sustainability

Review

Review of Design-Oriented Green Information Systems Research

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Abstract: Green IS (GIS) research addresses environmental challenges brought on by climate change and the need to preserve the natural environment. Within this scope, design-oriented research, most notably within the Design Science Research (DSR) community, aims to provide solutions to these environmental challenges in the form of novel artifacts. The resulting IS solutions are valuable instruments for reducing emissions, increasing energy efficiency, and mitigating waste. Over the past 14 years, the IS research community was called upon multiple times to focus on designing solutions suitable for facilitating sustainability. However, it is unclear how these calls for action resonated within the design-oriented research community. Against this background, we analyzed the landscape of design-oriented GIS research by looking at 60 different GIS studies that have designed and evaluated an artifact. By analyzing these publications, we were able to make six observations. Based on these observations, we discuss how design-oriented GIS research can evolve to live up to the expectations of creating an immediate positive environmental impact.

Keywords: Green IS; literature review; environmental sustainability; sustainable development goals; research directions

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1. Introduction

Research on how "Information Systems" (IS) can contribute to addressing environmental sustainability challenges has been termed "Green IS" (GIS) research [1]. The aim is to understand and develop IS that can reduce greenhouse gas emissions, cut back waste production, increasing energy efficiency or other ways to mitigate global climate change [2–4]. Against this background, GIS research focuses on IS that influence sustainable behavior of individuals, organizations, and societies [5–7]. GIS scholars complement the former type of research by design-oriented research, addressing questions regarding the design of GIS (e.g., tools to support decision regarding reducing emissions [8,9] and optimize transportation service operations [10,11]).

Until 2007, little to no research was conducted on solving sustainability challenges through IS [6]. Since then, GIS research has established itself as a pivotal part of IS research culture, showcased by dedicated tracks for GIS research (e.g., ECIS 2017, 2018, 2019; ICIS 2017, 2018, 2019) and special issues in IS journals e.g., [4,12,13]. Against the background of digital technologies' capability to exercise a profound impact on entire industries [14], and in the hope of leveraging this potential to increase environmental sustainability, GIS pioneers have called for more impactful research on the design of GIS e.g., [4,15]. However, it remains unclear how the IS research community has responded. With a missing review on design-oriented GIS, the potential of design activities in environmental sustainability remains underrealized as no directions for future research based on the present scientific discourse exist.

In this study, we explore the present and the future of design-oriented GIS research with a firm belief that the IS potential of creating and integrating IT artifacts that create a direct positive impact on the natural environment is far from being reached. We perform a scoping review [15,16] and provide six research directions for scholars in the field of GIS.

2. Research Background

Overall, GIS research has been attributed with great potential for developing relevant artifacts (e.g., GIS) [4,9]. Several analyses of the research field revealed that GIS research developing and evaluating novel artifacts could be considered a rarity. For instance, [7] looked at publications between 2008 and 2013 within the AIS basket of eight. Their analysis found that only one of the 30 identified studies was concerned with the design of IS. The remaining papers addressed issues related to conceptualization or analysis. Similarly, [4] extended the work of [7], adding journals from 2013 to 2016 from the AIS basket of eight. They were able to identify one more study concerned with IS's design, making it a total of two design-oriented studies. Furthermore, [17] looked at a more comprehensive selection of outlets (including two conferences and three established journals outside the AIS basket of eight) and focused on studies within the design science research paradigm (i.e., filtering out all studies not using the term "design science"). Overall, they identified only 23 studies concerned with the design of GIS.

Against this background, our study focuses on the so far not captured landscape of design-oriented GIS studies to provide a comprehensive overview of the entire GIS domain beyond the label of design science and beyond publications in the AIS basket of eight journals. This approach promises deeper insights into design-oriented GIS as the manuscript aims to represent the first dedicated study on this subject. Specifically, we are interested in understanding the nature of GIS artifacts being developed and their relation to environmental sustainability. The reason behind focusing on design-oriented research is twofold. First, the GIS research has already matured over the last years, providing our community with conceptual lenses required to address environmental sustainability [6,7,18]. While conceptualizing and explaining are and remain essential constituents in the overall effort to address unsustainable behaviors, the immediate impact of research outcomes on sustainability is required too and can be achieved by creating artifacts to attain sustainability goals. Second, design-oriented research can be seen as a subcommunity in Information Systems [19,20]. This community has access to methods and know-how in designing impactful artifacts. However, few access points to sustainability research exist for the design-oriented community, and our study is aimed to become one of these bridges.

2.1. Green Information Systems

Within research, a differentiation of "Green Information Technology" (Green IT) and GIS has been established [7,9]. Green IT research is focused on the use of IT and how to design it more energy-efficiently. Thus, it is primarily concerned with hardware [7,9]. In contrast, GIS research addresses the application of IS from a more software-focused position. The aim is to understand the development, implementation, and application of IS and how they lead to increased environmental sustainability [1,5,7]. In what follows, we elaborate on different aspects of GIS by grouping them into dimensions that we later use as a foundation for our literature review.

2.1.1. Influence

Following [6], IS can have different influences on the environment, whether directly or indirectly, altering sustainable perceptions or behavior. The following three sustainability impact types were formulated by [6]:

- Outcome: The reduction of waste and greenhouse gas emissions.
- Action Formation: The instigation of pro-environmental activities.
- Belief Formation: The positive influence on environmental awareness.

2.1.2. Impact Proximity

In previous studies, Refs. [4,7] structured GIS research along the dimensions *conceptualize*, *analyze*, *design* and *impact*; conceptualize having the lowest value for tackling climate change and impact having the highest. Due to this research's focus, all publications in our sample go beyond the first two levels of conceptualizing and analyzing to design an artifact, which always demonstrates some level of impact. However, we recognize notable differences like the exercised impact. To better differentiate the contributions, we refine the design and impact dimensions and keeping the original rationale to propose *impact proximity* as a dimension with three characteristics that can differentiate the artifact's value for tackling environmental challenges between enabling impact and exercising a measurable positive change:

- Enablement: The developed artifact, by its nature, cannot exercise any measurable impact but enables the implementation of other artifacts that can. It has, thus, an instrumental character.
- Implementation: The artifact is implemented to exercise a measurable impact on the environment but is not yet applied in its environment.
- Application: The developed artifact was already applied and demonstrated a measurable impact on the environment.

2.1.3. Sustainability Impact

A sustainable problem may arise from organizations, people, or technology [21], but solving it can impact different domains. In this regard, GIS can lead to real-world impact, having an economic impact [22,23]. Following Elliot [5], the impact can manifest itself in one or multiple of the following six domains:

- Environment: Direct impact on the environment (e.g., on harvesting, foresting)
- Society: Impact on the entire society without needing governmental oversight
- Government: Impact on policymakers
- Industry: Impact across organizations
- Organizations: Impact on single organizations
- Individuals: Impact on individuals or small groups

Artifacts are classified according to the domain that they directly address. For example, an artifact can reduce an individual's energy consumption and indirectly reduce the overall negative impact on the environment. In such a case, we assess the artifact as having an impact on the individuals' domain. For an artifact to impact the environment domain, it has to investigate how resources are consumed directly (e.g., harvesting, energy production, foresting).

2.1.4. Sustainable Development Goals

To dive deeper into design-oriented GIS studies' goals, we selected the United Nation's sustainable development goals (UN). In 2015, UN members adopted a set of 17 sustainable development goals, addressing urgent challenges in the context of environmental and social sustainability [24]. These goals reflect public, academic, and political discourse on sustainability and describe concrete areas in which sustainability challenges should be urgently addressed. Overall, 7 of these goals directly address environmental issues while others are outside the scope as they address either the social or the economic dimension of sustainability which are outside of this works scope:

- Clean water and sanitation: enabling more effective and efficient water supply management. This includes managing water access, consumption as well as sanitation.
- Affordable and clean energy: providing access to modern energy services and increasing the share of renewable energy sources in the overall energy mix.
- Sustainable cities and communities: mitigating effects of increasing urbanization by, for instance, enabling more sustainable transportation systems.
- Responsible consumption and production: increasing efficiency in using natural resources, e.g., by reducing waste (e.g., packaging or food waste).
- Education on climate action: educate people on the effects of climate change and manage an overall increase in preventive measures on a political level.
- Life below water: preserving marine life by, for instance, reducing any marine pollution and living room reduction.
- Life on land: preserving land life by, for instance, reducing any terrestrial pollution and living room reduction.

