the ultimate design of the BIM-CCS.

3) During the BIM-CCS development process, the researcher found that BIM modeling practices in the industry, the terms used and the BIM object parameters modelled were not consistent. This led to inaccuracy the BIM-CCS used in some models. Even though the industry has standards such IFC the modeling used across the industry still inconsistent at a practical level.

4) There is an absence of standard formats for the design of compliance reports used in the construction industry in Australia. Different certifiers have their own format for compliance reports. This solution used in this research was that the researcher brought designs from different reports together and created their own version.

DISCUSSION

The research process in Case Study 1 involved understanding the problem in collaboration with the management of the company. The problem was identified as a problem associated with the professional practices and their knowledge management in the company's product development processes. The problem was then further investigated to understand the extent and nature of the causes and effects of that problem with the practitioners, the design engineers. The solution demanded an evaluation of their existing practice and the designing of additional support to better address the problems of inefficient use of their professional knowledge. The next stage involved thinking about how to design that solution and this was done in collaboration with the practitioners, supplemented with evaluation of design principles and existing research on solving knowledge problems in organisations.

A co-design framework emerged as relevant and then supplemented with application of a Design Science approach to the research. In the following 12-15 months multiple iterations of a solution based on a knowledge management system design were co-designed, created and evaluated. The researcher became immersed in the practiced wisdom of the practitioners. In parallel, the design processes used by the practitioners were analysed using Heuristic Process Mining identifying redundant tasks/product development activities. The results of this HPM analysis were also evaluated by the practitioners and this became part of the whole solutions developed to address the initial problem identified. The research problem was an organised repetitive and iterative journey through the concepts framing the research process, a journey centred on the Research Problem (Figure 1) and set within a framework of Design Thinking and Design Science, interacting with the narratives of the practitioner as researcher and the researcher as practitioner, having a shared knowledge domain and therefore a common language of understanding.

It was practiced wisdom or phronesis in action and reflected the arguments of Antonacopoulou (2010a, 2010b) for the use of reflexive thinking and the development of practice-relevant scholarship. In this case the researched were part of the research process and the researcher was part of the design and testing process during the 4 months placement. As suggested by Antonacopoulou, throughout this process both the researcher and the researched continually asked why things happened the way they did. The research process was concerned with more than observation about what happened and how. The researcher was part of what was happened rather than the casual observer making observations based on their own perceptions. What the reflexivity used in this research produced was not only what happened and how, but why, based in the practices of the researched and within their 'practiced wisdom'.

