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Building a Cohesive Body of Design Knowledge: Developments from a Design Science Research Perspective

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BUILDING A COHESIVE BODY OF DESIGN KNOWLEDGE: DEVELOPMENTS FROM A DESIGN SCIENCE RESEARCH PERSPECTIVE

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Abstract

Design is an extremely diverse field where there has been widespread debate on how to build a cohesive body of scientific knowledge. To date, no satisfactory proposition has been adopted across the field – hampering scientific development. Without this basis for bringing research together design researchers have identified difficulties in building on past works, and combining insights from across the field. This work starts to dissolve some of these issues by drawing on Design Science Research to propose an integrated approach for the development of design research knowledge, coupled with pragmatic advice for design researchers. This delivers a number of implications for researchers as well as for the field as a whole.

Keywords: Design science, Research methodologies and methods, Design theory

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1 INTRODUCTION

The development of a cohesive body of scientific knowledge and theory in design research has been a matter of substantial reflection over the last decade (McMahon 2012). In particular, it has been recognised that the diversity of the field presents a number of substantial challenges to building a cohesive body of knowledge (McMahon 2012). Ability to produce a cumulative and consistent, 'progressive' body of theory is held up as one hallmark of a research discipline (Lakatos 1975). This has led to debate on how research approaches can support this effort in the field. However, there are still major challenges in bringing together design research studies and findings, both with respect to theory, and as a wider body of knowledge (Blessing & Chakrabarti 2009).

This paper explores one means for addressing these challenges by proposing an integrated approach to the development of design research knowledge, coupled with pragmatic advice for design researchers.

This is achieved by comparing developments in design research with similar theoretical development in Design Science Research (Hevner et al. 2004). This is then used as the basis for comparison and the identification of insights for design research - combining traditional design research perspectives with advances from design science research. In particular, this work adapts and explores the utility of a design science research (DSR) framework for the development of a more cohesive body of knowledge in the design research domain.

In this paper we develop an argument that DSR as a methodological framework can aid in bridging design practice with design research and enable contribution to existing knowledge in a structured manner. The contribution is a framework that enables combining useful design to rigorous theory development particularly in prescriptive, 'problem solving' research. The approach in the paper is conceptual, although empirical exemplars are used throughout. The analysis in the paper is conducted from an empirical realist perspective, in line with Design Science Research, which itself is open to epistemological pluralism (Niehaves 2007). Due to the overlap between Design Science Research and Design Research terminology Table 1 defines the key terms used in this paper. In particular the definition of Design Theory has been drawn from DSR and is therefore different from typical design research usage (see table and also Section 2.1).

Table 1. Key terms and their use in this paper.

Term	Definition
Design theory	Explanations of principles behind design artefacts
Problem solving	The act of changing one situation to a preferred one through design
Intervention	The activity of changing something to bring about the change of situation desired in problem solving

In order to achieve this aim the paper first explores the major elements underpinning design research and their impact on theory, and subsequently knowledge development. Next the design science perspective is explained and adapted with regard to design research. The utility of this approach is then illustrated in Section 4. This leads to a number of key implications for design researchers and design research as a whole. This work contributes an adapted design science framework for supporting knowledge development in the design research domain and illustrates its applicability for researchers.

2 KNOWLEDGE DEVELOPMENT IN DESIGN RESEARCH

In order to address the challenges facing knowledge development in design research it is first necessary to understand its two fundamental drivers – problem solving, and theory building.

2.1 Design Research and Design Science Research

A potential source of disciplinary and etymological confusion is that DSR has developed independently from the traditions of Design Research, Design Studies, and Design Science (Winter 2008; Piirainen et al. 2010). The key to understanding this paper is that in this context we refer to the field of research that studies the art, practice, processes, methods of, and behaviours associated with designing or synthesizing artefacts and systems i.e. Design Research in the sense characterized by Cross (2007; 1999) and Bayazit (2004). Conversely, we use Design Science (Research) (DS/DSR) to refer to research following the particular methodological framework we describe below. Further we use the term Design Theory (DT) in a general sense to denote theories that explain the principles behind design artefacts and the knowledge embedded in the design as proposed by Gregor and Jones (2007), instead of focusing on Design Theories in the sense of prescriptive systems, rules or methodologies to use in design processes as in e.g. axiomatic design (Suh 1998), mid-century modernism (Cross 1999) or design as practice or activity (Friedman 2003).

