Bus Inf Syst Eng 65(5):521–538 (2023)
https://doi.org/10.1007/s12599-023-00821-y

RESEARCH PAPER

The Design of Citizen-Centric Green IS in Sustainable Smart Districts

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Received: 22 June 2022 / Accepted: 30 May 2023 / Published online: 12 July 2023

Abstract Green information systems are often praised for their potential to foster sustainability in citizens' daily lives and meet their needs. With this focus on citizens, districts that use smart technologies provide a litmus test, the results of which will indicate how to design smart green information systems that better meet the needs and desires of citizens. To date, however, guidelines on how to design such green information systems in urban areas or actively involve citizens in this process are few and far between. In recognition and remedy of this shortage, the study draws on the design science research paradigm to develop seven design principles for citizen-centric green information systems that can be used in sustainable smart districts. These principles are evaluated in 15 semi-structured interviews and a prototype of a mobile district app for a citizen-centric green information system is instantiated. By taking this citizen-centric perspective, the paper fosters the active involvement of humans in the design of sustainable urban environments.

Keywords Sustainable smart districts · Smart cities · Green information systems · Sustainability · Citizen-centricity · Design principles

1 Introduction

In the highly charged discourse on climate change, cities are often caught in a problematic dichotomy: They are at once a partial cause of the problem and a significant element of the solution as they develop into smart cities. After all, smart cities have expedited sustainability transitions by implementing information and communication technologies (ICTs) in conjunction with smart energy technology (Gimpel et al. 2021; Kutty et al. 2020). The success of doing so has demonstrated that a sustainable smart city (SSC) can be a notable contributing factor to the attainment of the United Nations SDGs (Corbett and Mellouli 2017).

Since smart cities are complex constructs, the involvement of citizens in their development can pose certain challenges. One way of resolving them is to use dedicated urban areas – i.e., districts – as testing grounds for new implementation strategies in light of which the most suitable smart services can be introduced at city-level with more acuity and efficiency (Brauer and Kolbe 2016; Ramaswami et al. 2016). While urban districts in general are designed to connect several buildings and green areas, sustainable smart districts (SSDs) are designed to support their citizens in efforts to live lives of greater (ecological) sustainability (Hosseini et al. 2018; Keller et al. 2019; Martin et al. 2019). An essential component of these efforts is the use of Green Information Systems (Green ISs)

Accepted after four revisions by the editors of the special issue.

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(Bartelt et al. 2020; Corbett and Mellouli 2017; Velsberg et al. 2020).

Green ISs are developed to allow individuals, groups, organizations, and society at large to continue engaging with information systems but to do so in new ways that foster the emergence and establishment of (eco-) sustainable practices (Watson et al. 2010). By and large, the literature published to date has taken a provider-centric smart city perspective which offers a holistic view of Green IS applications in cities and looks closely at the potential for synergies (Corbett and Mellouli 2017; Ismagilova et al. 2019). This often leads to a top-down approach (Angelidou 2017; Corbett and Mellouli 2017) that somewhat disregards the perspective of its users, at least in their immediate environment. Due to this distance from the lived reality of the citizens, the sustainability potential of Green ISs could not be fully leveraged (Keller et al. 2019), not until recently when bottom-up approaches started to evolve and the citizen perspective was taken into account (Becker et al. 2023; Harnischmacher et al. 2020).

In efforts to bring Green ISs into closer alignment with the needs of citizens, there is a lot to be said for formulating and following guidelines for Green IS applications in SSDs (i.e., top-down or bottom-up). From an academic point of view, the best way of ensuring this is to formalize these guidelines into design principles (DP). DPs offer guidance for designers who have to negotiate a rather complex environment abounding with new possibilities for multiple stakeholders (Razmjoo et al. 2022; Rosemann et al. 2020). In this environment, as we have seen, bottom-up DPs foster citizen-centricity when designing Green IS solutions for SSDs, and this benefits designers as much as citizens as the latter profit from a district design that considers their needs, which is why they are inclined to accept and indeed welcome necessary changes in the newly designed district (Graf-Drasch et al. 2022). To integrate the various established perspectives on citizen-centric Green ISs in SSDs, this study develops a number of overarching DPs. Hence, this study aims to facilitate the sustainable behavior of citizens with the help of citizen-centric Green ISs by answering the following research question:

> *What are DPs for citizen-centric Green ISs within sustainable smart districts?*

Applying design science research (DSR) (Hevner and Park 2004), we formulated seven DPs (Gregor and Jones 2007). We derived the DPs by bilateral means: a systematic literature review and consultation with experts in SSDs, infrastructure, and social science. Given its adherence to the DSR paradigm, this study contributes to the theoretical work on design and action (Gregor 2006), its chief distinction being that the DPs developed in its context were subjected to rigorous testing in an iterative process until they came to represent prescriptive knowledge for the design of Green ISs in SSDs. Since IS designed in this manner can promote sustainable behavior among citizens, the contribution of this study is twofold: First, it advances research on Green ISs, specifically the strand of sustainable systems engineering (van der Aalst et al. 2023) by presenting a design theory that produces design knowledge in the form of operational guidelines for Green ISs in an SSD environment. Second, this study advances the practical development of Green ISs within SSDs by showing how to use the developed design guidelines in SSDs, including the prototype of a real-world instantiation in a German SSD.

2 Theoretical Background

2.1 Sustainable Smart Cities and Districts

The switch to a perspective with a greater focus on the citizen brings us from SSCs to the concept of SSDs, a planning approach where the citizen-centric service perspective is particularly well aligned with the core idea of sustainability (Ahvenniemi et al. 2017; Graf-Drasch et al. 2022). As defined by Keller et al. (2019, p. 1404), an SSD is "a district performing in a forward-looking way in economy, people, governance, mobility, environment, energy, and living, built on a sophisticated, smart ICT infrastructure that ensures benefits for every stakeholder, in particular a high quality of life for every citizen." In line with this definition, we see SSDs as integral, normative, and visionary subsystems of SSCs that bridge the gap between two sets of goals, the digital and the sustainable ultimately leading to a better quality of life (Martin et al. 2019).

In this study, we place a special focus on residential SSDs to look at how they perform to the mutual benefit of citizens and other city stakeholders, such as investors and service providers (Bisello 2020). Many SSDs already implement sustainability-related projects, ranging from the creation of new mobility projects or the sharing of concepts to the smart use of renewable energy sources and collaboration platforms that allow citizens to connect with one another more efficiently (Cappellaro et al. 2020; Hamari et al. 2016; Hosseini et al. 2018). It is important to note, however, that these projects rely on adequate technology infrastructure (Keller et al. 2019), such as mobile apps that make it possible not only to connect ever more citizens digitally but to provide and process a growing range of services (Anttiroiko et al. 2014; Staletić et al. 2020). Other examples include smart meters and sensors that facilitate the meticulous tracking of energy consumption in individual households, while advanced algorithms or artificial intelligence can provide greater transparency of energy supply and demand (Bonenberger et al. 2021; Mazur et al. 2019). Yet, even if a district makes full use of such technology, it is insufficient to make life more sustainable. Indeed, there is a clear need for approaches that ensure meaningful integration of the various characteristics and requirements of technologies, services, and human beings.

