DESIGN SCIENCE RESEARCH IN GREEN IS: ANALYZING THE PAST TO GUIDE FUTURE RESEARCH

Research paper

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Abstract

The field of Green IS research addresses the environmental challenges of our rapidly growing economy. IS-based solutions are valuable tools for emissions reduction and waste mitigation. The development of novel sustainable IS artifacts falls in the domain of Design Science Research. Applying the Design Science Research paradigm helps to design, develop, improve and implement IS related artifacts to solve prevailing problems or challenges. Hence, regarding sustainability, it acts as an aid to the goals of Green IS. Thus, the development of novel sustainable artifacts falls in the intersection of Green IS and Design Science Research.

We analyze the relationship between Design Science Research and Green IS by providing a deeper understanding of current research knowledge and opportunities at the intersection of these two important IS topics. Based on these findings, we present five directions for future research that aim to facilitate further contributions to theoretical knowledge, Design Science Research, and sustainable solution development in the field of Green IS.

Keywords: Design Science Research, Green IS, Literature Review, Research Directions

1 Introduction

"Green IS" (GIS) research investigates "Information Systems" (IS) that contribute to environmental sustainability (Watson et al. 2010) by providing solutions for environmental challenges (vom Brocke and Seidel 2012; Malhotra et al. 2013) such as greenhouse gas emissions and global climate change (vom Brocke, Watson, et al. 2013; Gholami et al. 2016; Seidel et al. 2013). GIS research strives to understand the influence of such artifacts on sustainable behavior at the individual, organizational, and societal level (Elliot 2011; Malhotra et al. 2013; Melville 2010). In parallel to developing a deeper understanding of the relationship between IS and environmental sustainability, GIS scholars also strive to understand the design of such innovative and sustainable IS-based artifacts. For example, GIS artifacts have provided practitioners with tools to monitor and reduce emissions (vom Brocke and Seidel 2012; Hilpert et al. 2013), and optimize mobility service operations (Brendel et al. 2017; Brendel and Mandrella 2016).

The development and evaluation of novel GIS artifacts falls under the overarching research paradigm of "Design Science Research" (DSR) (Gregor and Hevner 2013; Hevner 2007; Hevner et al. 2004; March and Smith 1995), which aims to understand the design and subsequently evaluate the effectiveness of the designed IT and IS artifacts for the purpose of solving societal, organizational, and technological problems (Hevner et al. 2004; Sein et al. 2011; Simon 1996). Although GIS research has been described as a domain with great potential for DSR application (March and Niederman 2012), DSR scholars often miss opportunities to link newly developed artifacts to valuable environmental impacts and contributions (vom Brocke and Seidel 2012). To address this research gap, we systematically analyze the current field of literature at the intersection of DSR and GIS research. We provide a comprehensive summary of the depth, quality and rigor of existing research in terms of application contexts,

methods utilized and generated outcomes, including artifacts, design theories, and sustainable impacts. This analysis could help gain a better understanding of DSR and its current status quo within the field of GIS research. In effect, we strive to answer the following research questions:

RQ1: How can current Design Science Research be characterized within the field of Green IS?

RQ2: What are possible directions for Design Science Research within the field of Green IS?

We answer these questions systematically by first presenting the DSR framework used and summarizing the GIS research domain, followed by a thorough description of the applied research design. We then present and discuss the results, formulate directions for future research, and close with a short conclusion summarizing the important insights from this analysis and its results.

2 Related Work

In this section, we introduce the DSR frameworks of Hevner et al. (2004) and Hevner (2007) that will guide us throughout this study. Furthermore, the DSR domain is discussed in the context of its relationship to the research field of GIS, which is subsequently summarized.

2.1 Design Science Research

The DSR process can be structured and described in different ways (Leukel et al. 2014). However, Hevner et al. (2004) developed a widely accepted (Arnott and Pervan 2012; vom Brocke and Seidel 2012; Gregor and Hevner 2013) and commonly applied framework of the DSR paradigm (Leukel et al. 2014; Stein et al. 2014). Therefore, we follow a combination of the frameworks from Hevner et al (2004) and Hevner (2007), utilizing them as a foundation for our analysis (see Figure 1). This helps define the general nature of DSR and consolidate its descriptive vocabulary.

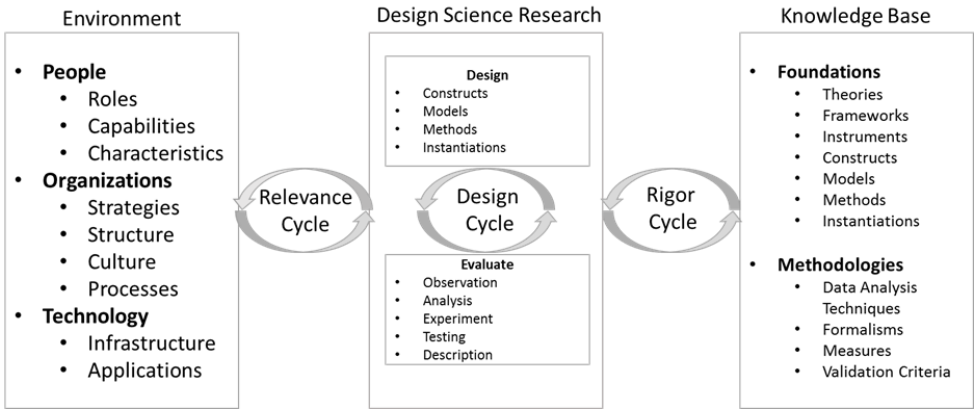

Figure 1. Design Science Research Framework (based on Hevner et al. 2004 and Hevner 2007)