2.2 Problem Solving

Fundamentally design research is an applied field with a focus on solving tangible problems in practice, improving the design process or the designed artefacts themselves (McMahon 2012). The nature of 'problems' can be wide and it can be argued that problem solving can be reduced to 'changing situations into preferred ones' (Friedman 2003). In this context the 'problem' (space) is something the designer as an actor defines, with or without stakeholder input, and design addresses that problem by proposing a solution that will change the situation to a preferable state. Thus, researchers are concerned with both creating understanding *and* the production of impactful interventions, such as, improved process models, support tools or design artefacts. The word intervention implies that the design researchers, especially when focusing on design methods and processes, might intervene in existing practices and processes trying to, again, change situations e.g. said practices, to preferable ones. This is not to say that current design research would or should entail an intervention in the clinical or experimental sense.

This problem solving focus has allowed design research to have significant impacts on practice, and defines one of the main aspirations in the field (Design-Society 2012). A drawback of this focus is that it is common to emphasise individual cases or situations where practical impact has been achieved, often with little theoretical grounding (Blessing & Chakrabarti 2009). Thus, although it is often possible to argue that an intervention works in the context of a specific study, it is increasingly difficult to distil core mechanisms that might work across contexts. This weakens the impact of design research interventions by making them highly susceptible to situational changes, as there is little codified understanding of what makes the intervention effective in the given context, and what the limitations to applying it elsewhere might be.

The lack of theoretical grounding in this context means that it is difficult to discriminate the mechanisms at work, and the contextual variables that influence their outcome. This is best articulated by Briggs: "*If we understand nothing of the causal mechanisms, then we can only achieve a given outcome by accident at first and by rote thereafter*" (Briggs 2006). Further, it is possible to see reactions to this issue in the development of Blessing and Chakrabarti's (2009) structured means for describing research logic in their design research methodology, or in Dorst's (2008) calls for the wider use of research frameworks. However, to date, no satisfying solution has been widely accepted. In an effort to dissolve this issue the next section explores what is required when theory building.

2.3 Theory Building

Theory is defined as a set of rules that explain the behaviour of a system by establishing causal relationships between constructs in order to offer predictions of system behaviour in a variety of circumstances. Further, a theory explicitly defines the phenomena it explains and those it does not (Popper 1963). Thus in order to build theory it is necessary to identify relevant constructs, principals of interaction, variables, explanations, and testable predictions (Dubin 1969). Specifically theory should answer (Whetten 1989):

- *What* constructs are needed to explain a given phenomenon?
- *How* are the constructs related?
- *Why* are the constructs expected to behave as posited by the theory? What are the underlying dynamics of the interaction that manifest in the expected behaviour?
- *What* are the boundaries of the expected interactions, and what is expected to happen between the constructs, where and when? What is not supposed to happen?

Linking this to the problem solving aspect of design research the role of theory can be described as explaining observed variations in phenomena such that predictions can be made about what would happen under a given set of conditions. In particular, effective theory supports the deeper understanding of the success (or otherwise) of design practices or design research interventions.

However, design research theory is often – although not without successful exceptions – only partially articulated or lacking in predictive power. However, examining the wider field there is a general lack of coherence in theory use, as explicitly highlighted by Love (2002). A manifestation of this is that research is often framed a-theoretically, or links to theory only weakly. This leaves research isolated, because without a consistent theoretical or scientific frame there are few means for bringing diverse works together cohesively. Without explicit articulation and explanation of underlying constructs and mechanisms, communication of scientific knowledge is difficult, and reinterpretation or development almost impossible. Ultimately this means that developing a cohesive body of scientific knowledge is extremely difficult. As such, this poses the question, how can design research best develop a cohesive body of scientific knowledge without sacrificing its problem solving elements.