2.2 Green ISs in Sustainable Smart Districts

A subfield of ISs research, Green ISs can be defined as "information systems to transform organizations and society into more sustainable entities" (Seidel et al. 2017, p. 41). In this context, 'sustainable' denotes conserving, deploying, and reusing resources responsibly (Malhotra et al. 2013; Seidel et al. 2017). Green ISs are understood to have far greater potential to achieve this as they leverage advanced technology to provide services to individuals, groups, or organizations while keeping the focus firmly on sustainability-related goals (Watson et al. 2008; Schoormann and Kutzner 2020). Initially examined in 2007, Green IS research largely remains devoted to environmental sustainability, which is also strongly related to energy informatics (vom Brocke et al. 2013; Wang et al. 2015; Watson et al. 2010). These days, however, Green ISs are also appreciated for their ability to automate, inform, and transform processes in all areas of sustainability, be it by estimating energy consumption or providing guidance for behavioral change in line with the social perspective of an SSC (Brauer et al. 2015). For Green ISs to support sustainable actions within an SSD, it has to be planned, designed, implemented, and managed with in-depth understanding (Watson et al. 2008; Graf-Drasch et al. 2022; Melville 2010), and this understanding extends to its core constructs, as posited by Alter (2013). A summary of these constructs is presented in Fig. 1.

It is worth pointing out that the workings of Green ISs are significantly affected by three contextual factors: environment, infrastructure, and strategy (Alter 2013). As for the internal dynamics of a Green IS, the interplay of *services & processes* and *technologies & information* among the district's *stakeholders* – especially its *citizens* – has to be brought into close alignment to create benefits for all stakeholders (Bisello and Vettorato 2018; Corbett and Mellouli 2017). When this is achieved, the Green IS can support an SSD in reaching its sustainability-related goals, in the process of which it facilitates notable improvements to the citizens' quality of life (Bisello and Vettorato 2018; Gimpel et al. 2021).

Designing such a Green IS has proven to be a constructive research process, one by which to find an effective way of achieving the goals of SSDs (Hevner and Park 2004). Unlike in the corporate context, users who engage with IS in the urban context do not tend to rely on the one provided by a central authority as they go about their daily lives. Suppose, then, that the goal of a more sustainable lifestyle is to be reached by a critical mass of citizens within an SSD. In that case, it is essential to let citizens and stakeholders in the respective district participate in this research process. Indeed, the best results are achieved if they also participate in the co-creation of the Green IS (Golla et al. 2020). Dalén and Krämer (2017), for example, state that the attitudes and norms of individuals could be targeted with user-centered Green ISs. So far, however, many Green ISs have been pushed on citizens from the top-down, the main focus being firmly placed on introducing the technology itself without considering the needs or priorities of citizens (Trencher 2019). One unfortunate risk associated with this introduction strategy is that it can diminish citizen support, render the service provision within an SSD inadequate, or cause malfunctions, all of

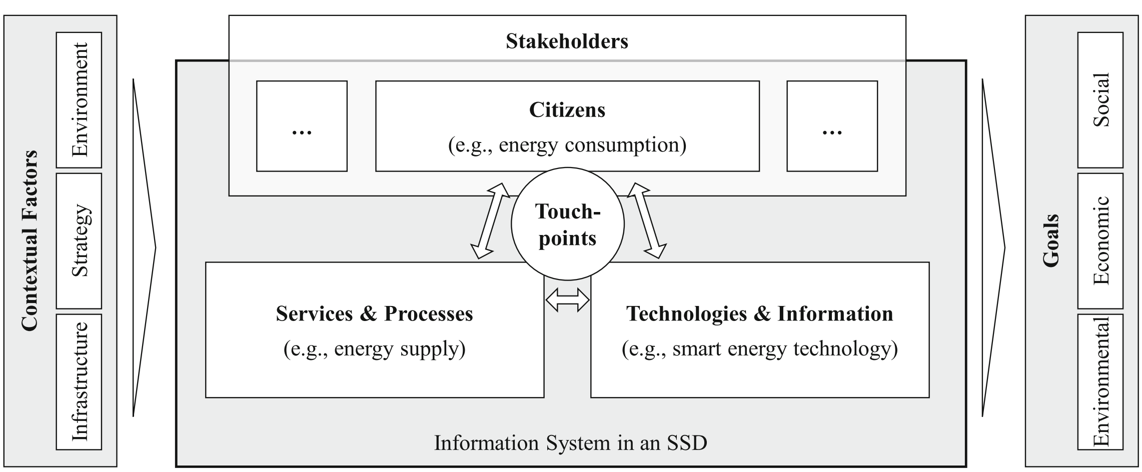

Fig. 1 Conceptual perspective on a Green IS in an SSD, building on the work of Alter (2013)

which can ultimately reduce the number of interactions and touchpoints (Graf-Drasch et al. 2022).

3 Method

The following section covers the method by which our IS design science research approach provides the overdue prescriptive knowledge on how to design a Green IS in SSDs (Hevner and Park 2004). For the research and refinement of this method, we adopted the process model of Peffers et al. (2007) for its particular applicability to urban area contexts (Bastidas et al. 2021). This process model comprises six phases, those being I) problem identification, II) definition of design objectives, III) design & development, IV) demonstration, V) evaluation, and VI) communication (Peffers et al. 2007).

Figure 2 illustrates all phases of Peffers et al. (2007) alongside the main activities. Our method's specific contribution is a nascent design theory that produces design knowledge in the form of operational principles and a situated implementation of a prototype, including its underlying architecture (Gregor and Hevner 2013). To rigorously demonstrate the high quality, utility, and applicability of our artifacts, we combined the IV) demonstration and V) evaluation phase and applied the established 'framework for evaluation in design science', as proposed by Venable et al. (2016).

I) Problem Identification: Drawing on the expertise we developed in the observation of various real-world SSDs and dialogues with its stakeholders, we could identify the overarching DSR problem (i.e., lack of design knowledge on Green ISs in SSDs) and the respective research gap. In the Introduction, we addressed the need for prescriptive guidance to be provided for citizen-centric Green ISs within SSDs. In the Theoretical Background section, we further identified the lack of prescriptive knowledge for Green ISs within urban areas.

II) Definition of Design Objectives: In recognition of the fact that a problem identified does not yield an objective for a design artifact (Peffers et al. 2007), we inferred our design objective based on our practical insights and knowledge of SSDs and Green ISs. In light of a thorough literature search, we then formulated our final design objective: *"Develop DPs for citizen-centric Green ISs within sustainable smart districts to foster a sustainable way of life for its citizens."* We operationalized this design objective with three broad meta-requirements in Appendix B (available online via http://link.springer.com), which enabled us to gain a holistic understanding of the aspects currently amiss in IS, including those widely used in the urban context. Ultimately, it was this design objective (i.e., the design principles) that guided our prescriptive solution based on which new Green IS can be instantiated both in SSD projects and beyond.

III) Design & Development: In this phase, we developed two main artifacts: 1) Seven holistic DPs and 2) a comprehensive prototype of a Green IS in SSDs. In developing our DPs, we took a supportive approach (Möller et al. 2020). This involved a systematic literature review (vom Brocke et al. 2015; Wolfswinkel et al. 2013) the purpose of which was to extract prescriptive statements about citizen-centric IS in urban areas, such as SSCs or SSDs. We then formulated our initial DPs in such a way as to serve as justificatory knowledge (Gregor and Jones 2007). We applied the search query *("smart" AND "sustainable" AND ("city" OR "district") AND ("information system" OR "information technology" OR "information and communication technology") AND "citizen")* to four established databases in the field of 'information systems', specifically AIS eLibrary, IEEE Xplore, Science Direct, and Web of Science. This resulted in a total of 1806 hits over the past five years, a period in which the use of Green ISs has increased notably in the urban context. After removing 3 duplicates, we screened the resulting 1803 distinct research papers iteratively and narrowed them down by sequentially analyzing titles and abstracts with predefined inclusion and exclusion criteria (see Table 1). Papers were excluded if they did not meet at least one inclusion criterion or if one of the exclusion criteria