The framework consists of three research cycles: relevance, rigor, and design. The relevance cycle inherits the interconnection of design activities and their corresponding environments of application. This enables assimilation of practitioners' requirements in order to solve real-world problems at the individual, organizational, or technological level. Furthermore, it allows the introduction of newly designed artifacts to the field. The rigor cycle connects design activities with existing research and knowledge bases, thereby integrating and eventually extending them by adding the results of the research process. At the core of the DSR model is the design cycle which represents the iteration of construction and evaluation of the artifacts to be designed. An artifact can take different forms, such as a construct, model, method, or instantiation. Artifact evaluation can be conducted by different means, including observation, analysis, experimentation, testing, or description (Hevner 2007; Hevner et al.

2004). Eventually, the artifact makes a contribution to IS knowledge by contributing new solutions to known problems, extending known solutions to new problems, providing known solutions for known problems, (Gregor and Jones 2007) or creating new solutions for new problems (Gregor and Hevner 2013).

2.2 Green IS

Given that IS research considers the duality of both "Green Information Technology" (Green IT) and GIS, it is also important to understand and define the concept of Green IT (vom Brocke and Seidel 2012; Malhotra et al. 2013). Green IT research is focused on the energy-efficient design and usage of IT (vom Brocke and Seidel 2012; Malhotra et al. 2013), whereas GIS research is a sub-domain of the IS discipline that investigates the design process, implementation, and use of IS to positively impact the environment and support sustainability within organizations (Malhotra et al. 2013; Watson et al. 2010). GIS has been identified as a research area of great potential (vom Brocke, Watson, et al. 2013) as it possesses the capacity to influence environmental sustainability on different levels in our society. In addition to producing sustainable outcomes (like reducing emissions and waste), IS can also influence action formation (e.g. inducing sustainable behavior) and beliefs formation (e.g. increasing environmental concern) (Melville 2010).

Consequently, GIS hold a unique position in the quest to resolving the environmental problems of our society (vom Brocke, Seidel, et al. 2013; Gholami et al. 2016; Malhotra et al. 2013). GIS research adds to the knowledge base of the IS community by providing insights regarding usage, design, adoption, and influence of IS from a behavioral research standpoint (vom Brocke and Seidel 2012; vom Brocke, Seidel, et al. 2013). Furthermore, GIS research can also produce purposeful and innovative solutions for environmental challenges in the form of IS artifacts by following DSR principles (vom Brocke, Watson, et al. 2013; vom Brocke, Seidel, et al. 2013; Gregor and Jones 2007; Hevner et al. 2004). This design-oriented form of GIS research has gained more attention in recent years. Nonetheless, it is still considered an emerging field of research (vom Brocke, Seidel, et al. 2013; Gholami et al. 2016; Malhotra et al. 2013).

3 Research Approach

To analyze the extent of DSR within the GIS domain, understand the application of its principles and identify future opportunities for DSR contributions to GIS research, we combine established structured research designs – including Webster & Watson's literature review (2002) and Arnott & Pervan's content analysis (2012) – to apply a three-step analytical approach. The individual phases are described in greater detail in the following sub-sections.

3.1 Phase 1: Gather Literature

The objective of the first phase was to compile a research database following the DSR paradigm which contributes to the domain of GIS. Publications were required to fulfill two criteria in order to be included in the database: first, publications must address the design and development of an artifact guided by a DSR-driven framework, method and set of principles (e.g. Hevner et al. 2004; Österle and Otto 2010; Peffers et al. 2006; Sein et al. 2011). Therefore, publications primarily focused on behavioral aspects of GIS and those presenting "ad hoc" developments not explicitly based on DSR are omitted. This criterion also filters out publications about DSR or GIS research in general, such as literature reviews or research frameworks. Secondly, the developed artifact requires a sustainable impact explicitly discussed by its authors. Hence, publications with unstated positive environmental impacts are excluded. Furthermore, we limited our literature search to studies and articles published after 2007 when the term "Green IT" and the concept of increasing sustainability by means of IT and IS were first introduced (Wang et al. 2015). The construction of the research database is divided into three steps.

In the first step, we searched for literature reviews focusing on GIS research or DSR, for initial identification of relevant publications in both fields. In total, we identified 6 relevant reviews. We analyzed the literature reviews of Klör (2016), Brendel and Mandrella (2016), Jorge and Correia (2013), Wang et al. (2015), Malhotra et al. (2013) and Gholami et al. (2016). In the process of reviewing each publication analyzed in the literature reviews, we gathered 14 relevant peer-reviewed publications matching our criteria.

