Bus Inf Syst Eng
https://doi.org/10.1007/s12599-024-00863-w

RESEARCH PAPER

Smart Urban Agriculture

A Study of Digital Opportunities to Feed City Dwellers

Anne-Sophie Christmann · Valerie Graf-Drasch · Ricarda Schäfer

Received: 3 July 2022 / Accepted: 5 December 2023

Abstract Given cities' rising environmental problems and increasing food insecurity, innovative organizational endeavors such as urban agriculture present a chance for additional ecosystem services and food production. However, urban spaces are hostile as they jeopardize the availability of air, water, or soil. While digital innovations enable the management of scarce resources in traditional agricultural contexts, little is known about their applicability in urban agriculture endeavors. This study proposes a multi-layer taxonomy focusing on digital technologies, data, and different approaches in urban agriculture, as well as 20 organizational readiness factors derived with academics and practitioners from the smart urban agriculture domain. Combining both perspectives, the study sheds light on the nature of smart urban agriculture and ways to leverage its economic, ecological, and social value.

Keywords Digital opportunities · Smart urban agriculture · Taxonomy · Readiness

Accepted after three revisions by Jens Dibbern.

A.-S. Christmann (✉) · V. Graf-Drasch · R. Schäfer
FIM Research Center for Information Management, Augsburg, Germany
e-mail: as.christmann@gmx.de

V. Graf-Drasch
e-mail: valerie.graf-drasch@uni-hohenheim.de

R. Schäfer
e-mail: ricarda.schaefer@fim-rc.de

A.-S. Christmann · V. Graf-Drasch
University of Hohenheim, Stuttgart, Germany

A.-S. Christmann · V. Graf-Drasch
Branch Business & Information Systems Engineering of the Fraunhofer FIT, Augsburg, Germany

R. Schäfer
University of Augsburg, Augsburg, Germany

1 Introduction

Cities are the main contributor to global energy demand and carbon emissions (World Economic Forum 2020), making them a key lever for addressing the climate crisis (Corbett and Mellouli 2017; Gimpel et al. 2020). The rising concentration of people in cities brings up the question of how these populations can best be provided with food – especially in times of uncertain global events such as pandemics or wars. Although worrisome, these challenges constitute a "window of opportunity" for innovative organizations. Researchers and practitioners are increasingly pointing to "urban agriculture" – a promising complement to traditional rural agriculture that involves growing crops and raising livestock in cities (Carolan 2020; Langemeyer et al. 2021). However, significant hindrances exacerbate realizing the potential benefits of urban agriculture: First, urban spaces – characterized by sealed surfaces and heat stress – are a hostile habitat for many species, creating challenging environmental conditions leading to a high energy and material usage (Gimpel et al. 2021; Lüttge and Buckeridge 2020). Second, urban agriculture often fails to compete economically due to high investment costs in prime city land and required workforce (Chang and Morel 2018; Azunre et al. 2019) or governments restricting land use to very particular areas (Diehl et al. 2020). When turning toward traditional rural agriculture, digital innovation – i.e., "the creation of (and consequent change in) market offerings, business processes, or models that result from the use of digital technology" (Nambisan et al. 2017, p. 224) – has proven to be

Published online: 30 July 2024

a significant value lever for driving economic and resource efficiency (Steininger et al. 2022). In urban agriculture, however, how to leverage the potential of digital technologies (i.e., smart urban agriculture) is less clear (O'Sullivan et al. 2019).

So far, researchers have primarily focused on understanding individual business use-cases of smart urban agriculture (SUA). Thereby, they specifically examined SUA's digital infrastructure and its economic and environmental impact (O'Sullivan et al. 2019; Weidner et al. 2022), as well as the social acceptance of the digital technologies used (Specht et al. 2016; Broad et al. 2021). However, many emerging SUA endeavors fail economically because of high investment costs, lacking skills, a wrong selection of technologies during implementation, or the inability to materialize the expected financial, ecological, and social benefits in the long run (Langendahl 2021). What organizations urgently need to master the challenges of innovation development and deployment in SUA and better prepare themselves for launching an endeavor in this field, is a clear understanding of the concept of smart urban agriculture and the associated digital innovation process. Hence our research question reads: *What is smart urban agriculture and how can its value be leveraged?*

To capture the essence of SUA across development, implementation, and scaling, we take two different perspectives. First, there is no shared understanding of which digital technologies, data, and functionalities SUA constitutes. In perspective 1, we thus conceptualize the phenomenon of SUA as a taxonomy by analyzing the relevant dimensions and characteristics of SUA. Second, to leverage the value of SUA, a sound understanding of the organizational requirements and prerequisites for leveraging SUA – a concept called organizational readiness – is critical (Lokuge et al. 2019). In perspective 2, we thus develop 20 organizational readiness factors for SUA by conducting semi-structured interviews with 9 research scholars and 16 smart urban farmers. Inspired by research combining different methods in one work (Venkatesh et al. 2016a), we combine perspective 1 and 2 to gain completeness: Both perspectives aim to deliver a more complete picture than one isolated approach by complementing the insights of each other. This yields so-called "meta-inferences" – a key result of this research. Meta-inferences depict interpretations of our findings in an integrative view. They provide the opportunity to look beyond the limitations of a single perspective and take a stance in conceptualizing SUA holistically.

Our work presents three overarching implications: First, our taxonomy offers a common ground for conceptualizing the scattered nature of SUA by uniting terms from various domains and generalizing subtypes. Second, we deliver insights on organizations' readiness to leverage digital technologies to address environmental, economic, and regulatory challenges in urban agriculture. Third, the integrative view of our findings from both perspectives, instantiated as meta-inferences, provides an opportunity for the IS discipline to capture the nature of SUA along the digital innovation process.