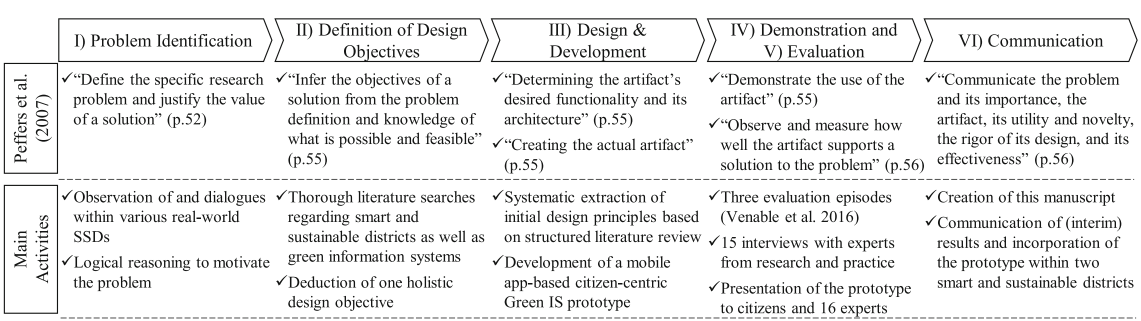

Fig. 2 Research approach in accordance with Peffers et al. (2007)

Table 1 Inclusion and exclusion criteria for paper during the systematic literature review

Inclusion Criteria	Exclusion Criteria
• Presents knowledge induced or abstracted from IS within SSCs or SSDs • Contains prescriptive design knowledge about IS, smart cities or districts supporting sustainable living • It deals with citizen- and inhabitant-centric decision support with a sustainability angle • Includes frameworks, models, taxonomies, or conceptualizations related to the smart city or district domain	• Was published before 2016 (which means it does not discuss current IS relevant to SSDs) • Is a book, (extended) abstract, presentation, or research-in-progress paper • Is not written in English • Does not mainly focus on SSCs or SSDs • Focuses only one specific service of an IS

applied. Instances of such exclusions include Cortinovis et al. (2019), in whose consideration SSDs or SSCs do not play a significant role, and Massana et al. (2017), who elaborated on only one potential service of an IS. After this deselection, the sample of relevant papers stood at 78. To this, we added 5 papers newly discovered by means of forward and backward searches. Having read these 83 papers, we identified 44 of them as being of relevance to sustainable smart urban areas and/or the use of IS within these areas.

Based on the papers we selected, we extracted a total of 210 prescriptive statements, which we subdivided into topic areas (see Appendix C). To do so, we exploratively used a natural language processing Python script with the Universal Sentence Encoder algorithm (Cer et al. 2018), capable of grouping the statements into 25 semantically similar clusters. By taking multiple iterative open and axial coding steps, we refined these clusters into 16 topic areas with a descriptive label (e.g., "[TA13] Big Data Analytics and Sources" or "[TA14] Data Management"). After taking further axial coding steps and processing the results in refinement workshops within the research team, we were able to merge the topic areas into seven initial DP names. For instance, the topic areas '[TA13]' and '[TA14]' formed the DP name '[DP6] Exploitation of the full potential of district data'. We then articulated the seven initial DPs in accordance with the structure proposed by Gregor et al. (2020) to summarize the various manifestations of each statement in a meaningful way, specifically the aim, context, mechanism, rationale, and exemplary actions. See Appendix D for a detailed description of these coding steps, Appendix E for definitions of the 16 topic areas, and Appendix F for the seven initial DPs. After evaluating and refining these DPs, we developed the second artifact, the comprehensive prototype of a Green IS in SSDs. The same DPs also guided the design and development of a prototype for a citizen-centric Green IS prototype. The resulting mobile app is intended to be rolled out in two real-world SSDs in two German cities, Stuttgart and Überlingen. To establish the required functionalities of this mobile app, we conducted two focus groups with SSD experts in the early stage of the mobile app development. The two focus groups comprised 9 and 11 experts, including city and SSD planners, SSD service providers, and sociologists. Doing so proved invaluable in that it allowed us to better tailor the prototype to the specific service needs of both districts. In due course, the prototype was iteratively and incrementally implemented in line with our DPs.

IV + V) Demonstration and Evaluation: The practical implications of the overarching problem called for a citizen-oriented design solution for SSDs. To demonstrate and evaluate our design artifacts, we took an outcome-oriented, practical perspective in pursuit of the aforementioned design objective (Peffers et al. 2018). This involved the use of the evaluation framework of Venable et al. (2016), rigor being our main evaluation goal. We deployed a human risk & effectiveness strategy with three evaluation episodes, each focusing on different evaluands and building on each other (see Table 2). To be clear, the evaluand represents the object of consideration, the properties of which are reviewed during an evaluation episode (Venable et al. 2016). This strategy allowed us to challenge our intermediate findings at an early stage and within naturalistic settings. It also allowed us to gradually improve our nascent design theory in the course of the project.

VI) Communication: It is essential to communicate the problem as well as our two artifacts if the resulting design knowledge is to find the wide audience that stands to benefit from it (Peffers et al. 2007). For scholars, this paper provides an in-depth discussion of the search process and our main findings, manifested in seven DPs for citizen-centric Green ISs in SSDs (also see Appendix A) and their prototypical instantiation in a mobile app. To extend the study's reach to the relevant audience of practitioners, we communicated all of our (interim) findings to citizens and experts of the Stadtquartier 2050 project, be it in meetings, workshops, or face-to-face encounters.

Table 2 Three evaluation episodes, as per Venable et al. (2016)

Episode	Evaluand	Evaluation Method	Specific Setting
1)	Design objective	Theoretical arguments from thorough literature searches	Formative, ex-ante, artificial
2)	Design principles	15 interviews with experts from the fields of research and practice	Formative, ex-post, naturalistic
3)	Green IS prototype	Presentation to various citizens and 16 experts	Summative, ex-post, naturalistic

4 The Design of Citizen-Centric Green ISs in Sustainable Smart Districts

4.1 Design Principles

In Table 3, we present our seven final DPs for Green ISs in SSDs, all of which were systematically derived from the literature and refined over the course of 15 interviews (see Evaluation Episode 2). The DPs are formulated in accordance with the conceptual scheme for DP, as proposed by Gregor et al. (2020). This scheme structures each DP in terms of title, aim, context, mechanism, and rationale. Specifically, the aim is what we want to achieve with the respective DP. The context clarifies the stage of the software cycle at which a given DP receives the greatest attention (Alter 2013). The mechanism denotes how a DP wants to achieve a given aim. The rationale answers the question as to why we should pay attention to a particular DP and which area of the current literature is most pertinent to it. To ensure better understanding and practical application, we detailed at least five exemplary actions concerning each DP (see Appendix A). These exemplary actions indicate which practical measures ought to be implemented for each DP. In the following, we provide a detailed description of the structural interdependencies between the various DPs. We also discuss the application of each at its particular stage of the implementation process. While the general focus of these DPs is on the non-technological aspects of SSDs, DPs 1 to 4 are more qualitative in their specific focus, DPs 5 to 7 more technological. As we identify the relationships between the individual levels of these DPs and the literature that influenced their respective development, we expand on the content of Table 3 and deal with the most pertinent issues noted by other academic researchers.

DP 1 – Involvement of Citizens: The first DP is an integral aspect of a bottom-up approach to the human-centered design of Green ISs in SSDs (van der Bijl-Brouwer 2017). Involving citizens at the stages of initiation, development, and implementation of a Green IS brings its design into far closer alignment with the real needs of its users and the objectives of their districts (DP 2) (Kumar et al. 2020). Such active involvement can be beneficial at different stages of the SSD design. At the initiation stage, for instance, citizens can be involved to ensure that they identify their real needs before the focus of the development and implementation has a chance to shift away from the true purpose of the design. Once the active operation is underway, this involvement of citizens remains an important quality control measure as the feedback loop can keep the focus on their real needs and any necessary adjustments can be made accordingly (DP 3). Subsequently, say at the implementation stage, a designer can involve special target groups to account for the needs of various demographics and redirect efforts to the proper channels to ensure that the Green IS will integrate diverse perspectives (Renyi et al. 2019). It is worth noting, however, that Green IS designers might struggle with certain challenges arising from this involvement process. In most cases, designers must work with large groups of citizens, not all of whom will automatically understand the design process or appreciate how it may benefit them. This makes it all the more important to involve them as early as possible, allowing them to identify their concerns in light of which a healthy environment can be designed and redesigned accordingly.