We added a dimension value 'indirect' to account for goals that do not directly address one of the above goals and can have an indirect positive impact on one or multiple of the above goals.

By analyzing these goals, the research is set into the greater context of public and political discourse on suitability. Hence, it enables an assessment of how design-oriented GIS research fits into current political discourses.

2.2. Design-Oriented IS Research

In order to extend beyond research that is labeled as "design science," "design science research" or "design research," we adhere to a more general and accustomed notion for the science of the artificial [25] by following a design-oriented research definition based on the following three interrelated points [26]:

(1) Design-oriented research produces innovative artifacts as its research output.
(2) Design-oriented research's core activity is constructive research on artifacts.
(3) Artifacts are developed with the epistemological goal of reaching utility over truth.

Hence, every research process that develops an artifact to reach utility (e.g., solving a relevant problem) is considered a design-oriented research process. Regarding the problem that is intended to be solved, we follow the understanding that the problem is the difference between the current state and a desired future state of the world [21,25,27].

Regarding the research process, various ways to conduct design-oriented research exist [20,28]. At the core of all design-oriented research stands the design and evaluation of an artifact, flanked with other research activities, such as theorizing [29–31], or cooperation in a consortium [32]. In this study, we will understand design-oriented research as research that develops and evaluates artifacts. In the following sections, we will go into more detail on the different aspects of design-oriented research, which we will later use in our literature review.

2.2.1. Problem Domain

The problem domain dimension describes the environment as an IS is developed for [33]. Following the DSR framework, three domains (environments) can be distinguished:

- Organization: Problems are caused by organizations and their internal structure, e.g., strategies, processes, and culture.
- People: The problem is caused by people and their roles, characteristics, and capabilities
- Technology: The problem is caused by Technology, such as IT-infrastructure and hardware in general.

Many problems and challenges can be attributed to multiple domains and their interaction [21]. Thus, many researchers may address multiple problem domains within the same research project.

2.2.2. Artifact Type

In general, artifacts can take many different forms and all of them can be related to IS, either because they are an IS or because they surround or interact with an IS [21]. Against this background, four different categories of artifact can be distinguished [21]:

- Construct: This type of artifact can be understood as language that can be used to describe and formulate a phenomenon or problem, for instance, modeling or programming languages.
- Method: A Method defines a finite set of steps to be taken. For example, methods can include algorithms or guidelines.
- Model: Models provide a purposeful abstraction of real-world entities and their relations, reducing complexity. They contain statements and propositions about problems and potential solutions.
- Instantiation: Implementations of constructs, methods, or models are called instantiations. They are often used to evaluate the artifact and, in IS research, take the form of software.

2.2.3. Evaluation Method

For any design-oriented research project, evaluation of the developed IS is essential

A central component of the DSR research process is the evaluation of the developed artifact [21]. There are various evaluation methods available to assess the capabilities and validity of a designed artifact, which can be distinguished into five categories [21]:

- Observation: case studies, field studies
- Analysis: static analyses, architecture analyses, optimizations, dynamic analyses
- Experiment: controlled experiments, simulations, expert evaluations
- Testing: functional (black box) testing, structural (white box) testing
- Description: informed arguments, scenario descriptions

However, despite the importance of evaluation to provide confidence in the proposed artifact and related design, some studies do not conduct any evaluation [34,35]. Hence, we add the characteristic 'no evaluation.'

2.2.4. Design Theory

Following Gregor and Hevner [36], developing artifacts can lead to gathering design knowledge in form of design theories. Design theories can be positioned on different levels of abstraction:

- Design Theory Level 1: Instantiation, e.g., a prototypical implementation
- Design Theory Level 2: Nascent design theory, providing knowledge about constructs, methods, models, design principles, technological rules
- Design Theory Level 3: Well-developed design theories, addressing overarching problems

Gregor and Hevner [36] noted that they were unable to identify a level 3 theory. Against this background, we use the classification of level 3 more loosely and term design theories that embed the developed design theory within a greater kernel theory. Furthermore, other studies e.g., [33,34] reported that some design-oriented publications do not address the aspect of design knowledge and design theory. Hence, we add the dimension value 'none' that signifies the artifact being not discussed and only its performance being reported.

Thus, even when a study may appear to contribute a level 1 theory, it would nevertheless be categorized as 'none.' These articles add to practice, but they do not necessarily add to the GIS discourse.

2.2.5. Role of Artifact

Artifacts (e.g., software) can serve different purposes and provide various functionalities. To reflect this, we follow [37] and adapt the following roles of IS:

- Automate: Automate the process, e.g., directly substituting human effort
- Transform: Fundamentally restructured tasks and processes
- Informate: Providing important information that is complicated to gather, compute or display

However, artifacts do not necessarily need to be an IS and can also be methods, constructs, or models [21], which can play a crucial role in the context of IS. To address the role of non-IS artifacts, we added the following two roles

- Support: Support a previously inefficient, complicated or inconvenient process or task
- Enable: Enabling a process or task that was previously impossible

Nonetheless, these roles can also be fulfilled by IS and thus will apply the five presented roles of artifacts to every artifact.

2.2.6. Contribution

It is essential first to understand its theoretical and practical implications to understand the impact an artifact has. The contribution of artifacts can take different forms. Following Gregor and Hevner [36], there are categories of contributions:

- Routine Design: Proving known solutions for known problems
- Invention: The artifact constitutes a new solution for a new problem
- Improvement: Developing new solutions for known problems
- Exaptation: Adapting known solutions to new problems

3. Research Methodology

In order to review design-oriented GIS research, we perform a scoping literature review [15,16] using the guidelines by vom Brocke et al. [38] and Webster and Watson [39] to provide structure and to ensure transparency of the review. We adapted the guidelines to fit our research, for instance, we did not conduct an extensive forward and backward search as we aimed to cover all outlets that satisfy our ranking requirements (see Section 3.1). The applied research process consists of three phases summarized in Table 1 and will be described in the following sections.

Table 1. Research Design.

	Phase 1 **Gather Literature**	**Phase 2** **Code Literature**	**Phase 3** **Analyze Literature**
Inputs	• Online publication databases • High ranking publication outlets	• DSR and GIS literature • Research database	• Coded research database
Methods	• Literature search	• Coding	• Structured literature analysis • Time series analysis • Cluster analysis • Citation analysis
Steps	• Analyze literature reviews • Conduct keyword search	• Define different dimensions and characteristics to code literature • Code literature	• Analyze coded literature • Identify shortcomings and problems • Elicit implications for future research
Results	Research database with 60 publications	Coded research database	Research clusters, implications, and guidance for future research

3.1. Phase 1: Gather Literature

The purpose of this phase was to gather a research database of publications that represent the current status-quo of design-oriented GIS research. Publications were required to fulfill two criteria: First, the publications must include the construction and evaluation of artifacts within their main research activities [21,26]. Therefore, publications primarily focused on behavioral aspects (explanation and prediction theory) of GIS or describing GIS-related phenomena (e.g., descriptive theories) are excluded [40]. Based on this criterion, we also filtered out publications that address DSR or GIS research in general (e.g., literature reviews or commentaries). Second, manuscript authors must explicitly discuss the artifact's positive impact on sustainability; otherwise, the publication is excluded. The rationale behind limiting our search to publications that include both construction and evaluation is twofold: On the one hand, this ensures to regard only publications where the artifact has undergone a full DSR cycle (or comparable methodology) and, hence, can be regarded as complete from a methodological view. On the other hand, this excludes research, which is still at an early stage, which is not relevant for journal publications, but an essential factor when looking at conference publications, which sometimes are less mature. Therefore, we limit our search to evaluated artifacts to prevent a data sample, which is shifted too much towards abstract knowledge.

Only high-ranking IS publication outlets are included in our literary database to ensure theoretical and practical rigor, impact, and relevance [41]. To be considered, the publication outlet must have been A+, A, or B ranked, following the VHB-JOURQUAL3 ranking [42]. We are aware that several options are available to distinguish how well regarded an outlet is (various rankings and metrics, such as impact factor), each having different pros and cons. We selected the VHB-JOURQUAL3 ranking because it includes a wide variety of outlets (in total, 39 outlets) from various organizations (e.g., IEEE, INFORMS, ACM, AIS), which can all be considered relevant for the IS community. Besides all A+, A or B ranked journals and conferences, we have added the proceedings of the International Conference on Design Science Research in Information Systems and Technology (DESRIST) to our list, because it is the leading domain conference on DSR. The final selection of outlets can be seen in Table 2. We used the following keywords for the title and abstract search:

Table 2. Search Results: Overall Literature Search.