2 Theoretical Background

2.1 Smart Urban Agriculture

SUA has links to two research streams: 1) urban agriculture and 2) smart farming. First, urban agriculture refers to the food production, processing, and marketing in urban ecosystems (Smit et al. 2001; De Bon et al. 2010). It can range from private gardens for self-consumption to sophisticated concepts such as commercially oriented, high-tech indoor farms, mostly producing vegetables, fish, and meat (Wood et al. 2020). As free space for traditional ground-based agricultural practices is scarce in most cities, some of these systems are aligned with growing food on housing facades, rooftops, or indoor greenhouses (Specht et al. 2016; Dorr et al. 2021). Second, smart farming refers to using digital technologies to optimize agricultural production in terms of efficiency, quality, and sustainability (Köksal and Tekinerdogan 2019; Balafoutis et al. 2017). Key technologies implemented include cloud computing, the Internet of Things, or robotics (El Bilali and Allahyari 2018). Robotics, for example, can control tractors, perform planting and mechanical weeding, sort and harvest fruits, or feed animals automatically (Nair et al. 2021).

In synthesizing the understanding of urban agriculture and the description of smart farming, we define SUA as the use of modern digital technologies to optimize food production in urban ecosystems in terms of efficiency, quality, and sustainability. SUA is promising for tackling the challenges of urban agriculture, by, for example, providing tools to automatically control environmental parameters (e.g., temperature, humidity) of cities (Goldstein et al. 2016; O'Sullivan et al. 2019). In addition, SUA enables the creation of entirely new concepts, such as closed-fielded vertical farming (Maye 2019).

2.2 Digital Innovations in Smart Urban Agriculture

To leverage SUA's sustainability potential, it is necessary to detect, implement, and scale associated innovations. While SUA research has not yet conceptualized these necessary phases, digital innovation research has already done so. SUA qualifies as digital innovations, as it uses digital technologies to transform market offerings or business processes in the urban agriculture realm. To conceptualize digital innovation, Kohli and Melville (2019) propose a model with four key innovation phases organizations undergo when creating new digital innovations: *initiation, development, implementation*, and *exploitation.* While the *initiation* phase describes opportunity detection, the *development* phase includes creating, customizing, and adopting respective innovations. In the subsequent phases, *implementation* incorporates the deployment and maintenance of the innovation, and lastly, the *exploitation* phase focuses on the ongoing value creation of existing solutions (Kohli and Melville 2019).

The key phases above are meant to apply to all digital innovations (Kohli and Melville 2019), including SUA. However, context is a critical factor in the exact execution of these phases, impacting innovation success (Kohli and Melville 2019; Nambisan et al. 2017). Therein, a deep understanding of the respective context (in our case: SUA) and its influence on the digital innovation process is indispensable for leveraging SUA's value.

2.3 A Taxonomy for Smart Urban Agriculture

During the four phases, high levels of knowledge regarding the specific contexts' possibilities for applying digital technologies are required (Kohli and Melville 2019). As application knowledge is highly context-specific, a closer analysis of SUA use cases is essential to drive SUA innovation. Understanding the different dimensions on which SUA can differ is needed to master opportunity detection and development. To address this need, developing a taxonomy pinpointing dimensions of SUA deems a promising approach (Nickerson et al. 2013).

In SUA, digital technologies, referring to the combination of information, computing, communication, and connectivity technologies, including the related hard- and software, are at the core (Bharadwaj et al. 2013). Understanding SUA applications thus requires three components: 1) the digital technology (hard- and software) itself (Bharadwaj et al. 2013), 2) the data these technologies work with to generate meaningful insights (Zhang et al. 2019), and lastly 3), the specification of the context, namely the selected SUA approach in which the digital solution is applied (Hong et al. 2014). In line with our understanding of BISE research covering the interaction between information technology, information, and people, the three presented components are suitable building blocks in the taxonomy and serve as a structuring tool for the different dimensions (Lee 2010). Table 1 summarizes the building blocks.

2.4 Organizational Readiness for SUA

Many innovation endeavors fail during the implementation and exploitation phases, for reasons such as financial challenges or difficulties with scaling (Roundy 2017; Battistella et al. 2021; Deserti and Rizzo 2020). Addressing this challenge, the concept of organizational readiness factors as necessary prerequisites to successfully implement and exploit the potential of an opportunity is emerging (Lokuge et al. 2019; Molla and Licker 2005). In the context of SUA, the underlying "organization" can range from large-scale professional firms, community-based public endeavors up until private household projects (Wood et al. 2020). As the readiness to innovate with digital technologies is associated with seizing business opportunities (Walczuch et al. 2007), Lokuge et al. (2019) propose an organizational readiness model for digital innovation in general. The model identified seven possible areas of organizational readiness for digital innovation (namely resource readiness, IT readiness, cognitive readiness, partnership readiness, innovation valance, cultural readiness, and strategic readiness). However, as readiness often includes psychological and structural factors, such as the commitment and capability to change, readiness models must be tailored to account for the attributes of the specific technology or context (Molla and Licker 2005).

3 Study Design

In analyzing the contextual implications of SUA on the general digital innovation process, we apply taxonomy research (perspective 1) and the development of organizational readiness (perspective 2). Inspired by meta-inferences in mixed-methods research (Venkatesh et al. 2016a), we derived an integrative view of both perspectives, which provides a fuller picture of the phenomenon under investigation and links both perspectives. The meta-inferences were developed in an inductive process of combining insights from all combinations of SUA's taxonomy dimensions and SUA's readiness categories to form broader generalizations. Thereby, we aimed at identifying causal mechanisms between both perspectives (Venkatesh et al. 2016a).