DP 2 – Realization of District Objectives: Modern urbanization has led to a complex fragmentation of cities into various districts that can differ in multiple ways, be it in terms of their infrastructure, their geography or, most importantly, their demographic. For instance, a district close to the city center may undergo transformation while being home to a hugely heterogeneous group of citizens from various social classes. Such districts tend to have objectives that differ significantly from newly developed districts in the suburbs of a city, where a typically rather wealthy and homogenous older population has taken up residence. Given these disparities, SSDs can have a host of highly differentiated objectives, all of which may have specific causal links to the particular characteristics of the respective district. At the same time, however, these SSDs are part of a larger city and its overarching objectives and values. Information systems must, therefore, meet a range of requirements to help the district achieve its individual objectives as well as the greater interests of the city (Bastidas et al. 2018; Heaton and Parlikad 2019). This, however, requires that the district objectives are known and

Table 3 The seven DPs for Green ISs in an SSD

DP	Name	Aim	Context (Stages)	Mechanism	Rationale	Supporting Literature
1	Involvement of Citizens	To foster a positive attitude to the Green IS among citizens, which should lead to a greater understanding and more extensive use	Initiation, development, implementation	Ensure appropriate involvement of citizens via active and goal-oriented participation	Involving citizens makes it possible to integrate their perspective at an early stage and facilitates their positive attitude towards using the Green IS (Venkatesh et al. 2012)	van der Bijl-Brouwer (2017); Heaton and Parlikad (2019); Renyi et al. (2019); Grotherr et al. (2020); Ji et al. (2021)
2	Realization of District Objectives	To align technology and its use with the objectives of the respective district under careful consideration of any potential conflict of interest	Initiation, development	Derive Green IS requirements and realize district objectives	Contextual factors (environment, strategies, infrastructure) that are specific to a district have to be considered in order to create an appropriate Green IS (Alter 2013)	Bastidas et al. (2018); Ji et al. (2021); Bibri (2018a); Palumbo et al. (2021); Heaton and Parlikad (2019); Mora et al. (2019); Kumar et al. (2020); Majchrzak et al. (2018)
3	Response to the Feedback of Citizens	To consider the feedback of citizens through an iterative process in order to improve the Green IS in response to their needs	Operation	Respond to new or changing needs by continuously collecting feedback from a sufficient number of diverse citizens	Focusing on the needs of citizens makes it possible to foster a wider application of the Green IS and allow sustainability growth among citizens (Graf-Drasch et al. 2022)	Kendel et al. (2017); Marsal-Llacuna and Segal (2016); Majchrzak et al. (2018); Keller et al. (2019); Bibri (2018a)
4	Adoption of a Holistic District Perspective	To facilitate constructive interaction among essential district components	Initiation, development, implementation, operation	Understand the interdependencies of stakeholders, services, and technologies by adopting a holistic district perspective	Broad perspectives prevent opinion silos and island solutions (Wang 2021)	Palumbo et al. (2021); Allam and Dhunny (2019); Brauer and Kolbe (2016); Keller et al. (2019); Belanche et al. (2016)
5	Facilitation of a Flexible IT Architecture	To run a scalable Green IS that supports continuous provision of services	Development, operation	Retain a stable and flexible IT architecture capable of dealing with short-term shocks as well as long-term transformations	A flexible and stable IT architecture supports innovation as well as systemic change (Jonkers et al. 2006)	Bastidas et al. (2018); Ruutu et al. (2017); Del M. Esposte et al. (2019); Kumar et al. (2020)
6	Exploitation of the Full Potential of District Data	To (re-)develop services with the help of data in order to tackle complex sustainability-related goals	Initiation, Development, Implementation	Explore and exploit any potential arising from the collected data within the district and beyond	Analyzing big data sheds light on complex urban interdependencies (Bibri 2018b)	Kumar et al. (2020); Bibri (2018a); Majchrzak et al. (2018); Keller et al. (2019); Lim et al. (2018); Ji et al. (2021)
7	Preservation of Privacy and Security	To protect the digital and physical integrity of each citizen under consideration of legal and ethical issues	Initiation, Development, Implementation, Operation	Comply with current laws, regulations, and ethical standards to preserve privacy and (IT) security	Upholding the fundamental freedoms of individuals supports them in living a self-determined life (European Commission 2016)	Majchrzak et al. (2018); Keller et al. (2019); van Zoonen (2016); Vandercruysse et al. (2020); Lim et al. (2018)

that they have been formulated according to the needs and desires of the citizens. If sufficient attention is not paid to the latter, citizens are likely not to use the IS on a regular basis, nor are the potential uses of specific technologies likely to be fully explored (DP 5 & 6). SSDs mitigate this risk by combining top-down and bottom-up perspectives on a district level (Mora et al. 2019). It is advisable, therefore, that a Green IS in an SSD brings its use of various technologies into alignment to overcome this challenge (DP 5 & 6) (Kumar et al. 2020). SSDs would then ensure accessibility across all ages and backgrounds (Majchrzak et al. 2018).

DP 3 – Response to the Feedback of Citizens: The involvement of citizens should not end with the initiation of the Green IS, nor with its development and implementation. Indeed, it is crucial to involve them further, first to keep ascertaining their needs and then to improve the Green IS accordingly. The focus of this involvement, however, ought to change in the operation phase; from a design to an assessment perspective. This should happen for the entirety of the operation phase, during which a range of communication channels should remain open to ensure that multifaceted feedback can be received from a representative cross-section of the district's citizen (Kendel et al. 2017; Marsal-Llacuna and Segal 2016). These communication channels should be set up to account for the district's particular context and special attention ought to be devoted to reaching citizens who are not already using the Green IS, given that its development is an opportunity to convince as yet disconnected groups of the benefits of the Green IS. The SSD can collect such feedback with quantitative monitoring by using smart meters or similar technology (DP 6), or it can do so with more conventional qualitative approaches, such as district meetings (Hopf et al. 2018; Kumar et al. 2020; Palumbo et al. 2021). Crucial to note in this context is the associated workload for the respective administration, and this should not be underestimated. The survey, evaluation, and implementation of any adjustments will require resources in terms of staffing and financing.

DP 4 – Adoption of a Holistic District Perspective: The designer in charge would be well advised to plan the Green IS for a connected district environment (Marsal-Llacuna and Segal 2016). An SSD is a complex construct of built infrastructure, diverse stakeholders, and various services (Keller et al. 2019; Palumbo et al. 2021). By designing the IS with an awareness of the interdependencies that exist between these district components, a Green IS can facilitate constructive interaction (Palumbo et al. 2021). What is more, by adopting a holistic district perspective from its initiation through its operation, the Green IS can leverage synergy effects and avoid island solutions that only work for specific services (Belanche et al. 2016; Palumbo et al. 2021). After all, an SSD connects a wide range of stakeholders, each of whom may wish it to serve a different purpose (Brauer and Kolbe 2016; Keller et al. 2019). Indeed, its many diverse stakeholders request a multitude of services while others provide just as many, including traditional housing services like waste disposal and more innovative ones such as car-sharing services (DP 1) (Brauer and Kolbe 2016). Since many of these depend on the SSD's built infrastructure (Kendel et al. 2017), the specific objectives of a district, as defined in DP 2, must not be disregarded. Instead, a holistic perspective must take in the full complexity and conflicting goals of different stakeholders. This poses significant challenges in terms of feedback analysis. It also has notable implications for the ongoing re-prioritization of goals within the district.