Publication Outlets	Total Hits	Filtering	
		First Phase	Second Phase
■ Business & Information Systems Engineering (BISE)	111	13	4
■ Computers and Operations Research	19	2	1
■ Decision Sciences	70	1	1
■ Decision Support Systems (DSS)	270	5	3
■ European Conference on Information Systems (ECIS)	1.265	102	20
■ European Journal of Information Systems (EJIS)	11	3	3
■ Group Decision and Negotiation	16	5	4
■ Information Systems Frontiers	1.019	13	4
■ International Conference on Information Systems (ICIS)	1.360	84	17
■ Journal of Management Information Systems (JMIS)	129	2	1
■ Journal of the Association for Information Systems (JAIS)	43	3	1
■ MIS Quarterly Executive	17	2	1
Total	5332 *	268 *	60

Note: we removed all outlets that contained no articles after the second phase of filtering. * Including hits in publication outlets that were later removed because they contained no hits after the second phase of filtering.

(("Green IS" OR "Green Information Systems" OR "Green IT" OR "Green Information Technology" OR "Green Computing") OR (("information system" OR "information technology") AND ("sustainability"))).

The keywords were designed to find articles that labeled themselves as GIS and articles related to environmental sustainability without terming it GIS or Green IT.

The literature search was conducted from May to July of 2018 by two of the authors. After subtracting doubles, an initial publication set of 5.332 articles was gathered. The large number of articles was not surprising because we refrained from using the terms "design" and "artifact," as they might exclude studies that use non-DSR terminology to describe their design-oriented study. Thus, the initial set of 5.332 articles included many studies that were not related to the design of artifacts. We filtered all articles in 2 phases. First, articles were filtered according to title, keywords, and abstract, reducing the initial set down to 268 publications. The remaining articles were then reviewed to decide whether they conducted design-oriented research (e.g., DSR) or not. A backward and forward search for the remaining articles was conducted but did not lead to any new publications fulfilling the aforementioned criteria (ranking and evaluation). Therefore, the final research database comprised 60 publications (see Table 2).

3.2. Phase 2: Code Literature

We coded the literature along the dimensions presented in Section 2. Notwithstanding, design-oriented research is challenging to characterize, and there is an ongoing discourse regarding the nature of DSR and design-oriented research in general [20,26,28]. Nonetheless, we decided to follow coding dimensions derived from pivotal articles on DSR in order to have a coherent framework. Furthermore, we follow well-regarded and advocated literature on GIS [4–6] to characterize the studies related to environmental sustainability. Additionally, we considered the UN's sustainable development goals [24] to open a political and global perspective in our coding. All applied coding dimensions and related characteristics are summarized in Table 3.

Table 3. Coding Dimensions and Characteristics.

	Dimensions	Characteristics							
Green	Influence	Belief Formation	Action Formation	Outcome					
Green	Impact Proximity	Enablement	Implementation	Application					
Green	Sustainability Impact	Environment	Society	Government	Industry	Organizations	Individuals		
Green	Sustainable Development Goals	Clean Water	Clean Energy	Sustainable Cities	Consumption & Production	Education	Life in Water	Life on Land	Indirect
Design-Oriented	Problem Domain	People	Organizations	Technology					
Design-Oriented	Artifact Type	Construct	Model	Method	Instantiation				
Design-Oriented	Evaluation Method	Observation	Analysis	Experiment	Testing	Description	No Evaluation		
Design-Oriented	Design Theory	Design Theory L1	Design Theory L2	Design Theory L3	None				
Design-Oriented	Role of Artifact	Automate	Transform	Informate	Support	Enable			
Design-Oriented	Contribution	Improvement	Exaptation	Routine Design	Invention				

To achieve consistent coding, two of the authors reviewed and coded the literature independently. After the initial coding, the results were compared and discussed, leading to a merged coding. Each article in our sample was coded to fulfill at least one characteristic of each dimension. Some publications were coded to belong to multiple characteristics of one dimension; for instance, in the case of artifacts evaluated with multiple methods.

3.3. Phase 3: Analyze Literature

We applied four analysis methods to our sample: a structured literature analysis, a time series analysis, a cluster analysis, and a citation analysis. In the structured literature analysis, we revealed the overall distribution of design-oriented research characteristics in the GIS domain. In the time series analysis, we analyzed the publications on a timeline to identify research trends or focus shifts. Lastly, we conducted a cluster analysis to identify groups of similar studies. The following sections provide details on the applied analysis approaches.

3.3.1. Structured Literature Analysis

For the structure literature analysis, we constructed a concept matrix (Table 4). A concept matrix enabled us to analyze literature from a concept-focused view [34], enabling us to develop insights beyond summarizing the content of each study [39]. In the end, it enables us to identify the distribution of characteristics within the coded dimensions, as defined in the previous section, paving the way for the following analysis methods.

Table 4. Concept Matrix.

	Problem Domain			**Evaluation Method**						**Artifact Type**				**Contribution**				**Design Theory**				**Role of Artifact**					**Influence**			**Impact Proximity**			**Sustainable Development Goals**							**Sustainable Impact**						
Article	**People**	**Organizations**	**Technology**	**Observation**	**Analysis**	**Experiment**	**Testing**	**Description**	**No Evaluation**	**Construct**	**Model**	**Method**	**Instantiation**	**Improvement**	**Exaptation**	**Routine Design**	**Invention**	**Design Theory L1**	**Design Theory L2**	**Design Theory L3**	**None**	**Automate**	**Transform**	**Informate**	**Support**	**Enable**	**Belief Formation**	**Action Formation**	**Outcome**	**Enablement**	**Implement**	**Application**	**Clean water and Sanitation**	**Affordable and Clean Energy**	**Sustainable Cities and Communities**	**Responsible Consumption and Production**	**Education on Climate Action**	**Life below Water**	**Life on Land**	**Indirect**	**Environment**	**Society**	**Government**	**Industry**	**Organizations**	**Individuals**
[43]			•			•		•			•			•					•						•	•			•	•				•	•									•		
[44]			•	•									•		•			•	•			•						•			•				•	•								•		
[45]	•			•									•				•	•	•	•				•	•			•		•							•								•	•
[46]		•		•								•			•				•						•			•		•			•					•				•				
[47]	•			•								•		•					•					•		•		•		•									•				•			
[48]		•						•				•		•					•						•			•		•				•									•	•		

Table 4. *Cont.*

Article	Problem Domain			Evaluation Method						Artifact Type				Contribution				Design Theory				Role of Artifact					Influence			Impact Proximity			Sustainable Development Goals							Sustainable Impact						
	People	Organizations	Technology	Observation	Analysis	Experiment	Testing	Description	No Evaluation	Construct	Model	Method	Instantiation	Improvement	Exaptation	Routine Design	Invention	Design Theory L1	Design Theory L2	Design Theory L3	None	Automate	Transform	Informate	Support	Enable	Belief Formation	Action Formation	Outcome	Enablement	Implement	Application	Clean water and Sanitation	Affordable and Clean Energy	Sustainable Cities and Communities	Responsible Consumption and Production	Education on Climate Action	Life below Water	Life on Land	Indirect	Environment	Society	Government	Industry	Organizations	Individuals
[49]	•	•						•				•		•					•			•		•				•		•					•				•				•			
[50]	•	•		•							•		•	•				•	•					•			•	•		•							•								•	•
[51]		•				•						•		•					•						•	•		•		•		•				•			•						•	
[52]		•		•							•			•					•					•	•			•		•										•					•	
[53]		•						•				•			•			•	•						•			•		•		•				•									•	
[54]		•		•								•		•				•	•						•			•		•										•					•	
[55]		•						•			•			•				•	•					•	•			•		•				•											•	
[56]		•		•							•			•				•	•					•				•		•		•				•									•	