2.4 Bringing Knowledge Together

In order to bring together effective theory building while retaining design researchers applied focus, one key element is needed. Namely, a consistent scientific framework i.e. what does 'good science' look like in design research? This brings together practical insight, with insights from specific studies, and deeper linking theory. The current situation in design research is that despite strong theory building efforts, a lack of scientific cohesion has led to a fragmented body of knowledge.

In order to address this fragmentation two key elements need to be considered. First, how to bring cohesion to design research as a scientific field? Second, how can this be supported pragmatically such that the problem solving focus is not lost? Following the evolutionary arc of Information Systems Research, we propose that DSR has potential to answer them..

3 THE DESIGN SCIENCE RSEARCH PERSPECTIVE

One possible source for supporting the development of a consistent scientific framework is Design Science Research (DSR). In DSR Hevner et al. (Hevner et al. 2004) define the difference between routine design and DSR as follows:

- *Design* is the application of knowledge to solve a problem.
- *DSR* contributes to knowledge by solving problems in novel and innovative ways, and *contributing back to the knowledge base*.

In the context of this work, it is this last element that provides the inspiration for bringing DSR elements into design research. More specifically, DSR uses a common scientific framework for bringing together problem solving and deeper scientific knowledge through construction of design theories that describe the principles embodies by the design artefacts (Gregor & Jones 2007). For clarity, when DSR refers to designing artefacts, these include constructs, models, methods, or instantiations of these (March & Smith 1995).

Hevner et al. (2004) link DSR to both the circumstantial (business) environment, and the knowledge base built by previous research. This is described by Hevner (2007) as three related cycles of activity, illustrated in Figure 1. These cycles are the relevance cycle – linking the business environment and DSR, the central cycle – describing the internal design process of DSR, and the rigor cycle – linking DSR and the scientific knowledge base. Through these three cycles, DSR produces artefacts that solve business problems (the relevance cycle), while also creating new additions to the knowledge base (the rigour cycle). Of these cycles, it is the final one that is the focus of this work. This is reflected in Figure 1, where this part of the DSR framework is detailed in full, while summarising other aspects.

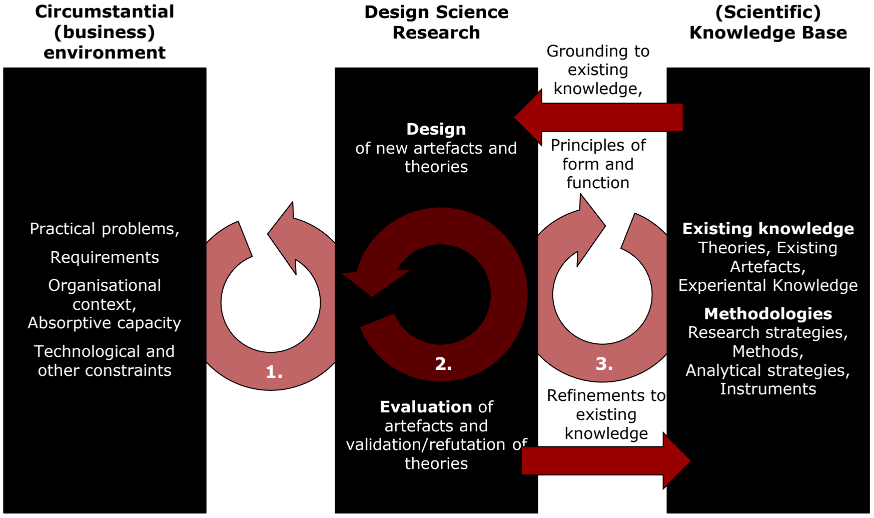

Figure 1. The DSR framework and the three cycles (Hevner 2007)