As a second step, we added publications by performing a keyword search in the following outlets as ranked by the VHB (2015): A-ranking IS publications outlets, the B-ranking Business & Information Systems Engineering journal and articles from the proceedings of the B-ranking European Conference on Information Systems. The last two are two of the main DSR outlets within the IS research community (Leukel et al. 2014; Stein et al. 2014). We decided to add only high-ranking publications to our literary database with the specific purpose of ensuring theoretical and practical rigor, impact, and relevance (Levy and Ellis 2006). Furthermore, by assessing the number of hits and publications relevant to our study, we shed light on the status of design-oriented GIS research within the IS community. We used the following keywords for our search:

("Green IS" OR "Green information system" OR "Sustainability") AND ("Design Science")*

Finally, we conducted a forward and backward search on all previously identified publications. After subtracting doubles, we gathered a total of 23 publications to form our finalized research database.

The literature search was conducted in January and February of 2017 by two independent academic researchers. All articles were filtered using two steps. Firstly, articles were selected by title, keywords and abstract. The remaining articles were then reviewed for their suitability for the research database according to the previously defined criteria. Each decision was discussed until it was agreed upon by both reviewers. The results of the literature search are quantitatively documented in Table 1.

Literature Reviews	**Total Hits**	**Filtered Hits**
Brendel and Mandrella (2016)	58	1
Gholami et al. (2016)	9	0
Jorge and Correia (2013)	26	0
Klör (2016)	23	6
Malhotra et al. (2013)	30	0
Wang et al. (2015)	214	7
Subtotal	360	14
Publication Outlets	**Total Hits**	**Filtered Hits**
Information Systems Research	1	0
Management Information Systems Quarterly	8	0
Journal of Management Information Systems	1	0
Journal of the Association for Information Systems	26	0
Journal of Information Technology	29	0
Information Systems Journal	64	0
The Journal of Strategic Information Systems	18	0
European Journal of Information Systems	30	0
INFORMS Journal on Computing	13	0
SIAM Journal on Computing	10	0
Business & Information Systems Engineering	31	1
International Conference on Information Systems	337	8
European Conference on Information Systems	228	9
Subtotal	796	18
	Filtered for Doubles	-9
	Forward and Backward Search	0
	Total	23

Table 1. Search Results: Overall Literature Search

3.2 Phase 2: Code Literature

To compare and summarize the publications in our research database, we coded the literature along DSR dimensions (similar to Leukel et al. (2014) and Arnott and Pervan (2012)). The dimensions were

identified based on the DSR framework guiding our research, and supplemented by dimensions regarding the research contribution (Gregor and Hevner 2013; Gregor and Jones 2007), provided design theory (Gregor and Hevner 2013) and sustainable impact of the artifact (Melville 2010). The additional dimensions help understand DSR in the context of GIS research by breaking down its contributions into sustainable and academic components. The coding dimensions and characteristics are described in the following sub-sections.

The authors reviewed and coded the literature independently, discussing inconsistencies subsequently to reach a common understanding and consistent coding. All 23 publications were characterized by at least one characteristic per dimension, while some publications fulfilled multiple characteristics in some dimensions, for example, artifacts evaluated with multiple methods.

3.2.1 Problem Domain

Due to the pragmatic nature of the DSR relevance cycle (Agerfalk 2010; Hevner et al. 2004; Iivari 2015), DSR must be situated within an environment to research relevant solutions. According to the DSR framework presented in the Related Work section, there are three domains (environments) from which a problem can arise: (1) **People:** Roles, capabilities and characteristics, (2) **Organization:** Strategies, culture or processes, and (3) **Technology:** Infrastructure and application of technology.

Problems and challenges are not necessarily limited to one isolated environment and may arise from the interaction between any of the three research domains (Hevner et al. 2004). Therefore, some research articles may address multiple problem domains.

3.2.2 Evaluation Method

A central component of the DSR research process is the evaluation of the developed artifact. Different evaluation methods are available for the assessment of the capabilities and validity of a designed artifact. According to Hevner et al. (2004), there are five groups of evaluation methods: (1) **Observation:** case studies, field studies, (2) **Analysis:** static analyses, architecture analyses, optimizations, dynamic analyses, (3) **Experiment:** controlled experiments, simulations, expert evaluations, (4) **Testing:** functional (black box) testing, structural (white box) testing, and (5) **Description:** informed arguments, scenario descriptions. However, some studies (Arnott and Pervan 2012; Leukel et al. 2014) observed that DSR publications did not use any evaluation method. To account for such publications, we added 'no evaluation' as a characteristic.

3.2.3 Artifact Type

DSR is not limited to the development of one specific artifact or artifact type. DSR artifacts can have different forms and have been classified by Hevner et al. (2004) into the following four groups (Leukel et al. 2014): (1) **Construct:** Constructs provide the language to formulate a phenomenon within a domain, such as a domain-specific modeling language or programming language. (2) **Model:** A model is a purposeful abstraction of real world entities that reduce complexity by comprising statements and propositions about the problem and solution space. (3) **Method:** Methods provide guidance for the solution search, defining the steps to be taken within a model's solution space for the achievement of tangible results. For example, methods can include algorithms or guidelines. (4) **Instantiation:** An instantiation is the implementation of a construct, model, or method, and is used to demonstrate validity. In the case of IS research, an instantiation is usually observed as software.