DP 5 – Facilitation of a Flexible IT Architecture: Given these potential peculiarities of an SSD, a Green IS requires a modular IT architecture to guarantee a scalable and reliable system for its services. Since a holistic perspective promotes interaction between the infrastructural levels (DP 5) (Bastidas et al. 2018), the current consensus in the academic community favors open interfaces in conjunction with approaches that facilitate data transferability (DP 6) (Ruutu et al. 2017). As those in charge of designing the Green IS lay the foundations for these requirements at the development stage, they are of major importance at the operation stage. It is worth remembering, however, how fast these requirements change, especially when dealing with an application in a built infrastructure, designed to last for a long time. It is, therefore, a considerable challenge to design the system in such a way that changing requirements can continue to be implemented meaningfully, even after years of use.

DP 6 – Exploitation of the Full Potential of District Data: Due to the complexity of SSDs, the amount of data is high even in basic SSD systems. Given the rapid ongoing development of modern technologies and services, we can watch in real-time as this wealth of data increases further (Bastidas et al. 2018). There is, therefore, not only an urgent need for an adequate IT architecture, as described in DP 5. There is also a provision of various potential services and applications that can help us tackle the different challenges of an SSD. They may, for example, tap into the potential of DP 3 by meeting the need to monitor the use of the Green IS in order to collect valuable feedback for the improvement of the system and its services (Bibri 2018a). Doing so often requires real-time data sources, which opens possibilities for advanced data processing approaches, such as process mining, pattern recognition, and machine learning (Bastidas et al. 2018; Kumar et al. 2020). It is advisable, therefore, that the Green IS should integrate various data sources, both within the district and beyond (Ji et al. 2021; Lim et al. 2018; Wolff et al. 2020). The large amount of data thus generated requires the Green IS to have a robust data-management approach (Bastidas et al. 2018).

DP 7 – Preservation of Privacy and Security: Privacy and security are key issues in the digital environment of an

SSD. The Green IS must guarantee each citizen's digital and physical integrity in all contexts (Vandercruysse et al. 2020). This means it has to comply with current laws, regulations, and ethical standards to preserve their privacy and security (Keller et al. 2019; Yeh 2017). Such preservation is aided by the ability to include user accounts as well as authentication and authorization functionalities (Majchrzak et al. 2018). It can also be aided by further means, such as rewards for voluntary disclosure of data. This can be done by means of economic incentives or by enabling new functionalities within the Green IS, although these measures require careful consideration as they bear the risk of putting considerable pressure on citizens.

4.2 Prototype of a Green Information System in Sustainable Smart Districts

Of the many different types of citizen-centric ISs, mobile applications have shown particular promise in getting close to the needs and user habits of the citizens (Naous et al. 2022). To date, Green ISs have often used this implementation to address multiple areas that bear relevance to an SSC or SSD, including mobility, pollution, recycling, water, or energy. Since members of the public carry mobile devices on their person most of the time, it is easier to reach them via these devices, and easier for them to provide feedback that way, for instance on issues like energy consumption (Bonenberger et al. 2021). With this in mind, we opted for incremental and iterative development of a Green IS mobile app within the project Stadtquartier 2050, working closely with relevant district stakeholders. The goal of this publicly funded project was to supply citizens of two German SSDs in Stuttgart and Überlingen with climate-neutral energy in a socially acceptable way. To this end, 960 residential units were constructed or renovated, whereupon the mobile app aimed to support all of their citizens in living climate-conscious lifestyles. During its development over several years, our design principles were treated as imperatives as far as their contextual factors allowed. Upon completion, the mobile app helped us to reconcile the practical and theoretical insights in the course of a summative evaluation of our DVs (see Evaluation Episode 3).

Throughout this project, and indeed the mobile app development, we made a concerted effort to involve citizens in multiple ways. This focus also heavily influenced the entire process of mobile app development. For example, we held several events and focus groups that gave citizens opportunities to actively participate in the app development (DP1). To optimize the ways in which we ingrained the goals of the project and the objectives of the SSDs in the mobile app, we held two initial requirements workshops with representatives of the citizens and other SSD stakeholders. Here, the main functionalities were aligned with the district objectives (DP2). As a result, the mobile app had the best chance of helping citizens within the SSDs to embrace more climate-conscious lifestyles by making use of these three core functionalities (see Fig. 3): First, the app provided users with near real-time monitoring of their energy and water consumption, not only in detail but also in relation to its ecological and economic impact. Second, it allowed users to set small tasks (e.g., changing the older light bulbs to energy-efficient LED lighting) as actionable goals, such as those used to level up in a gamification component. Third, it drip-fed small bits of information about a more sustainable way of living. Rather than put users off with an overwhelming glut of data, this strategy let them digest snack-sized lessons on energy-saving lifestyle choices by means of an interactive training component. After multiple feedback loops (DP3), additional functionalities were requested by users, such as the integration of local mobility offers (e.g., e-carsharing) and social features, including conveniences like access to the menu of a restaurant in the district. We believe these features should not only incentivize residents to use the app even more. They should also broaden the holistic perspective on the SSD in general (DP4).

What all of these frontend functionalities have in common is that they require a flexible architecture in the backend (DP5). This, in turn, requires consideration of multiple basic factors rarely discussed with the citizens. Examples include a baseline at which various elements of the distributed system interact. Further examples include compliance with standard data protection regulations and data security measures. In the case of the Stadtquartier 2050 project, three main non-functional requirements emerged in early discussions with district stakeholders. First, the mobile app should be used by citizens of two geographically-separate SSDs with their own technical hardware infrastructure. Second, the citizens of these SSDs should be able to use the app irrespective of the operating system of their mobile device. Third, the consumption data should only be accessible to the respective user upon initial registration and ongoing authorization. These requirements had a significant impact on the resulting architecture, as depicted in Fig. 4.

To ensure the architecture would remain flexible and expandable, we developed a communication layer able to combine multiple data streams from various (future) service systems. One of these is the artificial-intelligence-enabled self-learning grid system that leverages anonymized consumption data on the district to generate sustainability-improving notifications for users of the mobile app (DP6). To make this possible, individual measurement sensors provide data, a virtual machine uses particular scripts to import this data into a database, and that database

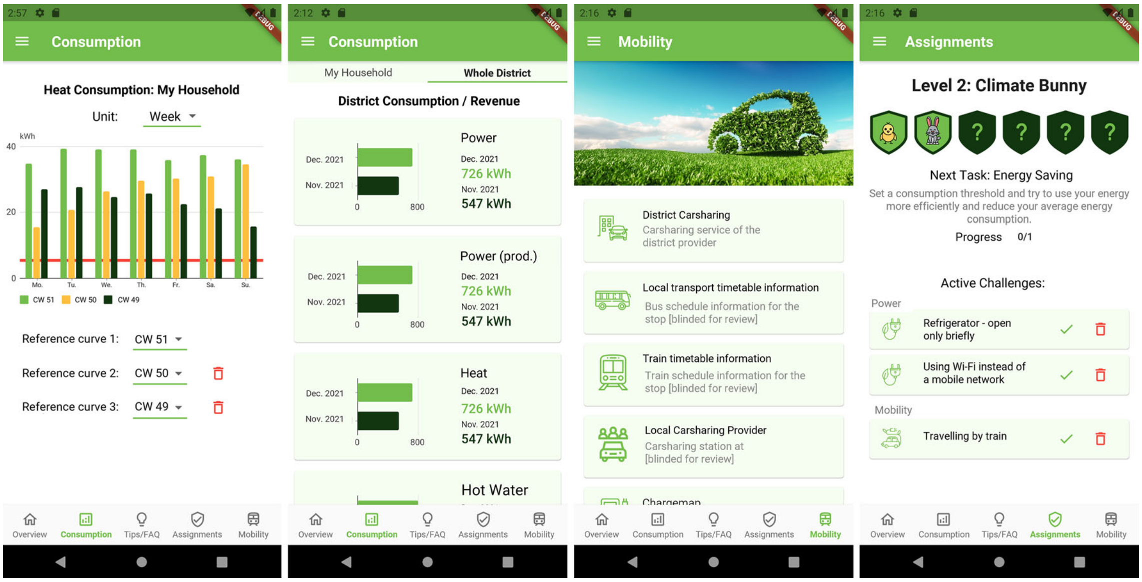

Fig. 3 (Translated) screenshots of the mobile app within the Stadtquartier 2050 project