Table 4. *Cont.*

		Problem Domain				Evaluation Method					Artifact Type				Contribution				Design Theory					Role of Artifact				Influence			Impact Proximity					Sustainable Development Goals							Sustainable Impact			
Article	**People**	**Organizations**	**Technology**	**Observation**	**Analysis**	**Experiment**	**Testing**	**Description**	**No Evaluation**	**Construct**	**Model**	**Method**	**Instantiation**	**Improvement**	**Exaptation**	**Routine Design**	**Invention**	**Design Theory L1**	**Design Theory L2**	**Design Theory L3**	**None**	**Automate**	**Transform**	**Informate**	**Support**	**Enable**	**Belief Formation**	**Action Formation**	**Outcome**	**Enablement**	**Implement**	**Application**	**Clean water and Sanitation**	**Affordable and Clean Energy**	**Sustainable Cities and Communities**	**Responsible Consumption and Production**	**Education on Climate Action**	**Life below Water**	**Life on Land**	**Indirect**	**Environment**	**Society**	**Government**	**Industry**	**Organizations**	**Individuals**
[57]			•			•					•	•	•		•			•	•			•		•				•	•	•				•									•			
[11]		•		•							•	•	•	•	•			•	•			•		•				•				•			•										•	
[58]			•			•					•		•	•	•			•	•			•			•	•		•	•		•				•									•	•	
[59]		•		•							•	•	•	•				•	•			•		•				•			•					•									•	
[60]			•			•					•		•	•				•	•			•			•				•	•										•				•	•	
[61]			•			•					•	•		•				•	•			•				•			•		•			•									•	•		
[62]			•			•					•	•		•				•	•			•		•				•	•	•				•										•		•
[63]	•							•					•	•				•						•			•	•				•				•									•	•

Table 4. *Cont.*

Article		**Problem Domain**					**Evaluation Method**					**Artifact Type**				**Contribution**				**Design Theory**					**Role of Artifact**				**Influence**			**Impact Proximity**					**Sustainable Development Goals**						**Sustainable Impact**			
	People	**Organizations**	**Technology**	**Observation**	**Analysis**	**Experiment**	**Testing**	**Description**	**No Evaluation**	**Construct**	**Model**	**Method**	**Instantiation**	**Improvement**	**Exaptation**	**Routine Design**	**Invention**	**Design Theory L1**	**Design Theory L2**	**Design Theory L3**	**None**	**Automate**	**Transform**	**Informate**	**Support**	**Enable**	**Belief Formation**	**Action Formation**	**Outcome**	**Enablement**	**Implement**	**Application**	**Clean water and Sanitation**	**Affordable and Clean Energy**	**Sustainable Cities and Communities**	**Responsible Consumption and Production**	**Education on Climate Action**	**Life below Water**	**Life on Land**	**Indirect**	**Environment**	**Society**	**Government**	**Industry**	**Organizations**	**Individuals**
[64]		•		•									•	•				•				•		•				•		•				•						•				•		•
[65]		•				•						•			•			•							•				•	•							•							•		
[66]		•				•					•		•	•				•	•			•			•			•		•						•									•	
[67]			•			•					•		•	•				•	•			•		•					•		•			•										•	•	
[68]	•			•									•	•				•						•	•		•	•				•			•		•									•
[69]			•						•		•			•				•				•							•	•				•	•									•		
[70]			•			•					•	•		•				•	•			•							•	•				•										•	•	•
[71]			•			•						•		•				•				•			•				•	•				•										•	•	

Table 4. *Cont.*

Article	Problem Domain			Evaluation Method						Artifact Type				Contribution				Design Theory				Role of Artifact					Influence			Impact Proximity			Sustainable Development Goals							Sustainable Impact						
	People	Organizations	Technology	Observation	Analysis	Experiment	Testing	Description	No Evaluation	Construct	Model	Method	Instantiation	Improvement	Exaptation	Routine Design	Invention	Design Theory L1	Design Theory L2	Design Theory L3	None	Automate	Transform	Informate	Support	Enable	Belief Formation	Action Formation	Outcome	Enablement	Implement	Application	Clean water and Sanitation	Affordable and Clean Energy	Sustainable Cities and Communities	Responsible Consumption and Production	Education on Climate Action	Life below Water	Life on Land	Indirect	Environment	Society	Government	Industry	Organizations	Individuals
[74]		•				•					•		•	•				•	•					•				•			•		•								•		•	•		
[75]		•				•					•		•	•				•				•		•				•		•						•					•			•		
[76]		•		•							•		•	•				•	•			•		•				•			•		•								•		•	•		
[77]	•		•		•						•		•	•				•	•					•	•			•		•						•										•
[78]	•	•	•		•								•	•				•				•		•				•		•				•											•	
[8]		•		•							•		•	•				•	•	•		•		•	•			•			•				•	•									•	
[79]	•	•		•								•	•	•				•	•	•			•			•			•			•			•										•	•
[80]		•				•					•			•				•	•			•		•	•			•		•						•					•			•	•	

Table 4. *Cont.*

Article	Problem Domain			Evaluation Method						Artifact Type				Contribution				Design Theory				Role of Artifact					Influence		Impact Proximity				Sustainable Development Goals							Sustainable Impact						
	People	Organizations	Technology	Observation	Analysis	Experiment	Testing	Description	No Evaluation	Construct	Model	Method	Instantiation	Improvement	Exaptation	Routine Design	Invention	Design Theory L1	Design Theory L2	Design Theory L3	None	Automate	Transform	Informate	Support	Enable	Belief Formation	Action Formation	Outcome	Enablement	Implement	Application	Clean water and Sanitation	Affordable and Clean Energy	Sustainable Cities and Communities	Responsible Consumption and Production	Education on Climate Action	Life below Water	Life on Land	Indirect	Environment	Society	Government	Industry	Organizations	Individuals
[81]	•					•							•	•				•							•			•		•					•	•										•
[82]		•				•					•		•	•				•	•			•			•			•			•				•								•		•	
[83]			•		•						•				•				•	•			•		•			•	•	•						•								•		
[84]		•				•						•		•				•							•			•		•						•									•	
[85]		•		•		•					•		•	•				•						•				•		•						•									•	
[86]	•			•				•					•	•				•	•					•	•		•	•			•					•	•								•	•
[87]		•		•							•			•					•	•				•	•			•		•										•					•	
[88]		•	•			•					•		•	•				•	•			•	•		•	•			•	•				•										•	•	

Table 4. *Cont.*

Article	Problem Domain			Evaluation Method						Artifact Type				Contribution				Design Theory				Role of Artifact					Influence		Impact Proximity			Sustainable Development Goals									Sustainable Impact					
	People	Organizations	Technology	Observation	Analysis	Experiment	Testing	Description	No Evaluation	Construct	Model	Method	Instantiation	Improvement	Exaptation	Routine Design	Invention	Design Theory L1	Design Theory L2	Design Theory L3	None	Automate	Transform	Informate	Support	Enable	Belief Formation	Action Formation	Outcome	Enablement	Implement	Application	Clean water and Sanitation	Affordable and Clean Energy	Sustainable Cities and Communities	Responsible Consumption and Production	Education on Climate Action	Life below Water	Life on Land	Indirect	Environment	Society	Government	Industry	Organizations	Individuals
[89]		●	●			●					●		●	●				●				●	●		●	●			●	●				●										●	●	
[90]		●		●									●	●				●						●				●			●					●									●	
[91]		●		●							●				●				●						●	●		●		●					●							●	●	●		
[92]		●		●		●					●		●	●				●	●			●		●				●		●				●											●	
[93]		●				●					●		●	●				●	●						●	●		●		●					●										●	
[94]		●	●	●							●		●		●			●	●					●	●			●	●	●				●								●	●			
[95]		●		●							●		●	●				●	●					●	●			●		●					●							●	●		●	
[96]	●					●							●		●			●						●	●			●				●				●										●