Starting with perspective 1, we built the taxonomy following Kundisch et al. (2022) who align with but extend Nickerson et al. (2013) (see Appendix A (online) for an overview of the taxonomy design's phases. The online-appendices are available via http://link.springer.com). After specifying the taxonomy's purpose in the *Introduction* and *Theoretical Background* sections of this study (*Phase 1: Identify the problem and motivate*), we proceeded to define the taxonomy's meta-characteristics,

Table 1 Building blocks of smart urban agriculture

Building Block	Description	Source
Digital technology	All soft- and hardware of the solution and its combination of information, computing, communication, and connectivity technologies	(Bharadwaj et al. 2013)
Data	Types, handling, and interaction of and with data	(Püschel et al. 2020)
Approach	The type of urban agriculture applied both with respect to end products and growing and harvesting methods	(Li et al. 2020)

ending conditions, and evaluation goal (*Phase 2: Define objectives of a solution).*

Meta-characteristic and ending conditions: Following Nickerson et al. (2013) advice, we defined the meta-characteristic of our taxonomy as *Characteristics of digital technologies in urban agriculture*. To iteratively evaluate whether our taxonomy had reached quality saturation, we chose a set of objective 'ending conditions' (Nickerson et al. 2013): a) no new dimensions or characteristics were added in the last iteration, b) no dimensions or characteristics were merged or split in the last iteration, and c) every dimension is unique and not repeated, d) at least one object is classified under every characteristic of every dimension. In addition, we applied the subjective ending conditions proposed by Nickerson et al. (2013), which require a taxonomy to be *concise*, *robust*, *comprehensive*, *extendible*, and *explanatory*. Overall, we conducted six iterations (*Phase 3: Design and Development)*. Iterations 1, 2, and 3 followed a conceptual-to-empirical approach (deductive reasoning), and iterations 4, 5, and 6 took an empirical-to-conceptual approach (inductive reasoning) (Kundisch et al. 2022). Table 2 details the six iterations.

Iterations 1, 2, and 3 (conceptual-to-empirical): During iteration 1, we conducted a systematic literature review (Boell and Cecez-Kecmanovic 2015) of English-language research papers with the database Web of Science covering broad terminology in the SUA realm. Appendix B (online) summarizes the search protocol. For title, abstract, and full-text screening, we specified the following inclusion criteria: Papers addressing (1) urban contexts, (2) digital technologies, and (3) the production phase of agriculture. Two authors screened each of the resulting papers and extensively discussed their inclusion. After both screening iterations, 53 were considered. Additional studies were identified in the second iteration via a search of the AIS eLibrary, yielding eight more studies. The full list of 61 studies can be found in Appendix C online. We drew on Wolfswinkel et al. (2013) approach to qualitative data analysis and coded all studies (see exemplary coding scheme in Appendix D online). Specifically, during open coding, we first highlighted information on SUA

Table 2 Iterations of taxonomy development and evaluation

#	Approach*	Basis	# of Changes in last iteration	Taxonomy
1	c-e	WoS literature	8 dimensions, 27 characteristics	8 dimensions, 27 characteristics
2	c-e	AIS eLibrary literature	4 dimensions, 15 characteristics	11 dimensions, 36 characteristics
3	c-e	Interviews with 9 researchers	2 dimensions, 4 characteristics	10 dimensions, 33 characteristics
4	e-c	10 real-life examples	1 dimension, 9 characteristics	9 dimensions, 25 characteristics
5	e-c	32 real-life examples	No changes	9 dimensions, 25 characteristics
6	e-c	Interviews with 16 practitioners	Renaming of 1 dimension	9 dimensions, 25 characteristics

**c-e* conceptual-to-empirical; *e-c* empirical-to-conceptual technologies' characteristics. For axial coding, we then grouped the characteristics into dimensions. Afterward, we assigned the dimensions to the three building blocks *digital technology*, *data*, and *urban agriculture approach*. For selective coding, we reduced and refined the characteristics in each dimension. Iteration 3 was based on interviews with nine scholars (see Appendix E online), whose feedback we used to refine the dimensions and characteristics. More information on the expert interviews, sampling strategies, and coding procedure is presented at the end of this section. To assess the real-life fit of the taxonomy, we created a set of ten SUA technologies (Appendix F online). Five of these digital technologies were identified from the literature, and the other five from real-life industry products. We built the sample based on three criteria: 1) technical aspects of digital technology described in detail, 2) advanced stage of development, 3) diverse types of urban agriculture (e.g., aquaponics, greenhouses). In each of the iterations, we classified the ten technologies using our taxonomy (Oberländer et al. 2019; Nickerson et al. 2013).

Iterations 4, 5, and 6 (empirical-to-conceptual): We compared real-life examples of SUA and identified similarities and differences (Nickerson et al. 2013). Iteration 4 leveraged the set of ten technologies which we extensively discussed and compared in light of our taxonomy. For iteration 5, we composed a more detailed list of 32 SUA technologies as an information source through a structured web search and classified these technologies using the taxonomy (Appendix G and H online). Following Amalia et al. (2020), we conducted our web search as a two-phased approach: 1) Website identification and 2) content analysis. For website identification, we searched the internet with keywords related to "smart urban agriculture," "smart urban farming," and the individual SUA approaches (e.g., "vertical farming" or "hydroponics"). For the content analysis, we analyzed respective websites concerning the taxonomy's dimensions and characteristics by screening for any information indicating an assignment to the characteristics of the taxonomy. This final classification also served as a tool to objective ending conditions c) and d) (*Phase 4: Demonstration)*. In iteration 6, we evaluated the taxonomy (*Phase 5: Evaluation)* with 16 semi-structured interviews with practitioners to assess the attainment of the subjective ending conditions (see Appendix I online for the interview guideline protocol). We ensured the highest ethical standards by having our research approved by the University of Hohenheim Ethics Committee. We recruited our initial participants via personal networks and continued via snowball sampling. We stopped data collection after a total of 25 interviews as no significant new topics were brought up. Individual interviews lasted between 11 and 57 min (12.6 h in aggregate). The interviewees resided in several countries, including Austria, Germany, Israel, and the Netherlands. We recorded and transcribed each interview.