In this framework formalization of knowledge as design theory (DT – see Table 1) makes contributions to knowledge more transparent and easily transferrable (central column). DTs differ from most social science theories, which are *descriptive,* because they specifically aim to explain phenomena in terms of constructs and their causal interaction, or predict what will happen given a set of circumstances. Crucially DTs also explain how to build an artefact to solve a problem based on existing theory and predict how it will behave in an organization. From these characteristics, it follows that DTs are *prescriptive theories* of procedural rationality (Simon 1978). Further, artefacts embody or operationalize theory to the extent that observing the artefact can validate theory. Table 2 builds on Gregor and Jones (Gregor & Jones 2007) and Piirainen and Briggs (Piirainen & Briggs 2011) to summarise the key components of a DT.

Table 2. Components of a DT from the DSR perspective

Components	**Guiding question**	
Purpose and scope	Which class of requirements, goals or problems does an artefact apply to?	Core components
Constructs	What constructs are needed to describe the behaviour of an artefact?	
Justification knowledge	Which theories explain the interaction of the constructs to help solve the problem?	
Principle of form and function	Which (class of) artefacts meet the requirements; what are the key functions?	
Artefact mutability	How is the artefact expected to interact with its surroundings and evolve when instantiated?	
Testable propositions	Does the design fulfil the requirements and does it behave as predicted?	
Principles of implementation	How to build an artefact based on the justification knowledge and principles of form and function?	Auxiliary components
Expository instantiation	Is an artefact consistent with the principles of form and function?	

Brining these elements together it is possible to develop specific suggestions for developing a more cohesive body of knowledge in design research by explicitly linking DSR, DTs and design research.

4 INTERFACE BETWEEN DESIGN AND THEORY

To highlight the possible contribution of DSR principals in design research consider the differing scientific perspectives adopted by the two fields. In DSR the idealized basic logic of discovery is deductive. One takes a previously unsolved problem and then tries to find existing theoretical elements from the knowledge base in order to formulate a DT. This is then used to define specific constructs to be examined, and subsequently variables to be affected by the artefact. In effect, the researcher takes a knowledge base theory and deducts a solution to a particular problem from this. This process is closed by the prediction of performance as design propositions and testing of variables, in order to validate the DT, which then feeds back into the knowledge base (Gregor & Jones 2007). The knowledge base theory offers general principles that can be applied to the specific problem to form a DT. Thus, in the process of developing the intervention artefact and refining the DT, DSR can refute, corroborate or extend the originating knowledge base theory. This fundamentally theory driven approach to knowledge building allows DSR to build up a cohesive body of knowledge that can be interrelated at different levels via the constructs and DTs used. This process is illustrated in Figure 2.

In design research the basic logic is closer to abductive. The researcher seeks to understand a problem by synthesising the variables at play into a pragmatic framework. This might then be linked to theory on the pre-condition that they are connected and that the theory has an answer to the problem. Based on this reflection, the researcher then develops an empirical hypothesis or artefact, which directly addresses the original problem. Finally, the research is ideally able to empirically demonstrate relationships between their target variables but not necessarily explicate the constructs or deeper theory at work. As such, the design research loop is left open with the knowledge base being limited to the variable level and thus fractured.(Kovács & Spens 2005; Burch 2014)