Table 4. *Cont.*

	Problem Domain			Evaluation Method						Artifact Type				Contribution				Design Theory				Role of Artifact			Influence				Impact Proximity				Sustainable Development Goals							Sustainable Impact						
Article	**People**	**Organizations**	**Technology**	**Observation**	**Analysis**	**Experiment**	**Testing**	**Description**	**No Evaluation**	**Construct**	**Model**	**Method**	**Instantiation**	**Improvement**	**Exaptation**	**Routine Design**	**Invention**	**Design Theory L1**	**Design Theory L2**	**Design Theory L3**	**None**	**Automate**	**Transform**	**Informate**	**Support**	**Enable**	**Belief Formation**	**Action Formation**	**Outcome**	**Enablement**	**Implement**	**Application**	**Clean water and Sanitation**	**Affordable and Clean Energy**	**Sustainable Cities and Communities**	**Responsible Consumption and Production**	**Education on Climate Action**	**Life below Water**	**Life on Land**	**Indirect**	**Environment**	**Society**	**Government**	**Industry**	**Organizations**	**Individuals**
[97]		•		•							•		•	•				•	•					•	•			•		•						•									•	
[98]		•						•			•			•					•					•	•			•			•					•									•	
[99]		•	•			•						•		•				•							•	•		•		•						•									•	
[100]			•								•				•				•					•	•			•		•						•								•	•	
[83]			•			•		•			•			•					•						•	•			•	•				•	•									•		
n = 60 ∑	12	39	19	26	3	25	0	8	1	0	37	18	34	48	13	0	1	48	43	5	0	24	4	34	37	12	4	49	16	42	13	8	3	16	15	23	5	1	3	5	4	5	12	22	37	12

3.3.2. Time Series Analysis

IS research is an ever-evolving field [101] that is influenced by changing trends [12], methods, and paradigms [102]. Hence, to understand recent developments of design-oriented research of GIS, we applied a descriptive time series analysis (similar to Leukel et al. [35]) summarizing the number of dimensions present in each publication for every year (see Figure 1).

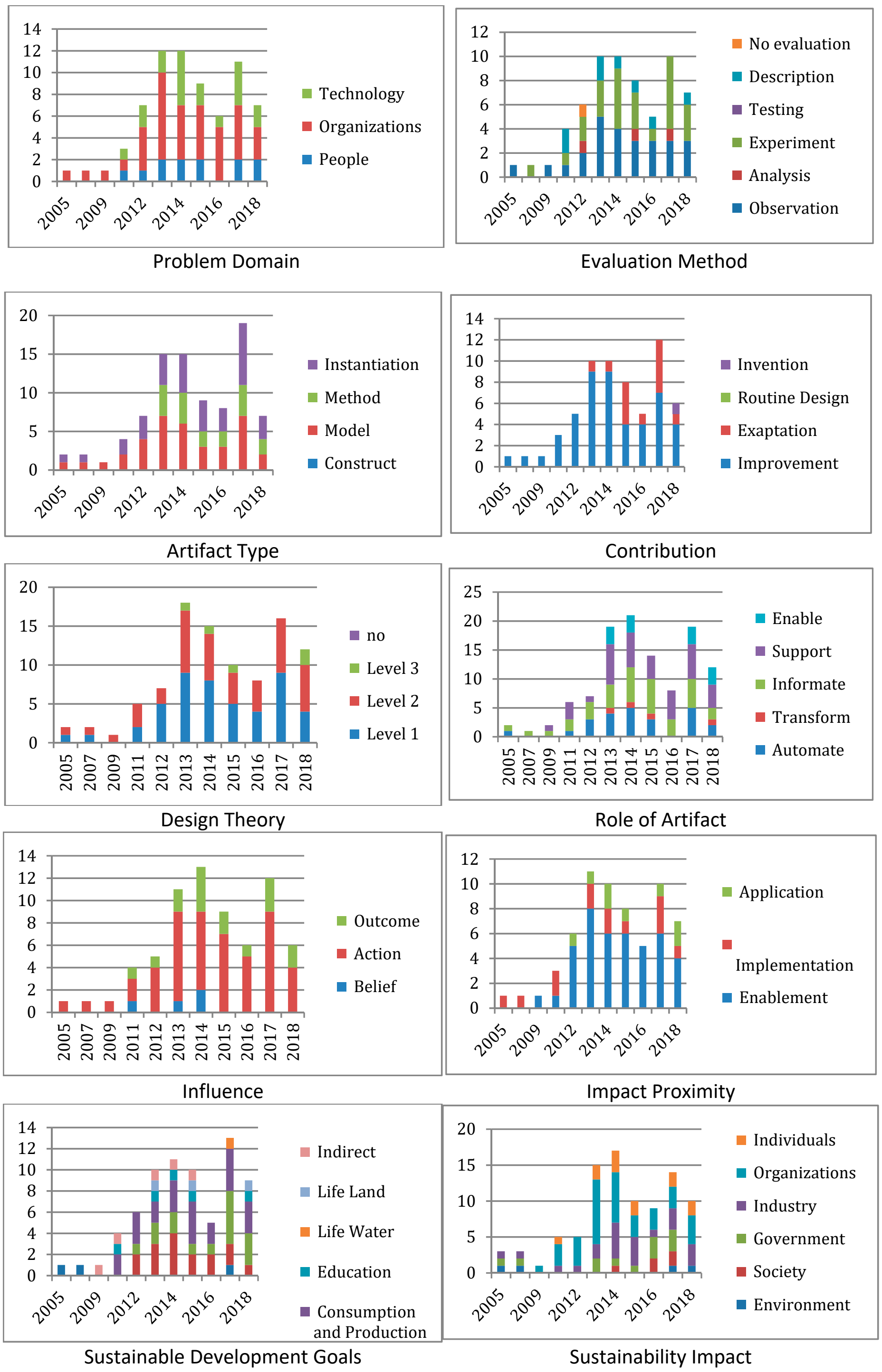

Figure 1. Results of the Time Series Analysis.

3.3.3. Cluster Analysis

To identify groups of similar studies, we applied a cluster analysis. A cluster analysis forms clusters that contain studies that are as similar as possible to each other, while being as dissimilar as possible from studies of other clusters [103]. A two-stage cluster analysis approach was applied to better understand the current foci of research within design-oriented GIS research. For the analysis, only the characteristics which demonstrated some variety were used. Therefore, all characteristics marked as less than 10% or more than 90% of cases did not show sufficient variety and were consequently not relevant enough for the analysis, leading to their omission for the cluster analysis.

First, we applied Ward's method [104] to identify the appropriate number of clusters. In this context, the similarity of two studies is determined based on the coded dimensions, measured as the squared Euclidean distance. Considering the resulting screen plot, dendrogram, and the distance between the coefficients [105], five clusters were identified to be the most useful.

Second, the k-mode method [106] was applied. The algorithm is an extension of the popular k-means method used for categorical data like dummy coding, as it uses modes instead of means for cluster definition. As a distance measure, the dissimilarities between answers are measured. Therefore, the papers designated into one cluster display consistent similarity throughout the characteristics. The results of our cluster analysis are shown in Table 5.

Table 5. Results of Cluster Analysis.

Dimension	Characteristics	Cluster 1	Cluster 2	Cluster 3	Cluster 4
		15	11	14	20
Problem Domain	People	0.00	1.00	0.07	0.00
	Organization	0.27	0.27	0.93	0.95
	Technology	0.93	0.18	0.07	0.10
Evaluation Method	Observation	0.00	0.45	0.71	0.55
	Analysis	0.07	0.18	0.00	0.00
	Experiment	0.87	0.18	0.43	0.20
	Testing	0.00	0.00	0.00	0.00
	Description	0.07	0.27	0.00	0.20
	No evaluation	0.07	0.00	0.00	0.00
Artifact Type	Construct	0.00	0.00	0.00	0.00
	Model	0.80	0.09	0.79	0.65
	Method	0.47	0.27	0.14	0.30
	Instantiation	0.40	0.82	1.00	0.25
Contribution	Improvement	0.80	0.82	0.93	0.70
	Exaptation	0.27	0.09	0.14	0.30
	Routine Design	0.00	0.00	0.00	0.00
	Invention	0.00	0.09	0.00	0.00
Design Theory	Level 1	0.87	0.82	1.00	0.60
	Level 2	0.67	0.55	0.71	0.85
	Level 3	0.07	0.18	0.07	0.05
	no	0.00	0.00	0.00	0.00
Role of Artifact	Automate	0.73	0.18	0.71	0.05
	Transform	0.20	0.09	0.00	0.00
	Informate	0.20	0.82	0.79	0.55
	Support	0.60	0.55	0.21	0.95
	Enable	0.40	0.18	0.00	0.20
Influence	Belief	0.00	0.27	0.07	0.00
	Action	0.33	0.91	1.00	1.00
	Outcome	0.93	0.09	0.00	0.05