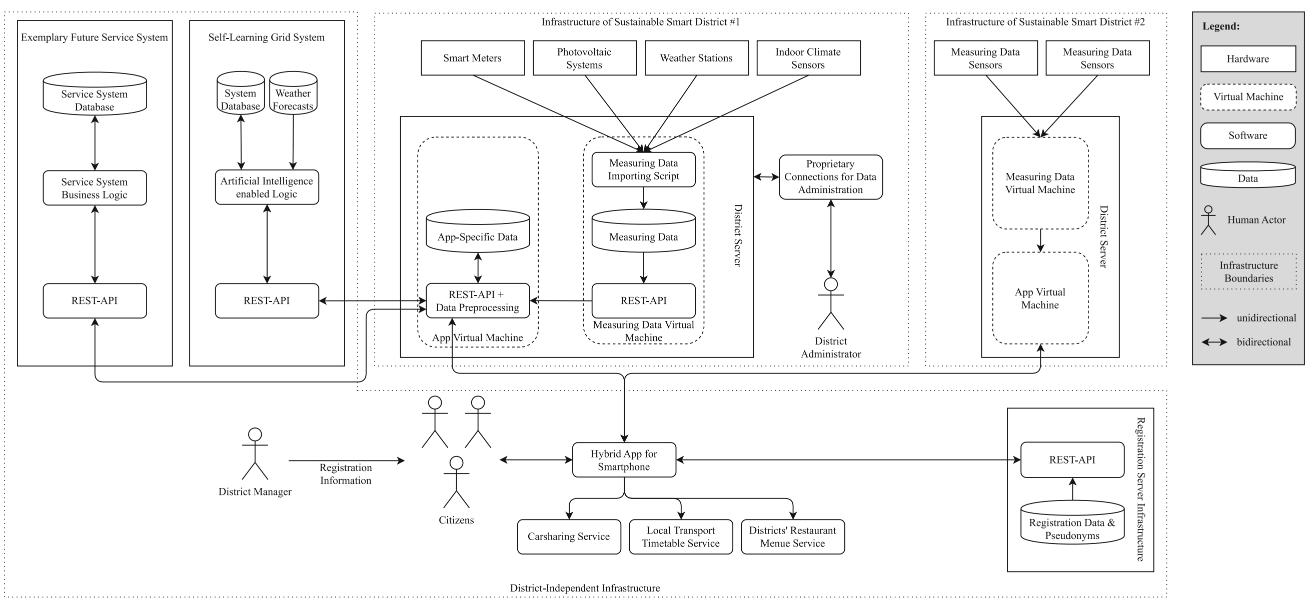

Fig. 4 Architecture of the Green IS within the Stadtquartier 2050 project

is made accessible via a secured application programming interface. Another virtual machine receives all requests from the mobile app, stores the core and transaction data required to operate all of the main functionalities, and forms the communication layer. At regular intervals, the system receives anonymized consumption data and offers updated notifications to specific citizen groups based on the respective data. During the application of the DPs, we were able to note several challenges (see Table 4) that affected the progress of the mobile app development. One such challenge in implementing the DPs was to observe all data protection laws pertaining to the rights and interests of citizens (DP7) as the legal situation and jurisdiction in the project Stadtquartier 2050 are neither transparent for the layperson nor designed for novel uses such as an app that leverages district data for sustainability purposes. While external experts were consulted to guide the development of an extensive data protection and security concept, and while the necessary revisions increased the quality of the work for all concerned stakeholders, they introduced extra challenges by delaying the development process for some functionalities (e.g., testing the detailed energy and water

Table 4 Main challenges impacting the mobile app development

DP	Name	Main challenge
1	Involvement of Citizens	Relevant contacts had to be established and the initial involvement of citizens facilitated during the COVID-19 pandemic
2	Realization of District Objectives	Economic satisfaction of all stakeholders (investors, landlords, and citizens) had to be ensured while observing the boundary condition of socially acceptable housing
3	Response to the Feedback of Citizens	There must be a trade-off between requested deviations from the project goals and the overall goals stated in the project's proposal
4	Adoption of a Holistic District Perspective	Developers and operators of the mobile app not belonging to the same organization makes it difficult to achieve an integrated and holistic set of features for the SSD
5	Facilitation of a Flexible IT Architecture	With measurement infrastructure (i.e., smart meters) being highly complex and the data obtained from it having to be managed centrally on-site, it is more susceptible to external shocks
6	Exploitation of the Full Potential of District Data	The resultant data protection and security concept being very restrictive, data is not readily available for analysis of the potential for innovative services that promote sustainability
7	Preservation of Privacy and Security	The legal situation and jurisdiction being neither transparent for the layperson nor designed for novel uses, such as this app, the coordination of one joint data protection concept is delayed by protracted and complex discussions

consumption display with real-world data). We resolved this by establishing a registration server located outside the district server infrastructure. This server made it possible for citizens to register with a pseudonym when using the app for the first time. Meanwhile, a clear data separation was implemented in the backend of the mobile app by tri-partitioning the data on the app virtual machine, the measuring data virtual machine, and the registration server. This proved very helpful in handling sensitive energy consumption data with care. It is worth noting, however, that this mobile app is only one of many possible manifestations of a Green IS in the SSD. In this case, we focused on energy and mobility, but the DPs that governed this application can also be implemented in other areas of sustainability.

5 Evaluation

To better evaluate the goodness of our evaluands (see Table 2), we formalized a set of specific criteria for each of the three evaluation episodes (Baskerville et al. 2018). Although this chapter is presented downstream of the results, the individual evaluation episodes were carried out incrementally and in parallel with the II) Definition of Design Objective and III) Design & Development phases. In the example of the seven design principles, this means that they have been evaluated and subsequently refined after their initial development, which is in line with Gregor et al. (2020). The steps performed in each evaluation episode as well as the resulting deltas to the initial version of the evaluands are examined in detail here.

Episode 1) Since it is not always enough to simply identify problems to transform them into design objectives (Peffers et al. 2007), the design objective we inferred from our research required careful evaluation in theoretical as well as practical terms before it was fit to guide us through the methodological phases of this project further downstream. The rationale of this evaluation was the 'fidelity with real world phenomenon' (March and Smith 1995). As discussed in the Introduction and Theoretical Background, we used deductive theoretical arguments inspired by real-world observations and scholarly literature to confirm the need for design knowledge to inform the development of Green ISs in SSDs. During the elaboration of the design objective, we ascertained that citizen-centricity ought to be dealt with explicitly both in the literature and in the wider industry, something we had initially only considered implicitly. Therefore, we adapted the design objective accordingly.