We coded the interview data with reference to Wolfswinkel et al. (2013), applying a pattern-inducing technique by gathering qualitative data and clustering text segments into concepts. We compared new categories as they emerged and discussed their connection. While going back and forth between data and descriptive codes, we systematically distilled readiness factors of SUA. The coding process was divided into three stages: open coding, axial coding, and selective coding (Wolfswinkel et al. 2013; Corbin and Strauss 1990). An exemplary coding scheme outlining the coding process is part of Appendix J online. Due to the explorative nature of our research, one author started by thoroughly reading the interview transcripts and highlighting important text passages. This way, text passages on factors that could contribute to or prevent SUA organizations from using digital technologies were highlighted. During this *open coding*, we relied on informant terms close to the original interview data. For *axial coding*, we used a workshop to paraphrase and group the identified text passages, searching for similarities and differences among the codes (Corbin and Strauss 1990). If agreements about certain codes were low, we revisited the transcripts, engaged in discussions, and developed mutual understanding and consensual decision rules. For *selective coding* the grouping was redefined, and categories of SUA readiness were built. By integrating existing literature (Lokuge et al. (2019) digital readiness categories of *Resource Readiness, Cultural Readiness, Strategic Readiness, Innovation Valence, Cognitive Readiness,* and *Partnership Readiness),* we evaluated our data asking whether the emerging categories help us to describe and explain the phenomena we were observing. Although presented linearly above, our analysis was dynamic and iterative. We continued coding new data and refining our findings until we reached theoretical saturation, where additional interviews did not yield any change in the readiness factors.

4 Results of Perspective 1: Taxonomy Development and Evaluation

We build on literature, real-life examples, and interviews throughout the six iterations to derive our taxonomy, as shown in Fig. 1. As outlined in the *Theoretical Background*, we use the tailored building blocks of *Digital technology*, *Data*, and *Approach* to structure SUA and cluster dimensions and characteristics in the three blocks (Püschel et al. 2020; Bharadwaj et al. 2013).

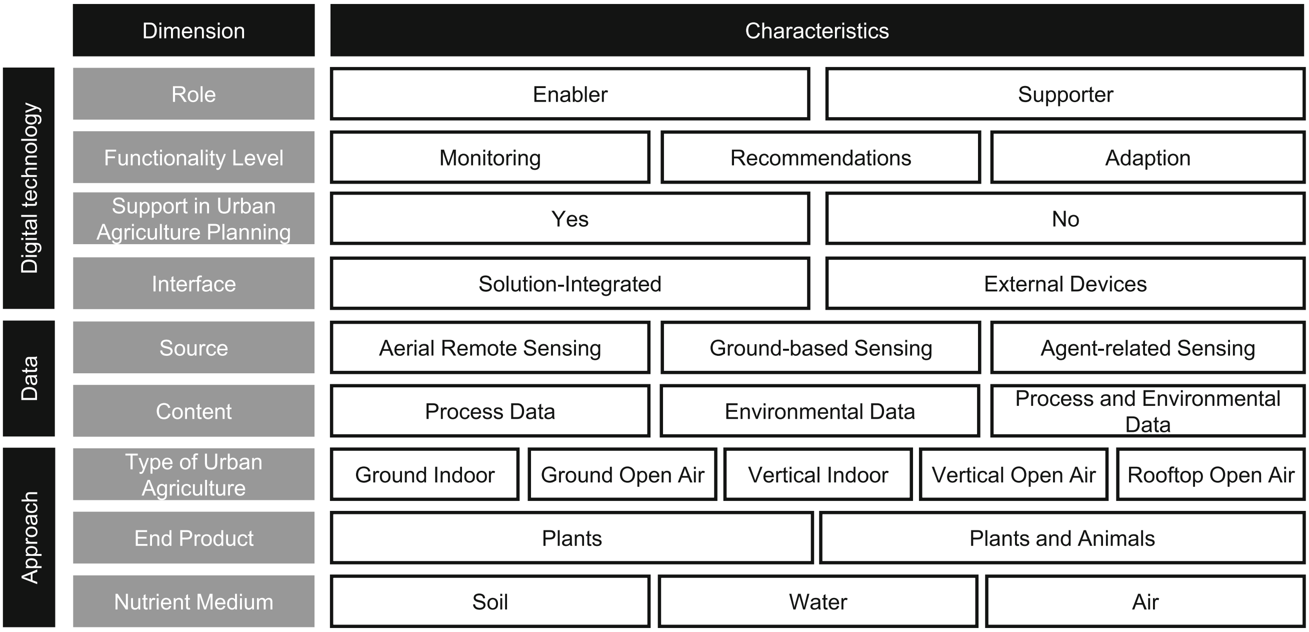

Fig. 1 Taxonomy of smart urban agriculture technologies

Digital Technology: The first four dimensions relate to aspects of digital technology applied in the context of urban agriculture. Firstly, the *Role of Technology* indicates whether digital technology is a *Supporter* or an *Enabler* of the urban agriculture solution (Benbasat and Zmud 2003; Hanelt et al. 2017). Supporters are digital technologies that improve existing solutions, for example, by reducing water resources required in a rooftop garden (Harada et al. 2018). By contrast, enablers are central components of urban agriculture solutions and are required for the solution to work at all. Examples include all types of highly automized robotic vertical farms, where operations would completely still stand if the underlying digital technologies (such as robotics algorithms) stopped working.