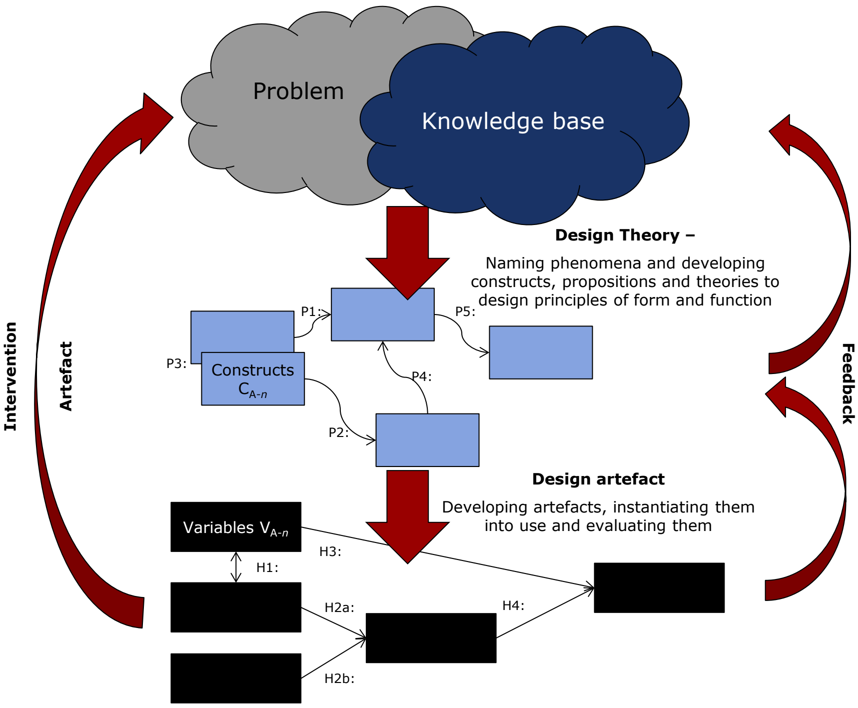

Figure 2. DSR research flow and feedback to the knowledge base

Bridging this difference has certain repercussions when seeking to develop a coherent body of knowledge in design research. This work explores two key elements in order to support this in design research. First, the concept of DTs integrated in the core problem solving process provides a more coherent scientific framework for carrying out design research. Second, the incorporation of and contribution to theories from the knowledge base provides a more robust means for developing scientific understanding in design research.

4.1 DTs and Design Research

As discussed, the key contribution of any theory is in answering the question: *why* do certain variables interact in certain ways? This links variables through constructs to the wider context in order to explaining a phenomenon through key mechanisms. These allow researchers to build upon previous works, which examine related mechanisms or constructs. Critically, this goes beyond the typical variable level relationships described in design research. As such, it is proposed that the concept of DT can be leveraged to bridge the gap in current abductive approaches. This would integrate DT development as a core element in the research process, encouraging the explicit linking of design research interventions and base theoretical knowledge. This provides a robust framework for transforming intervention principles into explicit, and refutable design propositions. This is important because it allows a research to take a previously contextually dependent intervention and distil out cross-contextual constructs. This distillation enables rigorous evaluation of both the artefact and validation of the underlying knowledge of causal relations between variables and constructs. As such, it means that success can be built upon and developed in new contexts without having to repeat the whole grounded development cycle every time. This would also allow for greater replication and development of design research results – something that is extremely rare currently (Cash et al. 2013).

This would be a small but significant change for design researchers. However, as with other research frameworks, adoption requires a recognition of the value added at a researcher level, and the acknowledgement of legitimacy at the field level (c.f. Dorst 2008). Without this field level debate and integration, peer review and scientific standards within the field will ultimately fall out of line with actual research practice. Overall, these points can be distilled into a number of practical heuristics to support the integrating of DSR DT practices into design research studies:

1. Incorporate and adapt base theory into the research process from the start. Consider variables, constructs, and context.
2. Link base theory to the problem in order to create the DT. Explicitly define elements that are problem specific versus more general mechanisms.
3. Define the mechanisms at work and explain their behaviour. Describe intervention impacts *ex ante* as design propositions that bridge the context and the general theory and try to refute the design theory by instantiating and testing it.
4. Feedback this understanding to the base theory, does this confirm or refute the base theory?

Based on these heuristics it is proposed that design research develop its own framework analogous to that used in DSR in order to more closely incorporate theory building as part of the design research process and establish a common view of what constitutes a design research contribution. In particular this would open the debate about how best to build a cohesive body of scientific knowledge in design research. In this regard, a number of points are addressed in the next section.