3.2.4 Contribution

An artifact's theoretical and practical implications must be understood first to understand its impact. DSR artifacts can provide different forms of implications and contributions for IS research. According to Gregor and Hevner (2013), there are four forms of contributions: (1) **Improvement:** Developing new solutions for known problems, (2) **Exaptation:** Adapting known solutions to new problems, (3)

Routine Design: Proving known solutions for known problems, and (4) **Invention:** Developing new solutions for new problems.

3.2.5 Design Theory

The goal of DSR is to provide both practical and theoretical contributions to existing literature (Gregor and Jones 2007; Gregory and Muntermann 2014). Following Gregor and Hevner (2013), DSR primarily contributes by way of design theories, ranging from Level 1 theories involving situated artifact implementation and Level 2 theories involving nascent design to Level 3 encompassing well-developed design theory on overarching phenomena. We defined the following contribution categories according to Gregor and Hevner (2013): (1) **Design Theory Level 1:** Instantiation, e.g. prototypical implementation, (2) **Design Theory Level 2:** Constructs, methods, models, design principles, technological rules, and (3) **Design Theory Level 3:** Design theories (mid-range and grand theories). However, other studies (e.g. Arnott and Pervan 2012; Leukel et al. 2014) observed that DSR publications often lack reflection and contribution to theory, prompting the addition of 'none' as a characteristic. This means that even when a study contributes a Level 1 or 2 theory, if the description of artifact performance is not extended to a discussion of design theory implications, it will be classified as 'none'. While such articles may add to practice, they do not necessarily contribute to the structured narrative of IS (design) theory, and were accordingly labeled 'none' for the purpose of this literature review.

3.2.6 Sustainable Impact

In accordance with Melville (2010), IS can have different impacts on the environment, altering sustainable perceptions or behavior directly or indirectly. The following three sustainable impact types were formulated by Melville (2010): (1) **Outcome:** Reducing emissions and waste. (2) **Action Formation:** Supporting sustainable behavior. (3) **Belief Formation:** Increasing environmental awareness.

3.3 Phase 3: Analyze Literature

To analyze our research database, we apply a structured literature analysis followed by a cluster analysis. In the structured literature analysis, we analyzed the coded literature to identify the overall distribution of DSR characteristics in the research domain of GIS. Furthermore, we applied a cluster analysis to identify dominant research archetypes.

3.3.1 Structured Literature Analysis

To analyze the coded literature within our research database, we constructed a concept matrix. A concept matrix helps view literature from a thematic or concept-centric (Arnott and Pervan 2012) position and thus, foster an understanding of research beyond descriptive content summarization (Webster and Watson 2002). Furthermore, it helps understand the overall distribution of characteristics within the theoretical dimensions defined in the previous section and paves the way for the following analysis.

3.3.2 Cluster Analysis

A cluster analysis is applied to form clusters, defined as groups of objects that are as similar to each other as possible and as dissimilar as possible from objects of other groups (Kaufman and Rousseeuw 2005). Clusters built from research publications can help identify predominant forms of research within a research domain. With this in mind, we applied a two-stage cluster analysis approach to better understand the current foci of research at the intersection of DSR and GIS (Punj and Steward 1983; Remane et al. 2016):

To begin with, we applied Ward's method (Landau and Everitt 2004) to define the number of clusters. The similarity between two DSR publications was computed using the number of identical characteristics along the coding dimensions, measured as squared Euclidean distance. Based on a dendrogram,

the screen plot and the distance between the coefficients (Remane et al. 2016), groupings of four or seven clusters proved to be useful.

Going further, the k-means method (Landau and Everitt 2004) was applied for both cluster solutions. Subsequently, the four-cluster solution was selected as it provides greater explanatory power (Remane et al. 2016). The seven-cluster solution includes clusters with a single member and fuzzy cluster characteristics, indicating that the four-cluster solution is more precise and comprehensive. The cluster analysis was conducted in SPSS version 24.

4 Results and Findings

The final database consisted of 23 articles, a vast majority of which come from IS conferences. No publications were found in A-ranking journals, and the only journal publication was the article of Hilpert et al. (2013) from the Business & Information Systems Engineering journal.

Furthermore, by incorporating articles reviewed within other literature reviews, we achieved two benefits: Firstly, it assisted in our initiation into the intended research field. Secondly, it was evident that only parts of previous analyses were relevant for the scope of this study. Hence, it is evident that the discussion of DSR in GIS research could benefit from the added perspective of this study.

4.1 Structured Literature Analysis

In this section, we present the results of the structured literature analysis, summarized and illustrated in the form of a concept matrix (see Table 2). We also discuss the implications to be incorporated in the subsequent development of research directions.