Secondly, the dimension *Functionality Level* indicates the highest functionality level sorted from least to most advanced functionality. Therein, the higher functionality levels such as adaptation also include the lower levels such as monitoring. The characteristic *Monitoring* describes all activities (such as data collection and analyses) related to measuring and tracking parameters during operation without actively changing them (e.g., nutrient levels, sunlight) (Félix et al. 2018). The characteristic *Recommendations* goes one step further and involve actively recommending specific alternatives (e.g., adding more water) (Galdon et al. 2021). *Adaptation* either refers to a) environmental adaptation by actively controlling and changing environmental parameters such as light, irrigation, and nutrients (e.g., by modifying the light intensity) (Gravalos et al. 2019), or b) production adaption by performing actions directly on the product, such as smart harvesting or weed management (Ampatzidis et al. 2017; Farhangi et al. 2020; Ofori and El-Gayar 2021). Those characteristics give insights into the smartness of SUA technologies. According to Alter (2020), the smartness of SUA technology depends on the technology's ability to use automated capabilities and physical, informational, technical, and intellectual resources to process, interpret and/or learn from information. Thus, the smartness of technologies classified in *Monitoring* is comparably lower than those in *Recommendations* which, in turn, has a lower level of smartness than *Adaption.*

Thirdly, *Support in Urban Agriculture Planning* involves using digital technology to find suitable spaces for urban agriculture or simulate different urban agriculture set-ups (Khan and Ahmed 2017; Ghandar et al. 2021). SUA technologies either support this planning process (i.e., *YES* characteristic) or do not (i.e., *No* characteristic). Lastly, the dimension *Interface* describes where humans and machines interact. An interface can be either directly integrated with the digital technology itself (S*olution-integrated),* through, for example, displays on the technology, or through *External Devices* such as wearables (Niemöller et al. 2019).

Data: The next two dimensions refer to the data collected, analyzed, and acted upon. This building block includes data collected directly by the operator or externals (e.g., weather data). Firstly, the *Source* refers to the location of data collection (Püschel et al. 2020). *Aerial Remote Sensing* describes data collected from drones and satellites in the air, for example, aerial images (Egerer et al. 2020).

Ground-based Sensing refers to all ground-based data sources collecting and acting upon information such as temperature, humidity, or nutrient levels (Surantha and Surantha 2020). Lastly, *Agent-related Sensing* refers to data collected directly at and by human agents (e.g., farmers, technicians) within the SUA solution, such as activities and movements tracked by smart watches, mobile phones, or smart glasses (Niemöller et al. 2019).

Secondly, *Content* specifies what data are collected and used by the digital technology and differentiates between *Process Data*, *Environmental Data*, and their combination (*Process and Environmental Data*). Process data includes data on a machine's operations (e.g., irrigation performed, robotic movements), refers to data on the actual product (e.g., growth level or health status information Ofori and El-Gayar 2021), or includes interactional data that involves communication between humans and machines, such as human-generated input to the system (Nadal et al. 2017). Conversely, *Environmental Data* comprises information on the surrounding environment (e.g., CO_2 levels, topography) (Nadal et al. 2017). SUA endeavors operating on comprehensive data types include *Process and Environmental Data*.

Approach: The third set of dimensions relates to the underlying urban agriculture approach. Each urban agriculture solution can be classified according to its basic *Type*. Urban agriculture solutions are either classified as *Ground Indoor* (e.g., greenhouses, hydroponic systems), *Ground Open Air* (e.g., community gardens), *Vertical Indoor* (e.g., indoor vertical farms), *Vertical Open Air* (e.g., productive façades), or *Rooftop Open Air* (e.g., rooftop gardens) (Dorr et al. 2021). *End Product* comprises the agricultural products produced in the urban agriculture solution. Urban agriculture solutions can contribute to food security by producing *Plants* (e.g., vegetables) or *Animal and Plant* products (e.g., aquaponics combining plant cultivation in a hydroponic system and fish farming in an aquaculture system) (Padilla et al. 2018; Wood et al. 2020). The dimension *Nutrient Medium* indicates the nutrient medium used to produce the end product (Padilla et al. 2018). Growth environments include *Soil*, as in traditional agriculture or greenhouses, and *Water* or *Air*, as in hydroponic or aeroponic systems (Padilla et al. 2018).

As detailed before, we classified 32 SUA technologies using the final taxonomy to first evaluate if all real-life examples are classifiable through our taxonomy, and second to test if every characteristic is addressable through at least one real-life example (objective ending conditions). Appendix H (online) lists the 32 technologies selected and their assignment to the different characteristics. Figure 2 shows the classification of these 32 technologies within the taxonomy. The number below the characteristics indicates how many SUA technologies were assigned to the characteristics. The classification proves that a) all objects could be classified within the dimensions and characteristics, and b) all characteristics were relevant to at least one SUA technology.

5 Results of Perspective 2: Readiness Factors in Smart Urban Agriculture

After conceptualizing the phenomenon of SUA as a taxonomy, interviews with 16 SUA practitioners on requirements and prerequisites needed for leveraging SUA laid the ground for the derivation of 5 SUA readiness categories that gather 20 SUA readiness factors. As stated in the section *Study Design*, we referred to Lokuge et al. (2019) proposed categories of digital readiness to gather emerging SUA readiness into categories. Table 3 presents our main findings: As shown in column one, most of Lokuge et al. (2019) readiness categories, namely, *resource readiness, cultural readiness, strategic readiness,* and *partnership readiness* were also relevant for SUA readiness. Further, our data revealed a new readiness category, namely *regulatory readiness*. Column three represents detailed descriptions of each of the 20 readiness factors named in column two. For *resource readiness,* the readiness factors *IT infrastructure, IT expertise,* and *finances* are in line with (Lokuge et al. 2019), whereas *integration,* and *sustainability* turned out to be specifically relevant for SUA readiness. With *cultural readiness*, the existing factors *knowledge sharing, trial-and-error mentality, appreciation,* and *fun factor* are complemented by *culture of change* and *transdisciplinary mindset*. Moving on to *strategic readiness*, only *stakeholder awareness* is found to be relevant for SUA readiness, expanded by *scale* and *scale-up pace*. *Partnership readiness* complements the existing factor *personal network* with *high-tech supply availability, ecosystem integration,* and *training opportunities*. *Regulatory readiness* categories the newly found SUA readiness factors of *adherence* and *laws.* Finally, column four provides an exemplary quote from the interviews for transparency.