Table 5. *Cont.*

Dimension	Characteristics	Cluster 1	Cluster 2	Cluster 3	Cluster 4
		15	**11**	**14**	**20**
Sustainability Impact	Environment	0.00	0.00	0.21	0.05
	Society	0.00	0.00	0.00	0.25
	Government	0.13	0.18	0.21	0.25
	Industry	0.87	0.00	0.36	0.20
	Organization	0.53	0.45	0.64	0.75
	Individuals	0.13	0.73	0.14	0.00
Sustainable Development Goals	Clean Water	0.00	0.00	0.14	0.05
	Clean Energy	0.67	0.09	0.14	0.15
	Sustainable Cities	0.20	0.36	0.29	0.20
	Consumption & Production	0.13	0.45	0.50	0.45
	Education	0.07	0.27	0.07	0.00
	Life under Water	0.00	0.00	0.00	0.05
	Life on Land	0.00	0.18	0.00	0.05
	Indirect	0.07	0.00	0.07	0.15
Impact Proximity	Enablement	0.80	0.55	0.43	0.90
	Implementation	0.20	0.09	0.50	0.10
	Application	0.00	0.36	0.07	0.15
Legend:	**0.01 to 0.24** **0.25 to 0.49**	**0.50 to 0.74**		**0.75 to 1.00**	

3.3.4. Citation Analysis

To understand the impact that an individual article possesses, we analysed how often each article is cited via Google Scholar. By this method, we are enabled in locating patterns for how often certain types of design-oriented research on the topic of environmental sustainability are cited. Thus, a dimension of scientific impact is added to the other analysis methods, which do not differentiate between highly recognized and niche articles.

Additionally, we analysed if DSR literature was cited due to DSR building the comprehending base of our understanding of design-oriented research. The results of our citation analysis are shown in Table 6.

Table 6. Results of Citation Analysis.

Article	Outlet	Ranking *	Citation Count	Citations Per Year	Cited DS(R) Literature
[74]	DSS	B	119	9.9	no
[92]	ECIS	B	50	10	yes
[53]	Information Systems Frontiers	B	49	8.2	no
[76]	DSS	B	46	3.3	no
[50]	JAIS	A	44	7.3	no
[52]	Information Systems Frontiers	B	41	4.1	no
[56]	MISQ-E	B	40	5.7	no
[54]	Information Systems Frontiers	B	37	6.2	no
[8]	BISE	B	33	5.5	yes
[82]	ECIS	B	30	5	yes
[55]	Information Systems Frontiers	B	26	4.3	no
[69]	ICIS	A	21	3	no
[48]	Group Decision & Negotiation	B	20	6.7	no

Table 6. *Cont.*

Article	Outlet	Ranking *	Citation Count	Citations Per Year	Cited DS(R) Literature
[70]	ICIS	A	18	3	yes
[99]	ECIS	B	17	2.1	yes
[87]	ECIS	B	16	2	no
[64]	ICIS	A	15	3.8	yes
[89]	ECIS	B	15	3	yes
[90]	ECIS	B	15	2.5	no
[60]	ICIS	A	14	1.8	yes
[45]	EJIS	A	13	13	yes
[47]	Group Decision & Negotiation	B	12	2	no
[59]	ICIS	A	12	2.4	yes
[62]	ICIS	A	11	2.2	yes
[68]	ICIS	A	11	2.2	yes
[72]	ICIS	A	11	1.8	yes
[84]	ECIS	B	11	2.8	no
[88]	ECIS	B	11	2.2	yes
[67]	ICIS	A	9	1.8	no
[93]	ECIS	B	9	2.3	yes
[83]	ECIS	B	9	2.3	yes
[66]	ICIS	A	7	1	yes
[46]	Group Decision & Negotiation	B	6	3	no
[63]	ICIS	A	6	1.2	yes
[96]	ECIS	B	5	1.7	yes
[43]	EJIS	A	4	4	yes
[44]	EJIS	A	4	4	yes
[51]	Decision Science	B	4	4	no
[75]	DSS	B	4	2	no
[77]	BISE	B	4	2	yes
[91]	ECIS	B	4	1	yes
[49]	Group Decision & Negotiation	B	3	0.8	no
[65]	ICIS	A	3	0.8	yes
[71]	ICIS	A	3	0.6	yes
[78]	BISE	B	3	0.4	yes
[81]	ECIS	B	3	1.5	yes
[86]	ECIS	B	3	0.4	no
[100]	ECIS	B	3	0.6	yes
[11]	ICIS	A	2	1	yes
[95]	ECIS	B	2	0.7	yes
[97]	ECIS	B	2	0.5	no
[73]	ICIS	A	1	0.5	no
[85]	ECIS	B	1	0.3	no

Table 6. *Cont.*

Article	Outlet	Ranking *	Citation Count	Citations Per Year	Cited DS(R) Literature
[57]	JMIS	A	0	0	yes
[58]	ICIS	A	0	0	yes
[61]	ICIS	A	0	0	yes
[79]	BISE	B	0	0	no
[80]	Computer and Science	B	0	0	no
[94]	ECIS	B	0	0	yes
[98]	ECIS	B	0	0	yes
			13.7 Ø	2.6 Ø	∑ 35

* According to VHB-JOURQUAL3.

4. Results and Finding

By examining individual analysis results (see Section– partly summarized in Table 7) and exploring them in concert, we made six observations. To formulate the observations, we followed an iterative procedure of formulating, clustering and discussing observations. In the first phase, the author team formulated individual observations based on the analysis results. In the second phase, the authors clustered and synthesized redundant or similar observations. In the last phase, the formulated set of coherent observations was discussed regarding completeness and potential for extension. When the potential for extending the observations was found, each author reiterated the previous phases. In total, three iterations were performed to conclude the final set of six observations. Thus, each observation is an interpretation of data that will subsequently fuel our discussion on how to address the identified issues and gaps formulated in our observations. In this context, we would like to point out that we do not claim all observations to be novel and unknown, especially from an experienced scholar in the domain of GIS research. Instead, the observations are intended to summarize what can be seen in the research articles we analyzed and to start and substantiate a discussion on design-oriented GIS research.

Table 7. Summary of Literature Analysis Results.

Dimension	Characteristic	% of Articles
■ Problem Domain	People	20%
	Organizations	65%
	Technology	32%
■ Evaluation Method	Observation	43%
	Analysis	5%
	Experiment	42%
	Testing	0%
	Description	13%
	No Evaluation	2%
■ Artifact Type	Construct	0%
	Model	62%
	Method	30%
	Instantiation	57%

Table 7. *Cont.*

Dimension	Characteristic	% of Articles
■ Contribution	Improvement	80%
	Exaptation	22%
	Routine Design	0%
	Invention	2%
■ Design Theory	Design Theory Level 1	80%
	Design Theory Level 2	72%
	Design Theory Level 3	8%
	None	0%
■ Influence	Belief-Formation	7%
	Action-Formation	82%
	Outcome	27%
■ Role of Artifact	Automate	40%
	Transform	7%
	Informate	57%
	Support	62%
	Enable	20%
■ Impact Proximity	Enablement	70%
	Implement	22%
	Application	13%
■ Sustainable Development Goals	Clean water and sanitation	5%
	Affordable and clean energy	27%
	Sustainable cities and communities	25%
	Responsible consumption and production	38%
	Education on climate action	8%
	Life below water	2%
	Life on land	5%
	Indirect	8%
■ Sustainability Impact	Environment	7%
	Society	8%
	Government	20%
	Industry	37%
	Organizations	62%
	Individuals	20%

4.1. Observation 1: Four Streams in Design-Oriented Green IS Research

The cluster analysis (see Section 3.3.3) aided us in revealing four clusters of articles in the sample.

- Cluster1—Technology-Oriented Studies: The first cluster includes research regarding the design of technologies to improve sustainability as outcomes. This research focuses on providing technically advanced solutions to automate processes (observed in 32% of all articles). The addressed problem space is limited to technological challenges, mostly leaving out the discussion of individual or organizational use of the developed solutions. These studies are close to the field of computer science. Through simulation experiments, such as the simulation environment for a smart grid energy market [89], artifacts are developed that enable industry-wide changes; e.g., facilitating more sustainable processes.