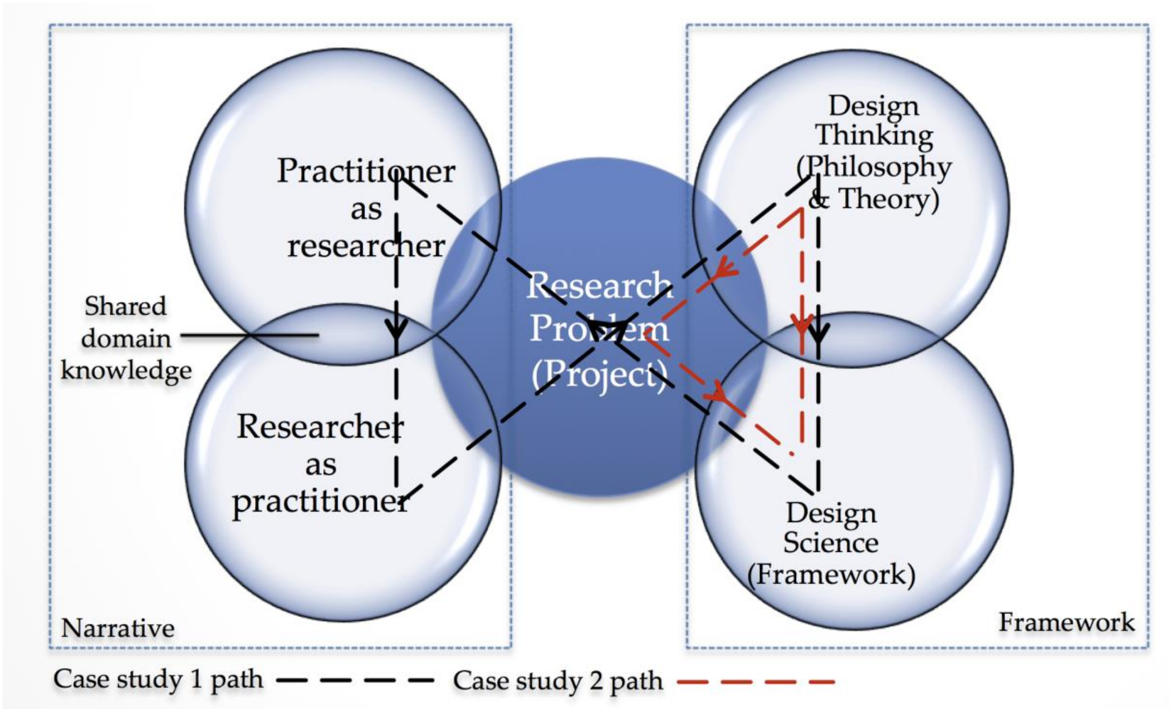

Figure 1 Integrated Research Methodology for Engineering Problem Solving

Case Study 2 also began with a specified research problem but this was a problem identified in the extant literature as an issue across the construction industry in Australia. There was a need for solutions to be designed and tested. The researcher here relied on professional and academic advice to begin the research process, involving initially thinking about the possibilities and principles needed to design a solution that would be effective in application with practitioners. That design thinking focused on the development of an IT-based artefact and this decision necessitated a research framework where the methodological focus was on the development and evaluation of an artefact, a situation resolved with adoption of the Design Science Research Framework. In this research study there was no immersion in the practiced wisdom of practitioners, rather there were frequent contacts with practitioners either to better understand the nature of the problem itself or to evaluate the IT-based solution that was developed. Although more limited in its investigation and use of the practitioner and their practiced wisdom, the formal structure of the Design Science methodology enabled the researcher to substitute that practitioner narrative with narratives supplied by practitioner academics involved in discussions and interactions throughout the research process. What this case study highlights is the impact of reducing the extent of research problems using Design Science when the researcher and the practitioner do not have a well developed shared knowledge domain.

There are however, two themes that these two research projects have in common. First, there is interaction between the researchers and the domain experts, which are the extensive collaboration and co-design process between the researcher and the group of engineers in the first project, and a lesser interaction between the researcher and a group of certifiers in the second project. The involvement of domain experts (and their organization) in the research enabled the values and power of the practitioner's knowledge to be utilised (Flyvbjerg 2006). That excursion into the practiced wisdom of the practitioner and the interactions between the practitioner as researcher and research as practitioner enable reflexivity in both the practitioners and the researcher. Taylor and White (2000) and then Kanjanabootra and Corbitt (2016, p. 13) argue ‘assists the (construction) practitioner to make sense of their practitioner situations and enables them to understand how new knowledge can be created or expertise enriched.’ However the first case study also highlighted the perceived paradoxical nature of affected practice as the research was unable to verify if the changes that happened were just the result of the solution developed or were the result of both that solution and the actual process of developing the solution. Figure 1 above is intended to highlight the multiple pathways possible using this type of research method illustrating that the narrative and its associated reflexivity, represented on the left hand side of the diagram, can be reflective of the knowledge and expertise in both the practitioner and researcher, and reflective also of design thinking and the impact of a formal research methodology like Design Science.