6 Discussion

There is substantial evidence that digital technologies are promising for mastering urban agriculture, e.g., by automizing tedious manual labor or reducing resource consumption during production (Langendahl 2021). However, in practice, their potential is not yet leveraged. The fundamental challenge is that many of the emerging SUA endeavors fail economically – may it be due to high

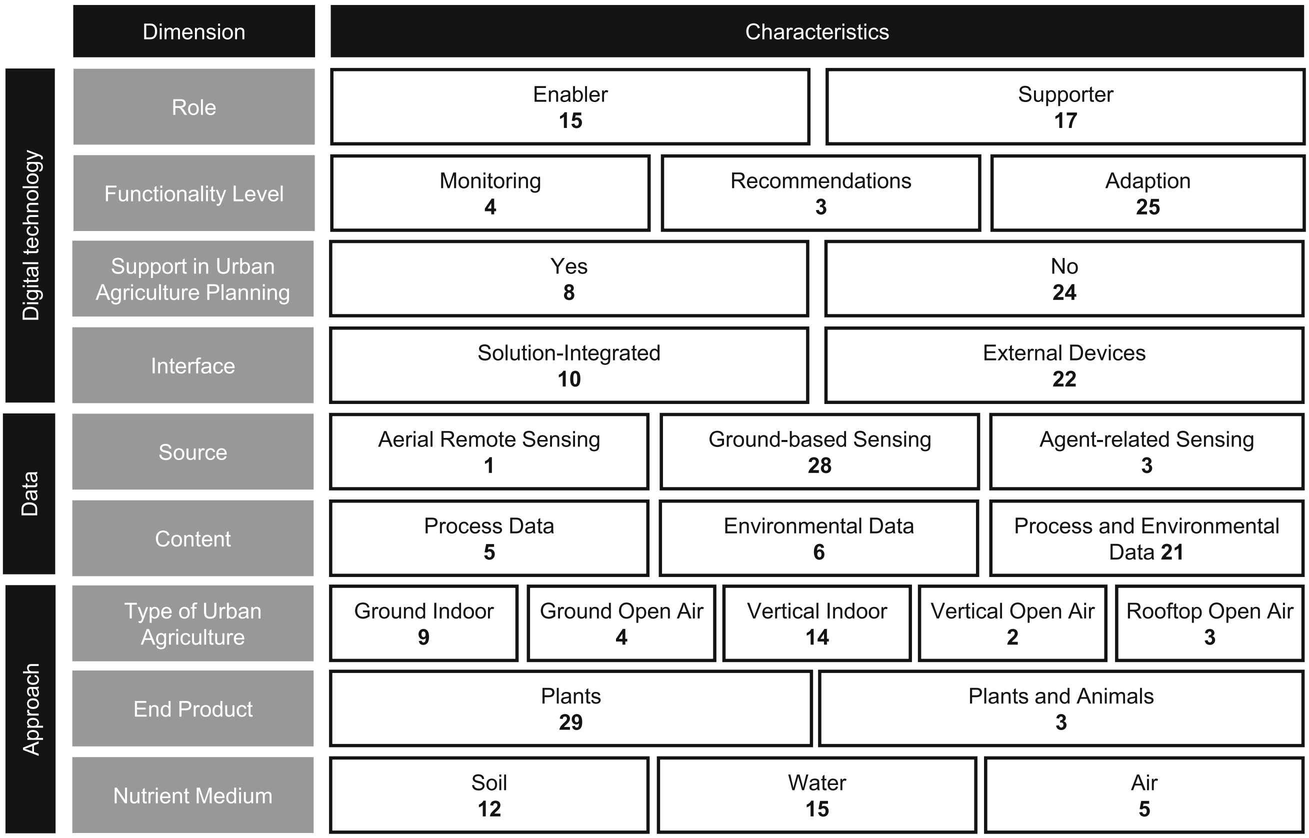

Fig. 2 Technology classification using the taxonomy of smart urban agriculture

investment costs, lacking skills and talent in workforces, a wrong selection of technologies during implementation, or the inability to materialize the expected financial, ecological, and social benefits in the long run (Langendahl 2021; Yigitcanlar et al. 2022). In respect to solving this challenge, our contribution is twofold.

First, we contribute a taxonomy that enables both research and practice to better understand what application possibilities "digital technologies in urban agriculture" comprise, and what differences exist between various types of SUA. Therein, we make use of the value of taxonomies which research in the BISE community describes as 1) building the basis for conceptualizing a new phenomenon (i.e., SUA) and 2), a necessary step towards reducing research and practice's overload caused by the multitude of different SUA technologies available (Kundisch et al. 2022). We build on urgent calls from digital transformation literature regarding the importance of enabling a conscious, well-informed adoption of digital technologies in order to reduce project failure (Hess et al. 2016; Riera and Iijima 2019).