The applied set of evaluation methods is diverse, ranging from primarily experimental methods (applied 11 times within our review) to functional testing (applied only once). In contrast to the main body of DSR research (Leukel et al. 2014), every article in our research database evaluated its developed artifact. Hence, design-oriented researchers in the domain of GIS research understand the importance of the evaluation of artifacts for the achievement of scientific rigor, practical usefulness (Corley and Gioia 2011), and theoretical relevance (Iivari 2015; Sein et al. 2011).

The types of artifacts analyzed predominantly are models that appeared 17 times throughout the database and instantiations that appeared 15 times. It is common for a researcher to develop a model and verify it by testing one of its instantiations. Constructs are not developed in any article within our database.

All articles contribute to the GIS research community and practitioners by contributing to the progress of the current status quo inform of improvements (Gregor and Hevner 2013). This may be due to the novelty of the GIS research domain (vom Brocke, Seidel, et al. 2013; Wang et al. 2015), and its consequent need for the extension of first wave artifacts to other problems and evaluation by routine designs in a second wave.

The current research predominantly focuses on providing additional information (e.g. Hilpert et al. 2013; Rickenberg et al. 2013) for the support of sustainable decisions and actions, a topic covered in 19 of the 23 articles. Four articles developed environmentally-oriented artifacts to improve sustainable outcomes (e.g. Boehm et al. 2011; Brandt et al. 2013). None of the reviewed publications, however, considered developing an artifact to influence sustainable belief formation. This may be due to the intricacy of measuring human belief formation, making it the evaluation of such artifacts difficult.

Regarding the extent of design theory discussion, a majority of publications (15 articles) provide highly context-specific knowledge (e.g. Level 1), while 8 articles abstract and generalize from such context-specific insights to develop architecture frameworks or design principles (e.g. level 2). The extension of a kernel theory (e.g. Level 3) is presented in a single article, while four articles completely omitted reflection on the design theory behind the developed artifact. To sum up, while the develop-

ment of a more abstract, complete, and mature knowledge (Gregor and Hevner 2013) on artifact design and performance has been addressed, higher-level abstractions of sustainably-oriented design knowledge are yet to be engaged with thoroughly. This may be due to the novelty of the problems encountered in the context of GIS (Elliot 2011; Watson et al. 2010). Nonetheless, the current direction of sustainable DSR is promising.

Article	Problem Domain			Evaluation Method						Artifact Type				Contribution				Sustainable Impact			Design Theory			
	People	*Organizations*	*Technology*	*Observation*	*Analysis*	*Experiment*	*Testing*	*Description*	*No Evaluation*	*Construct*	*Model*	*Method*	*Instantiation*	*Improvement*	*Exaptation*	*Routine Design*	*Invention*	*Outcome*	*Action Formation*	*Belief Formation*	*Design Theory L1*	*Design Theory L2*	*Design Theory L3*	*None*
Boehm et al. (2011)			X			X					X		X	X				X			X	X		
Brandt et al. (2013)			X			X							X	X				X			X			
Brandt et al. (2014)			X			X					X		X	X				X			X	X		
Dorsch and Häckel (2012)			X			X							X	X				X			X			
Frehe et al. (2014)		X				X					X		X	X					X					X
Hilpert et al. (2013)		X		X									X	X					X		X		X	
Kerschbaum et al. (2011)		X				X					X		X	X					X		X			
Koukal and Breitner (2014)		X				X					X		X	X					X		X			
Kurnia et al. (2014)		X		X							X			X					X			X		
Nuss (2015)		X						X			X		X	X					X		X			
Ojo et al. (2014)	X					X					X			X					X			X		
Reiter et al. (2013)		X			X							X		X					X			X		
Rickenberg et al. (2013)		X				X					X		X	X					X		X	X		
Schödewell et al. (2013)		X				X					X			X					X			X		
Sodenkamp et al. (2015)		X		X							X	X		X					X		X	X		
Sonneberg et al. (2015)		X		X				X			X			X					X		X	X		
Stiel and Teuteberg (2013)		X					X	X			X			X					X					X
Stindt et al. (2014)		X		X							X		X	X					X		X	X		
Thies et al. (2011)		X		X							X			X					X					X
Valogianni et al. (2014)	X	X		X	X						X		X	X					X		X	X		
Von Bomhard et al. (2016)	X		X	X									X	X					X					X
Wastell (2008)	X					X							X	X					X		X	X		
Zampou et al. (2015)		X	X	X							X		X	X					X		X	X		
n=23 ∑	4	16	6	9	2	11	1	3	0	0	17	2	15	23	0	0	0	4	19	0	15	12	1	4

Table 2. Concept Matrix

4.2 Results of Cluster Analysis

The applied cluster analysis resulted in the following four clusters (see Table 3): (1) Specific Artifact Design for Sustainable Outcomes Related to Technology, (2) Nascent Design Theory Development for Action Formation in Organizations, (3) Specific Artifact Design for Action Formation in Organizations, and (4) Limited Theoretical Implications for Design Science Research.

4.2.1 Cluster 1: Specific Artifact Design for Sustainable Outcomes Related to Technology

The first cluster includes research regarding the experimental evaluation of instantiations (e.g. Specific Artifact Design) influencing the sustainable outcome of technological implementation. An example of outcome related research is illustrated in the article by Brandt et al. (2014), where an IS for the integration of renewable energy sources through micro-grid operations is developed, and its sufficiency evaluated using a simulation.