CONCLUSION

The breakthrough Economist J.M. Keynes said that worldly wisdom teaches that it is better for reputation to fail conventionally than to succeed unconventionally (Keynes 1937). Novel research methodologies are challenging and often ignored because of fear of rejection by accepted conventions for publication of research which Besancenot and Vranceanu (2015) argue is conventional and a conservative or risk averse approach to research. Novel research methods do challenge the status quo. They represent new questions. New questions can include the practitioner asking the researcher, how does this work we are doing help me be a better practitioner? A researcher can ask a question of the practitioner about them explaining why they undertook a process in a certain way whilst they were participating in the building process themselves? Conventional research such as the use of surveys and interviews ask for perceptions and opinions, the researcher being the practitioner simultaneously when doing research means the research must ask themselves questions about what they were doing and how they undertook what they did. A novel research methodology as represented here as a complex methodology based on the researcher as practitioner and the practitioner as researcher asks not only traditional questions about what happened and how, but through participatory action, asks new questions to them about why this research process was used and why it was necessary. The researcher asks the practitioner why they do things certain ways and why they solve problems the way they do. Simultaneously the practitioner asks the researcher about why they are concerned about understanding their practices and why it is important to the researcher to reflect on these within theoretical frameworks and make sense of their practice in more generalised ways. Answers to the questions asked by both researcher and practitioner can offer new insights into engineering and construction processes that are accepted as conventional but which might require unconventional answers to change or improve. In the same way that Keynes changed economic thinking through challenging the conventional, using a novel research method offers the possibilities through simple questions of new understanding about what we think we observe. They are confronted with explaining why in their own praxis. They are confronted with asking about doing things they might not have previously done and why.

Novel research methods also offer researchers the possibility to dig deeper and uncover novel ideas. These novel ideas can, as Kanjanabootra and Corbitt (2016) showed, expand our understanding of expertise development in Construction, or challenge the effectiveness of construction project frameworks like PPP. In Construction research, (Dainty 2008, p. 10) argues that ‘the apparent lack of methodological diversity, coupled to an apparent lack of adventure in interpretative research design, suggests a research community rooted in methodological conservatism and disconnected from the debates going on in many of the fields from which it draws'. We argue that the use of a novel research design and methodology will however always add diversity to the focus on positivist research highlighted by Dainty. We also contend that integrating Design Thinking, a theory of co-Design and the Design Science Research Framework enable levels of interaction between researcher and practitioner which not only immerses the researcher in the practiced wisdom of the practitioner, but also offers a methodology which embeds the narratives of both practitioner and researcher within a research process oriented to finding out through research, but also adding the development of solutions to problems. However, this is not consulting, but research.

Consulting focuses on the attainment of immediate benefits, or on the development of specialized applications. Consulting is often simply production of an artefact or process aligned with only the key elements involved, often only dealing with the known. Research on the other hand has a focus on replicability, generalizability, and on introducing new elements or seeking to investigate the unknown (Mobjörk 2010; Shugan 2004). Research posits research questions e.g. why is the make-span inefficient? What causes inefficiencies in make-span in engineering production? Or how can knowledge be preserved and re-used within engineering or constriction organisations? These research questions necessitate the search for new knowledge, the primary purpose of research. They require thinking grounded in theory, producing outcomes that not only create or develop something tangible, an artefact, a process, a machine, a building, but they also produce modifications to existing theory or offer the possibilities of new theory.

The integrated methodology described here is novel in that it asks new questions and conceptualises the research process in an alternative framework, yet at the same time incorporates the accepted forms of research data collection and analysis, described usually as positivist or quantitative research or more socially oriented and empathetic qualitative research. The integrated research methodological approach here encourages the researcher to go beyond the collection and analysis of data from the practitioner. It offers new forms and methods of exchanging practiced wisdom and research knowledge in what Aristotle might call phronesis.

REFERENCES

Antonacopoulou, EP 2010a, 'Beyond co-production: practice-relevant scholarship as a foundation for delivering impact through powerful ideas', *Public Money & Management*, vol. 30, no. 4, pp. 219-26.

---- 2010b, 'Making the business school more 'critical': Reflexive critique based on phronesis as a foundation for impact', *British Journal of Management*, vol. 21, no. s1, pp. s6-s25.

Arnott, D & Pervan, G 2010, 'An assessment of DSS design science using the Hevner, March, Park and Ram guidelines', in D Hart & S Gregor (eds), *Information Systems Foundations: The Role of Design Science*, ANU Press, Australia.