Second, discussing our results against the broader context of smart city and IT-enabled green city literature, we interpret our findings as an extension to existing studies in the field. On a general level, existing research recognizes the need for digital technologies in cities for a sustainable transformation (Dewi et al. 2018; Maye 2019). However, the main focus currently mainly lies on use cases related to democratizing governance, healthcare, sustainable housing, mobility, or education (Yigitcanlar et al. 2022; Kinelski et al. 2022). Acknowledging the importance of these areas, we argue for a stronger integration of smart urban farming within the smart city and IT-enabled green city literature streams, given the demonstrated potential of SUA. Complementing previous studies on related fields such as smart city readiness (Yigitcanlar et al. 2022; Dewi et al. 2018), the readiness factors in these studies directly address the challenge of financially failing SUA initiatives by providing a list of factors to consider during project launch.

However, the contribution of both the taxonomy and the readiness factors is not isolated, which is why we provide an integrative view of the findings from both perspectives, called "meta-inferences". They are summarized in Table 4. The presented 15 meta-inferences allow the disclosure of interrelations and boundary conditions of SUA's taxonomy dimensions and readiness categories.

The complementary perspectives on SUA reveal relevant findings on the intersection of taxonomic research and readiness research, as presented by the meta-inferences. In addition, in order to explain how the two perspectives

Table 3 Readiness factors in smart urban agriculture

Readiness category	SUA readiness factor	Description	Exemplary quote from interviews (ID of Practitioner)
Resource readiness	IT infrastructure	The organization must provide IT infrastructure (hardware, software, connectivity) to quickly leverage new technological opportunities the market provides (e.g., robotics, AI) as a response to evolving automation requirements in urban agriculture	*I recently talked to our software manager about how far along we are with implementing adaptive AI systems. He just laughed at me and said we first have to build an AI system to then complement it with an adaptive system later. We are really at the beginning of this technology.* (ID16)
	IT expertise	The workforce must bring along a set of IT skills, such as machine learning and other data-science skills, to meet the requirements of high-tech SUA	*[We are talking about] a new type of farmer with a high affinity for IT. That point is very important for future planning to make sure that farmers of the future bring skills and that type of knowledge with them.* (ID10)
	Integration	The market is required to offer standardized interfaces for high levels of integration but should also offer options for individualization and tailoring to meet the needs of urban agriculture organizations	*The plan is to fully automate the regulations. That can only be realized effectively in close collaboration with our partners because they do not just sell a "product x," but a highly individualized one.* (ID12)
	Finances	Budgets must cover high initial investments and operating costs while balancing cost and expected benefits with acquiring the right set of digital technologies	*We still don't have the data to make the right choices and determine how we can reduce the costs for these kinds of technologies because the technologies are very expensive today.* (ID10)
	Sustainability	Substantial material resource investment must be balanced against expected technological benefits to support the sustainability goals of smart cities	*I always question the [material] resource input. The robotic components must come from somewhere that indicates production effort. What happens to the IT afterward? If I just harvest a tomato by hand, that requires fewer resources.* (ID17)
Cultural readiness	Knowledge sharing	Openness to share knowledge and best practices of digital technology use are required to drive technological advancements in the entire market	*You find out through partners where you can buy such an irrigation system and then build on the experiences of your neighbors.* (ID17)
	Trial-and-error mentality	A trial-and-error mentality is required to face the challenges of an immature market with little experience in best practices	*In this area, there is very little experience, which is why s/he has to try everything by herself/himself to make things work.* (ID16)
	Culture of change	A culture of change is required to leverage the opportunities of a fast-paced industry	*I also think sometimes we approach the topic from a traditional standpoint. That is the problem we have. I am very open to new and different approaches, and I believe other people have to share that.* (ID13)
	Transdisciplinary mindset	The corporate culture must unite perspectives from agriculture and IT to foster a transdisciplinary mindset, leveraging knowledge from both sides	*We are not farmers, but we are all from a technological area. […] We, in contrast, do not have the experience and the intuition to see [the needs of plants] ourselves.* (ID12)
	Appreciation	The workforce must understand the benefits of using digital technologies to continuously drive adoption and further developments	*People need to understand how to use it. It's more high-tech than the traditional way of growing plants. People need to understand the values of these technologies and how to use them.* (ID10)
	Fun factor	The adoption of digital technologies is motivated by the perception that using them is a fun activity	*It is easier for us [to use digital technologies] because we both work and are not always present with the farm animals. We do that as a hobby because it is fun. […] We mainly use technologies because my husband enjoys them and has a high technology affinity.* (ID18)