4.2.2 Cluster 2: Nascent Design Theory Development for Action Formation in Organizations

IS research in this cluster focused on sustainable action formation in organizations. The artifacts are mainly evaluated through observation (e.g. field testing) and summarized in the form of nascent design theories (e.g. frameworks). Hence, the artifact was initially instantiated and subsequently analyzed to gain a deeper understanding of the problem and solution design. For example, Hilpert et al. (2013) developed a model to track greenhouse gas emissions for logistic companies. This model was evaluated as an instantiation within a field test and its capacity to assist companies in monitoring their greenhouse emissions was revealed, inspiring a novel approach to business processes design. A organizational theory was adapted as a kernel theory (e.g. providing a mid-range theory) and the artifact was instantiated (level 1) and tested in a field-test.

4.2.3 Cluster 3: Specific Artifact Design for Action Formation in Organizations

Research in this cluster focuses on the sustainability challenges arising from action formation in organizations. Unlike cluster 2, the artifacts are evaluated through simulation and primarily assessed within their specific contexts. For example, Rickenberg et al. (2013) developed a decision support system to identify the best positioning of car sharing stations. This helps plan the implementation of a car sharing system, serving as a sustainable means of transportation.

4.2.4 Cluster 4: Limited Theoretical Implications for Design Science Research

Publications in this cluster do not discuss their design theoretical contributions in depth, and evaluation and discussion typically remain on a descriptive, superficial plane of artifact performance analysis. Components of a comprehensive design theory (Gregor and Jones 2007) might be present in the article but are not summarized or discussed. Hence, apart from presenting an instantiation (e.g. level 1) or a model (e.g. level 2), it is vital to independently communicate the design of the artifact to the reader.

Dimensions	Characteristics	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Number of publications per cluster:		***4***	***8***	***8***	***3***
Problem Domain	*People*	0%	13%	25%	33%
	Organizations	0%	100%	75%	67%
	Technology	100%	13%	0%	33%
Evaluation Method	*Observation*	0%	88%	0%	67%
	Analysis	0%	25%	0%	0%
	Experiment	100%	0%	88%	0%
	Testing	0%	0%	0%	33%
	Description	0%	13%	13%	33%
	No Evaluation	0%	0%	0%	0%
Artifact Type	*Construct*	0%	0%	0%	0%
	Model	50%	75%	88%	67%
	Method	0%	25%	0%	0%
	Instantiation	100%	50%	75%	33%
Contribution	*Improvement*	100%	100%	100%	100%
	Exaptation	0%	0%	0%	0%
	Routine Design	0%	0%	0%	0%
	Invention	0%	0%	0%	0%
Sustainable Impact	*Outcome*	100%	0%	0%	0%
	Action Formation	0%	100%	100%	100%
	Belief Formation	0%	0%	0%	0%
Design Theory	*Design Theory L1*	100%	75%	63%	0%
	Design Theory L2	50%	88%	50%	0%
	Design Theory L3	0%	13%	0%	0%
	None	0%	0%	13%	100%

Legend:	0% to 25%	26% to 50%	51% to 75%	76% to 100%

Table 3. Results of Cluster Analysis

5 Discussion and Directions for Future Research

The goal of this literature analysis is to examine the current status-quo of DSR within the research field of GIS. This research interest was broken down into two research objectives: (1) understanding the characterization of DSR in the domain of GIS research and (2) identifying possible directions for future research. We answered our first research question by combining DSR characteristics (Gregor and Hevner 2013; Hevner et al. 2004) with the belief-action-outcome characteristics of Melville (2010) and using them to characterize current publications. To answer research question two, we present the developed research directions in the following sections.

The research domain of GIS, which is a relatively new IS research field, is currently developing its paradigms and defining its scope (e.g. Vom Brocke et al. 2013; Watson et al. 2010). Therefore, the research community is still in need of guidance. In order to generalize the findings of this study, address GIS research barriers of DSR, and guide new GIS research, we formulated five possibly fruitful directions as follows.

5.1 Conduct and Publish more Design Science Research in Green IS to Solve Prevailing Problems

In alignment with previous studies (e.g. Gholami et al. 2016; Malhotra et al. 2013), the results of our analysis indicate that DSR is rarely a central topic in the research domain of GIS. The literature search process revealed that GIS research is primarily focused on other research topics such as the quantification of the environmental impact of IS, development of behavioral theory and description of socio-technical interactions of IS. Artificial solution development and design are rarely the research objectives of GIS publications. Furthermore, our findings provide further evidence supporting the existing view that applied DSR is under-represented in high ranking journals (Arnott and Pervan 2012, 2008; Gregor and Hevner 2013; Leukel et al. 2014). We can also further state that DSR in the research field of GIS remains under-represented in A-ranking journals or in the Business & Information Systems Engineering journal (a known outlet for DSR), where GIS artifacts are nearly non-existent. While conference publication numbers are higher, they still remain low when compared to other IS research fields (Wang et al. 2015). This stands in sharp contrast to the importance and potential GIS research holds for our society at large (vom Brocke and Seidel 2012).