Baskerville, R, Kaul, M & Storey, VC 2015, 'Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production', *MIS Quarterly*, vol. 39, no. 3, pp. 541-64.

Baskerville, R & Myers, MD 2015, 'Design ethnography in information systems', *Information Systems Journal*, vol. 25, no. 1, pp. 23-46.

Baskerville, R & Wood-Harper, A 1996, 'A critical perspective on action research as a method for information systems research', *Journal of Information Technology*, vol. 11, no. 3, pp. 235-46.

Bensimon, EM 2007, 'The underestimated significance of practitioner knowledge in the scholarship on student success', *The Review of Higher Education*, vol. 30, no. 4, pp. 441-69.

Besancenot, D & Vranceanu, R 2015, 'Fear of novelty: a model of scientific discovery with strategic uncertainty', *Economic Inquiry*, vol. 53, no. 2, pp. 1132-9.

Bichler, M 2014, 'Reflections on the state of design science research', *Business & Information Systems Engineering*, vol. 6, no. 2, pp. 71-2.
Brown, T 2008, 'Design thinking', *Harvard Business Review*, vol. 86, no. 6, pp. 84-92.
---- 2009, 'The making of a design thinker', *Metropolis, October*, pp. 60-2.
Buchanan, R 1992, 'Wicked problems in design thinking', *Design Issues*, pp. 5-21.
Chan, PW 2013, 'Queer eye on a ‘straight’life: deconstructing masculinities in construction', *Construction Management and Economics*, vol. 31, no. 8, pp. 816-31.
Conner, KR 1991, 'A Historical Comparison of Resource-Based Theory and Five Schools of Thought Within Industrial Organization Economics: Do We Have a New Theory of the Firm?', *Journal of Management*, vol. 17, no. 1, pp. 121-54.
Conner, KR & Prahalad, CK 1996, 'A Resource-Based Theory of the Firm: Knowledge versus Opportunism', *Organization Science*, vol. 7, no. 5, pp. 477-501.
Cross, N 2011, *Design thinking: Understanding how designers think and work*, Berg.
Dainty, A 2008, 'Methodological pluralism in construction management research', *Advanced research methods in the built environment*, vol. 1, pp. 1-13.
Dave, B & Koskela, L 2009, 'Collaborative knowledge management—A construction case study', *Automation in Construction*, vol. 18, no. 7, pp. 894-902.
Dorst, K 2011, 'The core of ‘design thinking’and its application', *Design Studies*, vol. 32, no. 6, pp. 521-32.
Dym, CL, Agogino, AM, Eris, O, Frey, DD & Leifer, LJ 2005, 'Engineering design thinking, teaching, and learning', *Journal of Engineering Education*, vol. 94, no. 1, pp. 103-20.
Eastman, C, Lee, J-m, Jeong, Y-s & Lee, J-k 2009, 'Automatic rule-based checking of building designs', *Automation in Construction*, vol. 18, no. 8, pp. 1011-33.
Ellis, D & Haugan, M 1997, 'Modelling the information seeking patterns of engineers and research scientists in an industrial environment', *Journal of Documentation*, vol. 53, no. 4, pp. 384-403.
Fisher, RB 2004, 'Applying knowledge to reverse engineering problems', *Computer-Aided Design*, vol. 36, no. 6, pp. 501-10.
Flyvbjerg, B 2006, 'Making organization research matter: power, values, and phronesis', in *The Sage Handbook of Organization Studies, 2nd edition, Thousand Oaks, CA, Sage*, pp. 370-87.
Flyvbjerg, B, Landman, T & Schram, S 2012, *Real social science: Applied phronesis*, Cambridge University Press.
Frank, AW 2012, 'Reflective healthcare practice', in *Phronesis as professional knowledge*, Springer, pp. 53-60.
Grant, RM 1996, 'Toward a knowledge-based theory of the firm', *Strategic Management Journal*, vol. 17, no. Winter Special Issue; ABI/INFORM Global, pp. 109-22.
Gregor, S & Hevner, AR 2013, *Positioning and presenting design science research for maximum impact*, MIS Quarterly & The Society for Information Management, 02767783, Essay, <http://search.ebscohost.com/login.aspx?direct=true&db=iih&AN=87369151&site=ehost-live>.
Gregor, S & Hevner, AR 2015, 'The Front End of Innovation: Perspectives on Creativity, Knowledge and Design', in *New Horizons in Design Science: Broadening the Research Agenda*, Springer, pp. 249-63.
Gregor, S & Jones, D 2007, 'The anatomy of a design theory', *Journal of the AIS*, vol. 8, no. 5, pp. 312-35.
Heusinger, JM 2014, 'On the ‘Impossibility’of Critical and Emancipatory Design Science Research', in *Enterprise Information Systems*, Springer, pp. 331-48.
Hevner, AR & Chatterjee, S 2010, 'Design Research in Information Systems', in R Sharda & S Voß (eds), *Design Research in Information Systems*, Springer US, vol. 22, pp. 23-31.
Hevner, AR, March, ST, Park, J & Ram, S 2004, 'Design Science in Information Systems Research', *MIS Quarterly*, vol. 28, no. 1, pp. 75-105.