4.2 Linking to the Knowledge Base

One key question not answered above is which base theory to draw on, as abduction in itself does not steer the search. As discussed, theories explain systems by abstracting constructs and positing causal explanations between them. These then lead to the definition of variables. However, problem focused research often begins the process at this point, by identifying observable variables to be influenced. These variables are often process or outcome related measures that measure whether the original problem was solved, which researchers wish to measure, minimise or maximise with the design.

To take a general example on a creativity/idea generation intervention, a researcher might identify lack of ideas during idea generation as a problem and number of ideas as the key variable. They then seek to influence this through creativity methods to increase the number of ideas generated. The direct approach in this type of case is to design and implement a range of possible interventions e.g. behavioural interventions, physical artefacts or a combination, drawn from various design and facilitator's cookbooks to increase ideation without establishing the underlying constructs at work. However, if the variables are picked based on the problem, and preferred outcome, without deeper understanding of the underlying causalities, they can mislead the intervention, or not prove replicable in different contexts. Leading to the finding that creativity methods in particular are often situational, being influenced by participant experience and in general understood in general terms, leading to problems with applicability (Cross 2004).

The theory driven approach entails identifying theoretical constructs that explain why ideas are lacking. To take a published example, the researchers identified an explanation for lack of ideation during brainstorming – unconscious cueing of deviancy – which influenced creativity across contexts (Förster & Friedman 2005). Using this explanation, the researchers designed a successful intervention to support creativity, while also contributing to the knowledge base in the form of explanation why and how the intervention worked in the given context, which could then be incorporated in other studies or interventions. This example illustrates the approach and advantage of constructs when developing a body of knowledge, which is difficult to achieve by focusing on variables.

Tackling this challenge requires a shift in how researchers develop and articulate their research. Building on the variable lead perspective it is still possible to guide theory integration. Here, the variables can guide the choice of theoretical framework through analogy, as variables are simply measurable representations of theoretical constructs. As such, a structuring of the search and development process is suggested. This constitutes four major steps and elaborates on traditional design research and DSR approaches. These are illustrated in Figure 3, where the numbered arrows correlate with the steps described below.

1. **First**, the researcher describes their variables based on the problem domain as normal. At this stage variables are filtered by level and unit of analysis to identify any consistency issues. For example variables associated with different levels e.g. cognitive and organisational, could lead to radically different perspectives. The level should be explicit to enable focusing, either on a single level or to directly identify cross level constructs. Once the main variables are established (V1) these should be used to search the current knowledge base for corresponding constructs.
2. **Second**, based on the search of the knowledge base a number of relevant theories are likely to be identified – resulting in a range of possible sets of constructs (CA-C). Here, there is iterative refinement of the constructs and corresponding variables as it is unlikely that any one set of constructs will explain all the variables. At this stage the aim is to explicitly identify one or more sets of constructs to be used, and subsequently refine the variables under consideration (V2). This could mean adding variables or removing superfluous factors.
3. **Third**, the refined variables are then used to bring together the problem and knowledge base to develop a DT specific to the research. This DT should explain the constructs (C_A and C_B in this illustration) involved and offer propositions as to their behaviour under given conditions such that the final variables (V_3) can be identified and the intervention developed. This should obey the basic rules of theory building as defined in Section 3 as well as the integration guidelines described in Section 4.1. The intervention is now ready for deployment and testing.
4. **Fourth**, with the research complete the various impacts on the variables should be compared back to the original constructs identified in Step 2. This process adds to the knowledge base by developing, refuting, or confirming the base theories. Further, by incorporating the problem variables included in the DT it is possible to refine the scoping of the base theories i.e. did they react as predicted in this case, and if not what were the deviant variables and constructs requiring further investigation. Unit of analysis and level should again be reflected on at this stage – what are the scope of the implications for the knowledge base?