In conclusion, DSR should be positioned as a fitting and valuable approach for problem solving in the context of GIS research, as described by vom Brocke and Seidel (2012). The application of DSR principles will contribute to GIS research by sharpening the development process, facilitating formulation of practical and theoretical implications and contributions. This will foster an overall richer discussion of IS-induced environmental sustainability. Consequently, it is important to motivate rigor and substantial research by providing aid, guidance, and publication opportunities. Calls for papers (e.g. vom Brocke et al. 2013; Gholami et al. 2016) are a good start, but are limited in scope as they only encourage short-term research and do not sufficiently contribute to fostering long-term DSR in the GIS research community. The GIS domain is fairly new (Wang et al. 2015) and DSR is in a state of "conceptual confusion" (Iivari 2015, pp. 107). Given this, researchers may be encouraged to address this research gap through opportunities to apply and re-work design-focused approaches to sustainable artifact development throughout the publication review process. Therefore, to encourage researchers to specialize in design-oriented GIS, we should take the risk of accepting papers and offering the option of revising it for publication, even though we would normally apply higher standards for first drafts.

5.2 Develop Guidelines for Structure and Documentation of Design Science Research to Ensure Scientific Rigor

The impact of the article of Hevner et al. (2004) should be adjusted first for its application. Observing the number of citations indicates a strong influence on the application of DSR. However, some publi-

cations in our sample only state that they apply DSR but make no further explanation as to what that means. Hence, DSR in GIS research has the same problem as the general domain of DSR (Leukel et al. 2014). Some research is presented and labelled as DSR by including one or two pertinent sentences. These articles lack an in-depth presentation and discussion of their DSR application. In addition to the lack of guiding DSR documentation formulas (Dinter and Krawatzeck 2015; Leukel et al. 2014), this obscures methodological processes whose transparency is crucial to the advancement of the DSR field. In their current state, these non-transparent publications leave the reader guessing and assuming associations of specific parts of the article to specific parts of the DSR framework of Hevner et al. (2004). While this may also be partially fueled by the inner struggle of relevance against rigor within DSR (Hevner et al. 2004), lack of transparency of methodological approaches are an unnecessary obstacle to understanding the research process, and can easily be mitigated by explicitly discussing research design. Furthermore, the described lack of rigor in the application and documentation of DSR goes hand in hand with the problem of weak theoretical contributions (Arnott and Pervan 2012; Gregor and Hevner 2013). The results of an improvement are often stated but not analyzed beyond the scope of application, failing to discuss contributions (Corley and Gioia 2011; Gregor and Hevner 2013; Whetten 1989) to theory and practice. Considering such challenges in existing literature, we present directions for developing or adapting guidelines and methods for the DSR rigor cycle in order to foster impactful DSR in in the research domain of GIS.

5.3 Engage Practitioners to Create Impactful Artifacts

To achieve practical relevance and usefulness in DSR, researchers should evaluate the artifact in its intended environment (vom Brocke and Seidel 2012; Iivari 2015) to ensure its practical impact (Iivari 2015; Sein et al. 2011). However, our structured literature analysis reveals a tendency within GIS research to apply simulations for artifact evaluation.

Following Arnott and Pervan (2012), DSR research should apply multi-method approaches, progressing from less expensive evaluation methods such as focus-groups or workshops with experts to more complex and expensive methods such as field tests. In the light of the important contributions GIS research holds for academia, companies, and practitioners alike, these parties would benefit greatly from cooperation enabling and meaningful multi-method evaluation of innovative artifacts (Hevner et al. 2004; Sein et al. 2011). As Hanelt et al. (2016) explain, innovative IS are the main drivers of eco-innovations within companies, leading to more cost-efficient and sustainable processes, and benefiting the company and environment. Hence, businesses can greatly benefit from cooperating with the GIS community. This is especially important in GIS due to a need for the development of impactful sustainable artifacts to protect our environment (Gholami et al. 2016; Malhotra et al. 2013).

5.4 Investigate Belief Formation as a Critical Factor of Sustainability

This literature review revealed that not a single study investigating the design of IS to support sustainable belief formation in individuals exists. The concept of belief formation describes how individual beliefs, desires etc., influence cognitive perceptions about the natural environment (Melville 2010). It is important to address belief formation as it holds the potential to drive environmental friendly behavior (Melville 2010). However, despite the potential and importance of belief formation, action formation and sustainable outcome remain most commonly addressed topics in current research. This may be due to the complexity of belief phenomenon and their respective research processes (Brendel and Mandrella 2016; Melville 2010). Designing artifacts that influence belief formation of individuals is a multi-disciplinary task, situated at the intersection of psychology and DSR. Hence, researchers are encouraged to form multi-disciplinary research groups and apply design and behavioral research methods to achieve theoretical and practical usefulness. Consequently, the high potential of research regarding belief formation can help further advance our understanding of IS-driven sustainability and develop impactful artifacts.