Hibbert, K 2013, 'Finding wisdom in practice: the genesis of the salty chip, a Canadian multiliteracies collaborative', *Language and Literacy*, vol. 15, no. 1, p. 23.

Hjelseth, E & Nisbet, N 2011, 'Capturing normative constraints by use of the semantic mark-up (RASE) methodology', paper presented to Proceedings of CIB W78-W102 Conference.

Kanjanabootra, S 2011, 'Improving strategic business performance with knowledge management: a case study of a refrigeration company', doctoral dissertation thesis, RMIT University.

Kanjanabootra, S & Corbitt, B 2016, 'Reproducing knowledge in construction expertise: a reflexive theory, critical approach', *Construction Management and Economics*, pp. 1-17.

Keynes, JM 1937, 'The general theory of employment', *The Quarterly Journal of Economics*, pp. 209-23.

Khemlani, L 2011, *CORENET e-PlanCheck: Singapore's Automated Code Checking System. AECbytes*.

Kimbell, L 2011, 'Rethinking design thinking: Part I', *Design and Culture*, vol. 3, no. 3, pp. 285-306.

Kinsella, EA & Pitman, A 2012, *Phronesis as professional knowledge: Practical wisdom in the professions*, vol. 1, Springer Science & Business Media.

Liebeskind, J 1996, 'Knowledge, strategy and the theory of the firm', *Strategic Management Journal*, vol. 17, no. Winter special issue, pp. 441-52.

Markus, ML, Majchrzak, A & Gasser, L 2002, 'A Design Theory for Systems That Support Emergent Knowledge Processes', *MIS Quarterly*, vol. 26, no. 3, pp. 179-212.

Maslach, C, Leiter, MP & Jackson, SE 2012, 'Making a significant difference with burnout interventions: Researcher and practitioner collaboration', *Journal of Organizational Behavior*, vol. 33, no. 2, pp. 296-300.

McKay, J, Marshall, P & Heath, G 2010, 'An Exploration of the Concept of Design in Information Systems', in D Hart & S Gregor (eds), *Information Systems Foundations: The Role of Design Science*, ANU Press, Australia.

Mobjörk, M 2010, 'Consulting versus participatory transdisciplinarity: A refined classification of transdisciplinary research', *Futures*, vol. 42, no. 8, pp. 866-73.

Myers, MD & Venable, JR 2014, 'A set of ethical principles for design science research in information systems', *Information & Management*, vol. 51, no. 6, pp. 801-9.

Nonaka, I 1994, 'A Dynamic Theory of Organizational Knowledge Creation', *Organization Science*, vol. 5, no. 1, pp. 14-37.

Norman, DA & Verganti, R 2014, 'Incremental and radical innovation: Design research vs. technology and meaning change', *Design Issues*, vol. 30, no. 1, pp. 78-96.