Episode 2) We made sure to reflect our initially developed DPs in a naturalistic setting to receive feedback from real people regarding the evaluation criteria: 'ease of use', 'elegance', 'simplicity', 'understandability', and 'completeness' (March and Smith 1995; Venable et al. 2016). To this end, we performed semi-structured interviews with 15 experts, all of whom were selected from the fields of research and practice (see Table 5) due to their competence in sociology, IS, and/or SSD domain or their expertise in services relevant to urban environments (Myers and Newman 2007; Schultze and Avital 2011). Ahead of the interviews, we briefed each interviewee by providing a OnePager, a single-page summary of this research project, allowing them to better prepare for the interview. We recorded and transcribed those interviews with the consent of each interviewee, used their native language, and took

Table 5 Experts selected for evaluation interviews

ID	Role of the interviewee	Background	Duration (min)
1	Sociologist	Innovation in sustainable tourism	56
2	Sociologist	Sustainability management	52
3	Service provider & consultant	(E-)Mobility services	66
4	Researcher	Sustainable smart districts	56
5	Green IS designer	Human-centered IS	52
6	Start-up founder	Digital service ecosystems	40
7	Researcher	Environmental sociology	70
8	Researcher	Human-centered IS	58
9	Researcher	Sustainable smart districts	46
10	Researcher	Sustainable smart districts	53
11	Sociologist	Energy efficiency and districts	42
12	Sociologist	Energy efficiency and districts	45
13	Service provider	Energy efficiency and districts	59
14	Innovation manager	Human-centered IS	44
15	Researcher	Sustainable smart districts	47

notes of relevance. Interviews lasted between 40 and 70 min, giving us a total of 786 min' worth of feedback in light of which we adapted the DPs and refined the research process in multiple iterations. First, language ambiguities were clarified (e.g., for aim and mechanism), then suggestions for more concrete exemplary actions were implemented. Meanwhile, feedback on how to improve the content of the design was evaluated throughout the interview process to identify recurring patterns and areas of consensus among the various expert opinions. All potential adaptations were discussed within the research team to mitigate confirmation biases, whereupon one DP was entirely overhauled, i.e., *'Adoption of a holistic district perspective'*; previously: *'Integration of an ecosystem perspective'*. The other DPs were substantially improved with regard to their aims, mechanisms, and exemplary actions. While Appendix F contains the initially developed list of DPs, we provide an overview of the feedback from the interviewees relevant for the revision of the DPs in Appendix G. For a detailed breakdown of the revised DPs, see Appendix A.

Episode 3) The two formative episodes concluded with a final in situ summative evaluation in a naturalistic setting, the Stadtquartier 2050 project. Having ingrained the DPs, the prototypical instantiation of a Green IS in SSDs had to be evaluated in terms of its operationality. This, in turn, gave credence to the applicability and effectiveness of the proposed DPs (March and Smith 1995), as we were able to demonstrate the working of our prototype to a broad range of citizens and experts with a thorough understanding of the two districts where this prototype will be put into operation. On an open-door day, we presented an early version of it to the interested citizens of one district, the majority of whom indicated their approval of its ability to track their energy and water consumption, a data analysis they welcomed as an opportunity to improve the quality of everyday life within the SSD and ultimately make it more sustainable. While some asked for further information on how their data is being processed, other, including district planners, asked for features to foster social interactions within the SSD. Based on this feedback, we revised the prototype and included a page with detailed yet easy-to-read information on the data acquisition and venue – a café – of the SSD. By including this in the app, rather than on a website of the SSD, we were able to create the mutual benefit of improved comprehension and convenience for multiple stakeholders. We also presented an updated version of the app to 16 experts and service providers in the same district, which led to further prototype modifications. We then adapted the architecture for ease of registration in each SSD. This transformation process was doubly beneficial in that it afforded us a valuable opportunity to ascertain the applicability of our DPs to the specific demands of the district and its citizens and it allowed us to bridge the gap between the objectives of the SSD and the priorities of its citizens. Similarly beneficial was the opportunity to receive open-ended feedback from real-world users after all of these updates. This feedback indicated useful ways in which to improve the user interface (e.g., more straightforward navigation within the prototype). It also identified which optional features could be included in the future. Since no changes to our DPs were deemed necessary, we were able to confirm both their applicability and effectiveness, the only caveat being that this prototype was still at an early stage of development and had yet to be put into operation in two districts.

After the three evaluation episodes, the research team met to conclude the reflective process. We found that our DPs are true to our overarching design objective. We proceeded on the understanding that our findings bring together valuable design knowledge, comprising the best of operational principles and a situated implementation (i.e., mobile app) of a Green IS prototype for SSDs.

6 Discussion

To date, DPs have proven helpful in the research areas of SSDs (Keller et al. 2019) and Green ISs in smart cities (Ramaswami et al. 2016; Seidel et al. 2018). They have helped designers navigate complex and often unknown environments full of novel possibilities and diverse stakeholders (Razmjoo et al. 2022; Rosemann et al. 2020). The research presented in these pages has identified seven holistic DPs for citizen-centered Green ISs in SSDs, all of which promise to foster sustainable behavior in residential urban environments. They address two major challenges discussed in the current literature. First, our DPs provide guidance on the design of Green ISs, offering a holistic perspective that views SSDs not only as a complex structure of diverse components but also as one part of a bigger entity, the SSC. Second, our DPs show the valuable potential of integrated and linked Green ISs to increase the sustainability of everyday life for citizens in an urban environment. It is important to note, however, that a set of DPs is not a magic bullet for sustainability-related design problems. Instead, our DPs provide an alternative to conventional top-down approaches in SSC contexts by offering complementary bottom-up approaches that involve citizens in both their development and implementation. This bottom-up approach fosters citizen-centricity and improves the quality of services. It also gets past the impasse of somewhat dated regulations, a stated objective of those conducting research on smart communities (Hosseini et al. 2018; Rosemann et al. 2020).

The second subject of this paper is the development of a design for citizen-centered Green IS and the demonstration of its role in an urban context, a research endeavor deemed necessary to meet sustainability development goals set by the global community (Corbett and Mellouli 2017; Harnischmacher et al. 2020). Achieving these goals requires a holistic perspective, so the scope of a Green IS ought to include an ecological focus as well as a broader view of sustainability (Corbett and Mellouli 2017). In this paper, we expand the conventional ecological focus on Green ISs by also looking at social and economic perspectives that take in the larger contexts of SSCs or SSDs. To appreciate these social and economic aspects, in particular, there is a strong case to be made for citizen-centricity in Green IS design approaches (Mattoni et al. 2019). In the course of this research, we observed several challenges encountered by designers trying to follow the many guidelines discussed in these pages (Kruse et al. 2022). We recognized that some of these challenges cannot be resolved within the cost and time boundaries previously established and that this bears various risks, not least the lapse into a classic top-down approach.

6.1 Theoretical Contribution

Our theoretical contribution is a nascent design theory that produces design knowledge in the form of operational guidelines for a Green IS in an SSD environment. Current research stands to benefit from this district perspective as it applies the fundamental pillars of IS Design on a smaller scale than the much-discussed SSCs. As such, it is more relevant to the everyday lives of most citizens (Graf-Drasch et al. 2022; Keller et al. 2019; Mattoni et al. 2019). Following the rationale of Gregor and Jones (2007), namely that a design theory should consist of eight components, we list the specific components that relate to design knowledge and originate from this study in Table 6. This design knowledge is the essential theoretical contribution of the present paper. It extends the prevailing top-down approaches by introducing a citizen-centric bottom-up approach to the design of Green ISs. Ultimately, this promises to advance research in the domain of sustainable systems engineering (van der Aalst et al. 2023).