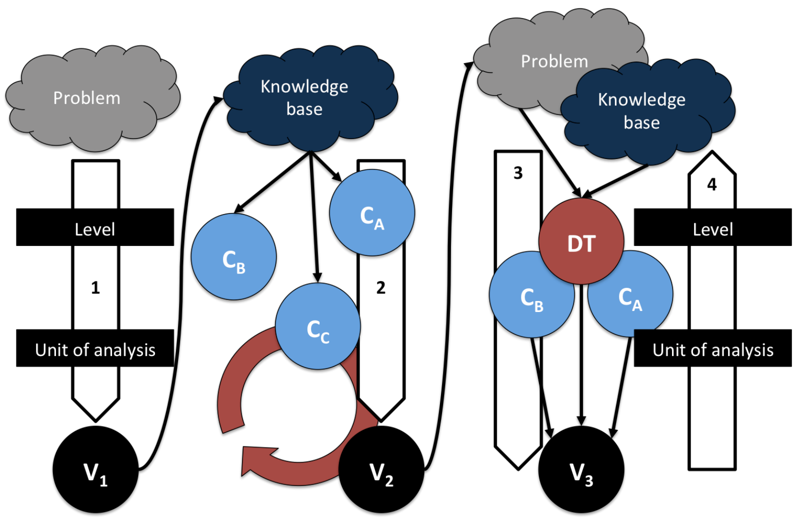

Figure 3. A four-step guideline for identifying and incorporating theory from the knowledge base into typical design research approaches

4.3 Implications

There are a number of key implications to be drawn from this work.

First, DSR provides an important analogous scientific or methodological framework, which can be developed and applied in the context of design research to improved overall scientific cohesion.

Although further development is required the DSR framework provides significant potential for building a more coherent body of knowledge in the design research field. Further, adopting a widely recognized framework helps in integrating knowledge across research fields.

Second, the integration of DTs as a core part of the design research process helps to bring together the debate on scientific approach and quality in design research. In particular it provides a mechanism for retaining design research's problem solving focus whilst also making theory core to the research process. This helps to address many of the challenges faced by a field with both significant industrial and scientific demands.

Third, the proposed guideline for theory search and integration in design research practice provides pragmatic support for individual researchers as well as a high level formalisation of the theory integration process. This gives a foundation for further development in the design research domain. In particular, this supports the active debate of what constitutes scientific best practice in the field, and how this can be practically achieved whilst retaining scientific cohesion and integrity.

4.4 Limitations

The major limitation of this work is the scope of the issues to be addressed. Here, the very nature of the problem means that case-by-case refinement is required and thus any framework must, by necessity, be on a high level. Although the question of how best to support theory identification based on problem definition is extremely open, the presented process and heuristics providing a first step in a wider scientific debate. Here, the authors are not aware of any guided processes for theory search and identification, and thus contend that this work offers a significant contribution in supporting scientific best practice in design research. In particular the fact that this question is of such magnitude, it is unlikely to be resolved without field wide development and recognition. As such, by explicitly articulating the proposed process it is possible to traceably address the question for the first time. The crucial next steps are 'empirical validation' of the framework in research projects and developing a set of best-practices for applying the framework specifically to design research.

5 CONCLUSIONS

This work offers a new perspective on developing a robust scientific framework for design research, coupled with support at each level of research – body of knowledge, theory building, and research design. This effort is both timely and necessary in design research where there is the need for synthesis of research knowledge in a highly diverse field. Although this work provides a first step there are substantial efforts required in order to gain wider acceptance for theory and knowledge building across design research practitioners, and to tailor these to our field and specific research approach. Although this paper has started to address these issues there is a clear need for field wide scientific best practices from epistemological approaches to choice of field methods (Blessing & Chakrabarti 2009).

This paper has explored the utility of Design Science Research (DSR) for developing deeper scientific understanding in design research. In particular the overall scientific framework of DSR has been discussed, and specific guidance developed in better integrating theory into design research. Further, a theory integration approach has been proposed to support both the individual research, and the wider development of a body of scientific knowledge in design. In developing this support this work contributes directly to the debate on how to improve scientific quality in design research, and offers a pragmatic means for achieving better integration of industrial impact and scientific research.

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