Omari, A & Roy, G 1993, 'A representational scheme for design code information in an expert systems approach to building design', *Computing Systems in Engineering*, vol. 4, no. 2-3, pp. 253-69.

Payne, A, Storbacka, K & Frow, P 2008, 'Managing the co-creation of value', *Journal of the Academy of Marketing Science*, vol. 36, no. 1, pp. 83-96.

Porter, ME 1991, 'Towards a dynamic theory of strategy', *Strategic Management Journal*, vol. 12, no. (Winter Special Issue) 2, pp. 95-117.

Razzouk, R & Shute, V 2012, 'What is design thinking and why is it important?', *Review of Educational Research*, vol. September 2012 82, no. 82, pp. 330-48.

Richey, RC & Klein, JD 2014, *Design and development research: Methods, strategies, and issues*, Routledge.

Rowe, P 1987, *Design Thinking*, The MIT Press, Cambridge, Massachusetts.

Sanders, E & Stappers, PJ 2008, 'Co-creation and the new landscapes of design', *CoDesign*, vol. 4, no. 1, pp. 5-18.

Shih, S-Y 2016, 'Challenges Associated with Implementing BIM-Enabled Code-Checking Systems within the Design Process', The University of Newcastle, Australia.

Shugan, SM 2004, 'Editorial: Consulting, research, and consulting research', *Marketing Science*, vol. 23, no. 2, pp. 173-9.

Simon, HA 1988, 'The Science of Design: Creating the Artificial', *Design Issues*, vol. 4, no. 1-2, pp. 67-82.

So, H-J, Seah, LH & Toh-Heng, HL 2010, 'Designing collaborative knowledge building environments accessible to all learners: Impacts and design challenges', *Computers & Education*, vol. 54, no. 2, pp. 479-90.

Sohaib, O & Khan, K 2010, 'Integrating usability engineering and agile software development: A literature review', paper presented to Computer design and applications (ICCDA), 2010 international conference on.

Spohrer, J & Maglio, PP 2008, 'The Emergence of Service Science: Toward Systematic Service Innovations to Accelerate Co-Creation of Value', *Production and Operations Management*, vol. 17, no. 3, pp. 238-46.

Svihla, V 2010, 'Collaboration as a dimension of design innovation', *CoDesign*, vol. 6, no. 4, pp. 245-62.

Szebeko, D & Tan, L 2010, 'Co-designing for Society', *Australasian Medical Journal AMJ*, vol. 3, no. 9, pp. 580-90. Doi10.4066/AMJ.2010.378.

Taylor, C & White, S 2000, 'Practising reflexivity in health and welfare', *Buckingham: Philadelphia*.

van der Aalst, WMP, Reijers, HA, Weijters, AJMM, van Dongen, BF, Alves de Medeiros, AK, Song, M & Verbeek, HMW 2007, 'Business process mining: An industrial application', *Information Systems*, vol. 32, no. 5, pp. 713-32.

Vargo, SL, Maglio, PP & Akaka, MA 2008, 'On value and value co-creation: A service systems and service logic perspective', *European Management Journal*, vol. 26, no. 3, pp. 145-52.

Venable, J, Pries-Heje, J & Baskerville, R 2014, 'FEDS: A Framework for Evaluation in Design Science Research', *European Journal of Information Systems*.

Voordijk, H 2009, 'Construction management and economics: the epistemology of a multidisciplinary design science', *Construction Management and Economics*, vol. 27, no. 8, pp. 713-20.

Weijters, AJMM & van der Aalst, WMP 2003, 'Rediscovering workflow models from event-based data using little thumb ', *Integrated Computer-Aided Engineering*, vol. 10 no. November 2/2003, pp. 151-62.

Wernerfelt, B 1984, 'A resource-based view of the firm', *Strategic Management Journal*, vol. 5, pp. 171-80.

Zack, M 1999, 'Developing a knowledge strategy', *California Management Review*, vol. 41, no. 3, pp. 125-45.