6.2 Practical Implications

The seven DPs presented in these pages have a range of practical implications for the various stakeholders in SSDs, including citizens and service providers. Citizen-centric development benefits the design of Green ISs in SSDs in a number of new ways. First, it reduces the risk that the developed Green ISs will remain unused, as has happened with many top-down approaches. Second, it fosters transparency as well as a positive relationship with Green ISs, given that the citizens who are meant to use it were part of its creation (Heaton and Parlikad 2019). Third, it helps citizens understand how to use the Green IS as they come to appreciate its underlying principles (DP 2). In part, this is achieved by actively involving them in the design process (DP 1), specifically in the initiation, development, and implementation phase. The benefits are leveraged, however, by further involving citizens in the operation of the Green IS, where they provide feedback on the status quo (DP 3). If such feedback is collected continuously and subsequent updates made accordingly, the Green IS

Table 6 Manifestation of the eight components of an IS design theory (Gregor and Jones 2007)

Component	Description
Purpose and scope	It is the purpose and scope of this project to promote a citizen-centric perspective that aids urban stakeholders with regard to sustainable behavior in SSDs, the ultimate benefit being a better chance of tackling sustainability-related challenges in cities
Constructs	Citizen-centricity, SSD, Green IS, urban stakeholders, mobile app, architecture
Principle of form and function	The seven DPs for citizen-centric Green ISs within an SSD that better enable sustainability-conscious living
Artifact mutability	The nature of the SSD under consideration and its specific objectives determine the characteristics of the Green IS, and these have a direct impact on its instantiation
Testable proposition	The application of these DPs at the various stages of the Green IS design leads to citizens living more sustainable lives in SSDs
Justificatory knowledge	Extant knowledge of citizen participation, SSDs, Green ISs design, and sustainability-related challenges in a residential environment
Principles of implementation	A district planner or IS designer aiming to create Green ISs for SSDs ought to be cognizant of the specific context in which this project applies the seven DPs. These DPs serve as guidelines for enhanced sustainability, rather than as strict instructions
Expository instantiation	A prototypical instantiation of the DPs has been applied to two SSDs in two German cities, resulting in the development of a mobile app for citizens

remains citizen-centric and up-to-date, despite changes in the needs of the citizens or the specifics of their environment (Bibri 2018a; Keller et al. 2019). Further worth noting is the fact that these DPs also provide guidance for system designers at the various stages of the IS development process. Meanwhile, adherence to the DPs assures a certain level of user-centricity (DP 1,3), a holistic perspective of the district (DP 4), and the use of safe, expandable technology (DP 5,7). As our research indicates, a Green IS must be scalable to respond to changing requirements, for example, substantial increases in data volume due to the use of big data-related technology or new functionalities (Bastidas et al. 2018). It must also be scalable in case the district undergoes spatial expansion (Kumar et al. 2020), and, as we have seen, it must remain flexible and extendible to enable the independent development of its components and the interoperability with other systems (Del M. Esposte et al. 2019). The Green IS designed for this project complied not only with the seven DPs discussed above but also with specific district objectives, by virtue of which it will be especially helpful to SSD managers wishing to realize these objectives (DP 2). As our findings indicate, Green IS designers must also be aware of potential conflicts of interest between different demographics. Older or disabled citizens, for example, may have the same need for Green IS services in an SSD yet find such services harder to access (Renyi et al. 2019). Associated benefits include those reaped from the fact that, since Green ISs often supports citizens in their daily lives, the SSD manager stands to make a profit from satisfied citizens in the SSD if an appropriate level of privacy and security can be assured for services accessed through the Green IS (DP 7). A solid privacy and security concept is, therefore, not merely a legal necessity but also a lucrative opportunity to foster trust and service usage among the citizenship of the SSD (Bastidas et al. 2018). Without confidence in its safety and security, many people may refuse to use any Green IS that impacts their personal life and property (Lim et al. 2018). In short, data protection is key to a durable and sustainable use of a Green IS (Vandercruysse et al. 2020). To bridge the gap in the current research on Green ISs in SSDs, we established a range of robust DPs, as depicted in Fig. 1. DP1 and DP3 are located at the center, where they act as touchpoints between citizens and services & processes and technologies & information. DP2 is linked with goals, as opposed to DP4 which is linked with contextual factors. DP5, DP6, and DP7 are most closely connected to services & processes or technologies & information, depending on their particular manifestation when implemented.

6.3 Limitations and Future Research

There are, of course, certain limitations to the general validity of our results, and these limitations, inevitable in a field as novel and vast as the science of sustainability, indicate promising starting points for future research. The first one to note is that we conducted 15 interviews with experts from research and practice, all of whom were originally from Germany, meaning that further interviews with experts from abroad will have to be added to ensure the quality of the DPs when used in an international context. Similarly, our prototype was developed for use in locations around Germany, a geographic limitation that could lead to problems when applying the DPs in different countries. The international background of our literature indicates that our DPs are usable in most Western civilizations, but this assumption will have to be evaluated in future research. Secondly, the vast number of districts meant that our DPs were formulated very broadly. When observing DP 2 at the stages of initiation and development, they will have to be adapted to suit the SSD under consideration. Future research could do so by using case studies for standardized district types and real-world implementations. Also worth noting here is that challenges remain with regard to achieving district goals (DP 2) in harmony with a holistic perspective (DP 4), and resulting interdependencies will have to be subject to future research. Thirdly, the prototype presented in these pages is an instantiation limited to the interests of citizens and does not involve service providers, utilities, or the city government. Furthermore, it is currently in the implementation phase where its focus is limited to ecological sustainability, without due attention being given to significant social aspects. At this early stage, we have no information on how the prototype's approval rating among citizens will develop over time. Fellow researchers may, therefore, wish to evaluate our DPs in different cultural and national environments to ascertain their validity for a broad range of districts and a fully implemented, holistic prototype. A final important consideration to mention here is that the public sector exerts a notable influence on districts by means of regulation. Despite explicit demands voiced by the research community, contributions to the Green ISs literature are still few and far between, particularly with regard to the public sector perspective (Fernandez et al. 2020; Lehnhoff et al. 2021; vom Brocke et al. 2013). Since these calls have largely gone unheeded, many questions remain unanswered, particularly concerning the design of citizen-centered Green ISs in an urban context (Corbett and Mellouli 2017; Harnischmacher et al. 2020). Research in this area should help to appreciate how restrictions or incentives affect the design of Green ISs in SSDs.

7 Conclusion

Our direct environments – the places where we live and work together – are changing significantly as humanity faces global challenges. With our seven holistic DPs for citizen-centric Green ISs within SSD, we provide a way to foster sustainability in the everyday lives of citizens, and in response to their real-life needs. To develop these seven DPs, we used a design science research approach in conjunction with a systematic literature review. We then evaluated these seven DPs using 15 semi-structured interviews with experts from research and practice. To demonstrate the DPs' use in a realistic environment, we have provided a prototype of a citizen-centric Green IS, namely the "Stadtquartier 2050 Quartiers-App"" mobile district app. This makes a contribution to both research and practice, specifically in the form of guidelines for the structured design of Green ISs in urban SSD environments. In contrast to the narrow focus of existing top-down approaches, these guidelines are informed by broader insights from the district perspective and the reflective process of actively involving citizens to gain a holistic view, one that considers the characteristics of multiple infrastructural peculiarities and stakeholders. May this encourage future research on the design of Green ISs in SSDs and SSCs, the benefit of which, one hopes, will be the development of urban environments that support lifestyles of much-needed sustainability.

Funding Open Access funding enabled and organized by Projekt DEAL.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12599-023-00821-y.

Acknowledgements This research was supported in part by the BMBF (German Federal Ministry of Education and Research) and the BMWi (German Federal Ministry for Economic Affairs and Energy) under the funding of the PtJ (Project Management Jülich) in the course of the project "STADTQUARTIER 2050 – Herausforderungen gemeinsam lösen" (03SBE116) as well as by the BMBF under the funding of the PtJ in the course of the project "ODH@Jülich" (03SF0608).

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