5.5 Reflect on Design Theories and Implications for Theory

Our analysis also revealed that some publications (10 of 23) lacked a deep discussion on the design knowledge collected during artifact development. Identifying principles of form and function (Gregor and Jones 2007) or reflecting on kernel theories (Gregor and Hevner 2013; Kuechler et al. 2008) is difficult and rare. This observation is further supported by the fourth cluster, as its primary characteristic is its lack of discussion regarding design theory implications. However, following Rai (2017), not every DSR process must lead to high-level contributions in the form of mid-range theories. Instantiations and frameworks can also provide valuable new insights and contribute to theory. Nonetheless, we argue that researchers should systematically analyze and present their design theory approach (Gregor and Jones 2007) to reach beyond practical implications and also contribute to scientific theory. Currently, the design theories presented in DSR in GIS research are often specific (e.g. Level 1) as shown in the first and third clusters, and some lack a reflection or discussion on generalizable aspects of the presented artifact and its corresponding design (e.g. Level 2 or 3).

In this context, the lack of a "universal" formula for the development of a coherent and well-grounded design theory presents an obstacle, and the development of a design theory is often characterized as difficult or fuzzy (Gregory and Muntermann 2014, 2011; Mandviwalla 2015). Nonetheless, it would be beneficial to adopt approaches like heuristic theorizing (Gregory and Muntermann 2014) that emphasize a theory development based on iteration of problem structuring and artifact design, that fits the development of artifacts in close conjunction with practice (Iivari 2015). In addition to such systematic and methodological approaches for design theory development, Gregor and Jones' "anatomy of a design theory" (2007) provides an excellent framework for guidance in design theory approach. The essential six components serve as a "checklist" of topics to be addressed, requiring a detailed reflection on design. Additionally, publications often lack a discussion on contributions to theory (Gregor 2006) or research streams (Banker and Kauffman 2004) outside of Green IS (vom Brocke, Seidel, et al. 2013). Relating the findings and developed design theory to the research challenges and goals within an IS research stream provides a deeper understanding of the contribution (Whetten 1989) and its possible impact. Therefore, it is important to address challenges and theories from other domains to further understand DSR within the field of GIS research and to ensure greater exposure for the entire IS research community.

6 Limitations

The inherent time-constraint of any literature-based analysis applies to our research as well. We could only include articles that were known and accessible to us up to the time of submission in our research database, meaning that the discussed research database will become less relevant with the passage of time and will require future updating and re-analysis to incorporate new literature. Furthermore, only literature that self-identifies as DSR and GIS research was included. This comes with two problems: Firstly, research is sometimes labeled as DSR to disguise methodological shortcomings and to "sell" the research as DSR without an application of rigorous DSR methods (Leukel et al. 2014). Secondly, design-oriented research articles unaffiliated to DSR principles were not included, nor were sustainable IS publications unaffiliated to the GIS domain. Additionally, the classification of a publication's artifact as an invention or an improvement is partly subjective. It is difficult to identify whether a problem is new in the context of GIS due to the relatively novel nature of the research field, one inherently comprising many novel problems. Therefore, we could only evaluate the innovative character of an artifact based on the content of the written article. If the researcher had referenced other solutions and previous research, we concluded that the developed artifact served as an improvement rather than an invention. Lastly, it is to be noted that clusters are never perfect but allow for a structured approach to identifying well-researched problems and research gaps (Nickerson et al. 2013; Remane et al. 2016). Therefore, we cannot confirm that the defined clusters are the ideal clusters. But given the rigorous research process, the clusters hold substantial theoretical validity nonetheless, and the usefulness

of this approach will become clearer as researchers begin to use the clusters as guidance for future research.

7 Conclusion

To bridge the lack of research regarding sustainable artifacts in the intersection of DSR and GIS research and to gain a deeper understanding of this dynamic, we conducted a literature review of the same. Firstly, we developed a coding framework combining common DSR dimensions with dimensions of GIS research, and applied it to the analysis and classification of publications. Secondly, building on the coded literature corpus, a cluster analysis was applied. The cluster analysis produced four coherent research clusters, characterizing and summarizing the current orientation of DSR in the context of GIS. The clusters were not mutually exclusive and some publications could have engaged multiple clusters. However, these clusters clearly showcase the areas of focus for DSR with regard to GIS research. Building upon the cumulative analyses, five directions were formulated to guide researchers towards an impactful and insightful design-oriented research in the important domain of GIS. The directions address the problems of DSR in GIS on different levels. The first direction addresses the general lack of GIS research and specific lack of DSR within the GIS domain. The second direction addresses the DSR community's need to deconstruct and analyze complex DSR projects in the context of scientific theory within high-ranking journals. Accordingly, the last three directions address individual, methodological and theoretical shortcomings and challenges of DSR in the research field of GIS.

In conclusion, this study provides an overview of current literature in the domain of design-oriented GIS research and proposes directions for future research. Furthermore, the coding framework and identified clusters bring contributions of their own, and as an implication for future research, can be used to classify DSR applications within the GIS research domain. This can help researchers conducting DSR in the field of GIS classify their own research, sharpen their contribution's positioning and identify research gaps within or supplementary to the identified clusters.

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