- Cluster 2—Individual-Oriented Studies: Research in this cluster focuses on problems and IS solutions on the individual level (20% of all articles). The artifacts aim to influence and to change actions towards more sustainable behavior. In this context, research instantiates artifacts to provide users with sustainability-related information and trigger more environmentally friendly actions. Prime examples are artifacts that support sustainable energy use in offices [63] or encourage users to select more environmentally friendly transportation options like bikes [68].
- Cluster 3—Process-Oriented Studies: Primarily addressing research in the organizational context, studies in this cluster present developed and instantiated artifacts to measure their impact in a field test. Processes are mostly automated, and decision-makers are informed. For instance, carbon management systems can persuade employees to perform ecologically responsible behaviors [50], while a framework for area-based pricing for carsharing can aid in more environmentally friendly management of vehicle demand and supply [11].
- Cluster 4—Decision-Oriented Studies: Research in this cluster is primarily concerned with organizational decision-making. Decision support models are developed to improve the overall decision-making process regarding sustainability-related topics. The majority of decision support models are improvements by their nature as they *support* or *enable* better decisions and provide a basis for *action formation*. However, the developed models are not applied for making real-life decisions, positioning this type of research on the impact proximity level of *enablement*. An example study in this cluster is developing a decision-making technique for planning an energy system with a focus on sustainability, which helps to evaluate alternative energy technologies [48].

4.2. Observation 2: Missing Artifact Applications for Immediate Impact

By looking at the time series (see Section 3.3.2) of the *impact proximity*, the *enabling* artifacts' time-consisted dominance is striking. Following Malhotra [7], early research on GIS had to be conceptualization-based and, as time goes by and the research matures, the contributions move towards the measurable impact on sustainability. Nevertheless, although the research arrived at the stage where solutions are designed, it still struggles with creating an immediate, measurable impact on the environment. The majority of the artifacts are either unable to create a measurable impact on the environment and represent an inherent part of another ensemble artifact (e.g., being a sub-part of a bigger system) or lack actual application in the environment, rendering their impact hypothetical. This goes hand in hand with the observed focus on *action formation* in the sample.

When Elliot [6] described different types of IS influence on sustainability, he explicitly distinguished action formation from outcomes. Although both influence types appear to be at the frontline of impactful research, there is a hierarchical relationship between the two, in which the outcome (e.g., emission reduction) is the final goal and the action formation of its prerequisite. In the sample, however, we observe a tendency to leave out the discussion of the outcome dimension, limiting the research scope to *action formation*. What remains missing are explicit strategies required for successfully transforming action formation into outcomes or aiming at outcomes directly.

4.3. Observation 3: Low Abstraction of Design Theories

In design-oriented research, utility and practical knowledge is the primary research objective [20,21,26,28]. However, current design-oriented GIS studies seem to provide contributions that fall short in this regard. On the one hand, as stated in Observation 2, most artifacts do not directly impact the environment. On the other hand, the level of abstraction of the provided design knowledge [107] is low; e.g., being focused on problem instantiations instead of generalization [40,108]. Hence, against the expectation that a lack of artifacts capable of creating an immediate positive impact on the environment would provide opportunity space for creating theoretical contribution on a higher level of abstraction, the study sample delineates mostly specific artifact designs that are neither (nascent) design theories nor applications of the artifacts in real-world environment. A related observation can provide a potential explanation: Only half of the studies relate to DSR literature e.g., [22,35,109]. Although using DSR does not necessarily increase scientific impact [110,111], its use could guide research toward higher abstraction of design contributions [107].

4.4. Observation 4: Low Diversity in Addressed Sustainable Development Goals

The majority of design-oriented GIS contributions are improvements (80% of all articles), a common observation in DSR [107]. Recent years have seen a shift towards exaptation (observed in 22% of all articles), such as the development of a decision support system for the second life of the electric vehicle batteries. This artifact borrows from existing literature on decision support systems and the second life of the hardware and applies it in electric vehicles' emerging domain [44]. However, the continuing dominance of improvements is striking, as design-oriented GIS does not have a long history where a wide range of solutions exist that can be improved. Instead, existing systems (e.g., for production processes) are improved to be more environmentally sustainable.

4.5. Observation 5: Focus on Improvement Design

The majority of design-oriented Green IS contributions are improvements, a common observation in DSR [107]. Recent years experienced a shift towards exaptation, such as the development of a decision support system for the second life of the electric vehicle batteries—an artifact that borrows from existing literature on decision support systems and second life of the hardware and applies it in the emerging domain of electric vehicles [44]. However, the continuing dominance of improvements is striking as design-oriented Green IS has no long history where a wide range of solutions exist that can be improved. Instead, existing systems (e.g., for production processes) are improved to be more environmentally sustainable.

4.6. Observation 6: Lack of Focus on Artifacts to Influence Belief Formation

In Observation 2, we already highlighted the lack of outcomes that demonstrate a measurable impact on sustainability. The majority of contributions focus on *action formation* and *outcomes* with a potential impact on sustainability. This also means that, despite their potential to drive environmentally friendly behavior [6], contributions in the area of *belief formation* are positioned outside of the design-oriented GIS community's primary targets. One reason for this could be the complexity of the belief phenomenon and its respective research processes [6,10]. This research is primarily pursued in the Human-Computer-Interaction and Psychology community, for which journals were not included in the search process. The reasons notwithstanding, the lack of belief formation artifacts shows limits of current design-oriented GIS research, potentially limiting the impact of artifacts focused on *action formation* and *outcomes* due to the lack of environmental beliefs held by the target users of said artifacts.

5. Discussion and Research Directions

This literature analysis aims to examine the current status-quo of design-oriented research within the domain of GIS. We characterized design-oriented GIS by developing a comprehensive coding framework for design-oriented GIS publications. Based on the characterization, we interpreted the gathered data in the form of six significant observations, which we will leverage in the following to discuss directions for future research (see Table 8). There is a direct link between observations and directions. While observations are descriptive in nature, directions represent our interpretation of the observations against the background of the extant GIS research. Observations can be seen as symptoms resulting from challenges the GIS research is facing. Therefore, the prescriptive directions for further research represent a synthesis of measures to address the prevalent challenges.

Table 8. Summary of Literature Analysis Results.

No.	Direction	Indicator	Examples
■ 1	Avoid Limbo between Theory and Practice to Achieve Higher Impact	Observation 2 Observation 3	Researchers set a focus on either theoretical or practical implications. Papers present theories or demonstrate the measurable impact of artifacts on the actual environment.
■ 2	Extend the Problem Space Beyond Business Processes and Organizational Contexts	Observation 1 Observation 4 Observation 5	Researchers report on the design of new and innovative artifacts instead of improving existing ones in organizations.
■ 3	Establish Research Beyond Decision Support for Constructed Decision Situations	Observation 1 Observation 2	Real-world scenarios are used for artifact implication instead of highly abstracted decision situations.
■ 4	Investigate Belief Formation as a Critical Factor of Sustainability	Observation 6	A manuscript addresses artifacts' influence on the beliefs of individuals regarding environmental sustainability, e.g., educating people on environmental issues or making the environmental impact of decisions transparent.

5.1. Avoid Limbo between Theory and Practice to Achieve Higher Impact

During the literature analysis, it became apparent that most publications engage in the development of Level 1 and 2 design theory contributions. These publications mostly lacked an extensive discussion on the design knowledge collected during the artifact development, e.g., identifying principles of form and function [108] or reflecting on kernel theories [29,107] (Observation 3). Following Rai et al. [20], 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. However, it was surprising that most studies also lack artifact applications and demonstrations of direct impact. They conceptualize solutions but refrain from applying them in practice (observation 2), with the notable exceptions of [11,76]. The former applied a DSS for water restriction policies, while the latter constructed pricing areas in an existing free-floating carsharing system. Both studies demonstrate impact in the form of a research "aftermath" and report how the artifacts applications in a problem space became part of the running system. The exceptions notwithstanding, design-oriented GIS seems to be trapped in limbo in-between theory and practice.

Calls for the impact of GIS are not new e.g., [2,4,7]. In addition to the calls for practical impact created by solving a problem at hand via an instantiation (e.g., a concrete proof of the design [21]), we would like to encourage theoretical contributions in design-oriented research. Specifically, theoretical contributions in the form of a design theory [40,108] can lead to a better understanding of the design of GIS (e.g., how a design can solve problems in multiple instances).

We would like to propose that the lack of well-developed design theories (i.e., design theories that reach Level 3) for GIS is caused by a missing understanding of how to reach the required level of abstract/generalization and how to communicate it. Similarly, other scholars [30,31,112] have noted that the development of design theories is fuzzy and, overall, complicated. In this regard, we would like to highlight existing concepts, which might help overcome the challenges of theory development. First, "heuristic theorizing" [31] provides guidelines on how to develop design theories during intensive development and evaluations of artifacts, applicable for real-world environment. Second, the "anatomy of a design theory" [108] proposes six core components for a design theory. Based on these components, researchers can ensure that they address all aspects of a design theory, refining them interactively to reach higher levels. Last, we see the lack of intensive discussion on theory and related research as one major flaw of current publications. It is highly important to integrate findings and contributions in the greater discourse of GIS and related research domains because it enables follow up studies to build upon existing knowledge, potentially reaching higher levels of abstraction/generalization.

Regarding the practical implications of a study, an artifact does not necessarily need to be applied in order to show its potential utility [21,26,28], while still representing a logical and rigorously developed research outcome [20]. However, the urgency of the environmental problems dictates a timely application of design outcomes. Hence, ensuring such an application should be part of the researcher's task, aiming to address today's environmental challenges. In this context, we would like to direct GIS research toward DSR approaches, which notify application and transfer into practice as essential: Action Design Research [113] and Consortium Research [32], or focus on the evaluation of a developed artifact in the context of its actual and continues application and use.

5.2. Extend the Problem Space beyond Business Processes and Organizational Contexts

IS research primarily focuses on research within the context of organizations, e.g., business enterprises [114]. Hence, increasing sustainability in organizations (Observation 1) by improving process efficiency (Observation 5) consumption and production (Observation 4) is an easily accessible opportunity for the GIS community. This type of research can be communicated effectively and generates interest by IS researchers and companies, as any increase in resource efficiency can translate into decreased costs and increased revenue or contribute to a raised standing for the enterprise. Simultaneously, improvement through IS retains its relevancy for other IS research areas [114].

Nevertheless, improvements are matched against the current state's baseline [107,115], even if the baseline is shifting downwards due to ongoing deterioration of the natural environment. This phenomenon is called the *shifting baseline syndrome*, i.e., the improvements are objectively getting less and less significant, but our perception remains that each improvement is quite significant compared to the current baseline [115,116]. The improvement is evaluated relatively and not absolutely, making our perception of the impact of an innovation warped [116]. Hence, there is a requirement to change the perception of sustainability from improving existing processes to innovating new ones. Much is written on the need to create innovative artifacts [14,117], but our sample does not reveal a substantial enough effort to develop them (Observation 5). We understand that approaching innovations to achieve transformations is challenging, yet it needs to be acknowledged there can hardly be substantial changes in the trajectory of addressing sustainability issues without a larger vision. In this context, we would like to highlight the examples of the smart grid [118], virtual power plants [119], and energy informatics [1]. These innovations provided entirely new ground for improving environmental suitability. Similarly, additional problem spaces like circular economy can be explored, focusing on inter-organizational networks.

5.3. Establish Research beyond Decision Support for Constructed Decision Situations

The majority of artifacts among the analyzed studies are decision-supporting artifacts; e.g., mostly decision support systems or decision models (Observations 1 and 2). First, most DSS and decision models in the sample were developed for *constructed decision situations* meaning that grounding in real-world environments is overlooked, and input from stakeholders is often missing. For the most part, they are developed via mathematical modeling based on assumptions and evaluated via simulations. This makes it difficult to assess the validity, the potential impact, and the desired *aftermath* (e.g., increase of environmental sustainability) of the presented decision support artifacts. Second, digital technologies offer opportunities to improve and innovate beyond supporting decision-making. Hence, the design-oriented GIS research should embrace currently underrepresented research areas, such as digital platforms and digital business models [61,90,120]. In more general terms, research should investigate design to *automate* and *transform* instead of primarily focusing on *enablement*. Thereby, the design-oriented GIS community can comprehensively investigate IS-based solutions' design and potential instead of limiting themselves to decision support.

5.4. Investigate Belief Formation as a Critical Factor of Sustainability

Our analysis reveals a lack of studies investigating IS's design to support *belief formation* regarding sustainability on the individual level (Observation 6). In general, belief formation considers an individual's desires and beliefs, and how they influence their perception, cognition and behavior [6]. Hence, the importance of belief formation lies in its influence on action formation and outcome. Individuals with a mindset geared toward sustainability will change organizations and societies [121]. Despite the importance and potential of belief formation, our sample was mostly comprised of studies addressing action formation and outcome. We propose that this focus on action formation and outcome is caused by the complexity of belief formation, requiring multi-disciplinary teams of researchers. Therefore, we would call researchers to try to relate their belief-formation research topic to research in other disciplines, creating a joint interest that will facilitate cooperation.

6. Limitations

Our research is subject to limitations. First, as with any literature-based analysis, our inquiry is inherently time-constrained, meaning that our literature sample only includes articles that we published and were accessible during our literature search. Similarly, the selection of publication outlets constitutes a limitation. In this study, we selected studies from IS-related outlets, omitting publications from other disciplines (e.g., computer science and transportation) and followed a specific ranking to select outlets. Utilizing other rankings might lead to different results; however, the results are not expected to be much different as we focused on high-quality outlets. However, since the selected ranking includes journals and conferences, we might have created a sample that tends to focus on more abstract knowledge than concrete instantiations. We have tried to reduce this error by limiting our literature search to artifacts, which have already been evaluated, as a demonstration or evaluation is often based on concrete or prototypical instantiations. However, we cannot guarantee having entirely eliminated such a shift. Furthermore, our focus was on the larger IS community's research, which does not reflect the entirety of current efforts regarding environmental sustainability. A look beyond our community's borders is arguably a step that needs to be made once the GIS efforts have been streamlined.

Second, our results have limitations because of the chosen research approach. The selection of characteristics and dimensions strongly influences the explanatory power of structured literature analysis. The time series and cluster analysis are heavily influenced by the applied coding. In this context, clusters have to be understood as tentative and are not definitive. Nonetheless, they allow for a structured approach for identifying patterns [105,122].

Third, although coding was made as rigorously as possible by the authors, some classifications are more ambiguous than others (e.g., artifact roles and sustainability impact)—a fact that became apparent during the internal discussions. For example, the study of [44] provides a DSS for repurposing electric vehicle batteries. Hence, the question was whether it is supporting, transforming, enabling, automating, or informing processes. Eventually, we decided to classify its role as to informate, even though arguments for a different classification remain valid. Furthermore, sustainability itself is a rather ambiguous term. We may only know in a couple of years, maybe even decades, if the IT artifacts we are building today have had a genuinely positive impact. While this constraint comes from the applied DSR methods, a further reflection of the future's-built artifacts is undoubtedly required.

Fourth, the six presented observations are interpretative, and the resulting suggestions for the future of GIS can be considered subjective. However, we utilized a range of different analysis techniques and used independent analysis to limit the subjectivity. Hence, we believe in having identified valid observations and have found research gaps whose investigation provides value.

7. Conclusions

To understand and guide design-oriented GIS research, we conducted a comprehensive literature review. Based on our developed a coding framework (consisting of dimensions based on DSR and GIS literature), we coded, analyzed, and classified analyze an extensive sample of 60 design-oriented GIS publications. Based on our analyses results, we formulated six observations. For example, design-oriented GIS research is primarily focused on decision support and improvement of existing solutions and ignores the full scope of sustainability challenges, for which IS can provide solutions. Based on our observations, four directions were formulated to guide future research. For instance, we see a limbo between contributions for theory and practice, which should be breached by reflecting on the design of artifact. Based on these results, our study contributes to theory by highlighting potential areas for future research and promising ways to improve the overall theoretical contributions and integration of future GIS studies. Regarding practical contributions, we highlight that GIS research needs to be conducted in close cooperation with practitioners to provide real-world impact and ensure diffusion of results. Overall, we hope our review and directions will spur design-oriented GIS, addressing one of the most critical challenges of our modern world: preventing the natural environment from deteriorating.

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