Table 3 continued

Readiness category	SUA readiness factor	Description	Exemplary quote from interviews (ID of Practitioner)
Strategic readiness	Stakeholder awareness	The entire ecosystem must be aware of the financial and sustainability-related benefits of SUA to foster trust and willingness to invest	*This industry is really at the beginning of a long journey. It'll take a long time until we will have come up with economic benefits for those who will invest […]. Currently, people are not happy to jump over to invest. They prefer to invest in other stuff.* (ID10)
	Scale-up pace	Significant potential to rapidly scale up is required to leverage digital technologies once more stakeholders recognize the market's importance and more data becomes available	*[It's] a fast, fast-evolving topic, which many firms are currently jumping onto.* (ID11) *Partially, just not enough data is collected. […] If it's going well, things are documented in an Excel sheet. Automatic data collection and the integration of analysis are rare, but this will increase.* (ID19)
	Scale	The necessary investment in, and potential impact of, the digital technology should be appropriate to the scale of the organization – particularly in the case of highly automated, high-tech systems – to fully leverage and drive profitability	*We have three sizes [of products. …] The machine support and smart systems are more in the largest size. […] In a large farm, everything has to be optimized because the forklifts drive around, and it is very highly automized.* (ID16)
Partnership readiness	High-tech supply availability	High-tech components that cannot be produced internally must be reliably available to uphold the operation of urban agriculture	*So, in such cases, they are dependent on other external partners. It would be difficult to develop or operate the systems themselves. That's why they cooperate with tech companies*. (ID11)
	Personal network	Organizations must build strong networks of personal contacts to find the right suppliers of IT and components in a niche market	*[The founder] has a large network with contacts for, for example, IT solutions from SAP, where he knows it is working well. [..] We use personal contacts as much as possible because it is working well for us.* (ID12)
	Ecosystem integration	Urban agriculture ecosystems must be closely connected to integrate perspectives from all actors (investors, farmers, communities) and not miss out on important knowledge	*We are now seeing investors – bankers, machine engineers, different types of people – turning to smart urban agriculture. But the normal farmer who produces our food is left out. I, thus, see our responsibility to connect everyone.* (ID13)
	Training opportunities	Organizations looking to enable the operation of urban agriculture solutions in their ecosystem must ensure knowledge building and training in their external network	*In total, there are multiple stakeholders that have to be introduced to the technologies in different locations.* (ID11)
Regulatory readiness	Adherence	Organizations must continually adapt to new regulations in the evolving market	*Data security makes it more complex and difficult to bring out a legally compliant product.* (ID15)
	Laws	To enable benefits for smart cities, policymakers must adapt existing regulations – established with reference to traditional farming – to the new requirements of urban agriculture	*Yes, still, in many countries, no developed policy makes it hard for farmers to grow this method. […] for example, in Israel, we don't have anything related to it, so you actually cannot build factories like that in Israel today unless you have a special agreement with the government to do it. […] For example, if a farmer grows lettuce, all of the regulation that gives him water subsidies are for the size of his land and for this specific plant. Let's say that someone builds a factory that grows lettuce. The law just counts how many square meters the factory is; even though the factory grows 400 times more crops per square meter, he will still get 1/400 of subsidies of water for this use. The laws are not really in line with the subsidies we should have for farmers.* (ID10)

Table 4 Development of integrative meta-inferences

Inference from readiness categories	inference from taxonomy development	Meta-inference	Exemplary links to existing IS research streams
Resource readiness	Digital technology	With the technological *functionality* of SUA reaching up to fully autonomous systems, the resource readiness factors of *IT expertise* and *IT infrastructure* become the backbone of SUA endeavors. While the resource readiness factors *finances* and s*ustainability* remain relatively stable across rising digital functionality levels, the importance of IT expertise and infrastructure readiness increases with technological maturity	IT capabilities research (e.g., Chen et al. 2015; Nwankpa and Datta 2017) Maturity model research (e.g., Stoiber et al. 2023) Data management research (e.g., Zhang et al. 2019)
Resource readiness	Data	With SUA's data *content* ranging from environmental parameters to the process interaction of individual SUA components, resource requirements include not only the acknowledgment of data as a valuable resource. Rather, SUA organizations must also build transdisciplinary data handling skills to understand technical and domain-specific data analysis activities	
Resource readiness	Approach	The *types* of SUA range from those similar to traditional rural farming (e.g., ground open air) to highly innovative forms (e.g., vertical indoor), each requiring a different level of technological resources. Given an organization with very low readiness level in respect to, for example, *IT expertise*, they should rather choose *supporter* classified SUA than *enabler*	
Cultural readiness	Digital technology	Successful SUA endeavors require a culture supporting digital change. Given that SUA is drastically different from traditional rural farming, organizations need to build a culture that trusts the functionality of digital technologies and appreciates its benefits. How strongly the respective culture should be digitally focused depends on digital technologies' role as *supporters* or *enablers*	Digital change management research (e.g., Salmimaa et al. 2018) Technology acceptance research (e.g., Venkatesh et al. 2016b)
Cultural readiness	Data	As new data sources emerge that must first be meaningfully combined and analyzed, a culture of learning is required. Given that employees can even act as the data *source* in agent-related sensing, a higher awareness for the value of data and its generation needs to be achieved	
Cultural readiness	Approach	It is not enough to build a generally tech-savvy culture because an important part of cultural readiness is to understand the benefits of digitalization in the respective work context. The *type* of SUA implicates the different possibilities of digital technologies and culture-building activities must refer to its specific value for each type	
Strategic readiness	Digital technology	SUA and its two *roles* bring out digital technologies' dual nature. Digital technologies serve as 1) a facilitator of new value propositions as an integral part of the end product and 2) a lever for scaling existing solutions more efficiently through technological characteristics such as convergence and generativity	Digital social innovation research (e.g., Qureshi et al. 2021) Twin transformation research (e.g.,Graf-Drasch et al. 2023) Data-oriented perspective for addressing sustainability issues (e.g., Melville et al. 2017; Zampou et al. 2022)
Strategic readiness	Data	As SUA approaches are in their infancy, strategies must build on available data (e.g., machine and interaction data) and be designed to adapt quickly to new data and sources. Therein, data plays a leading role in developing profitable business models and can determine the success of SUA	
Strategic readiness	Approach	An urban agriculture organization must choose wisely which *type, end product* and *nutrient medium* to implement as those parameters have implications on the *scale*, *scale-up pace* and *stakeholder's acceptance*. For example, *plants* cultivated vertically in *air* or *water* are easier to scale-up efficiently in cities but require a lot of persuasion beforehand for stakeholders to trust those new endeavors	

Table 4 continued

Inference from readiness categories	inference from taxonomy development	Meta-inference	Exemplary links to existing IS research streams
Partnership readiness	Digital technology	Many SUA solutions are complex and highly automated systems, representing niche products due to the nascent market. This is a particular challenge in cases where SUA technologies take the role of *enabler* and are crucial for keeping the urban agriculture organization going. SUA stakeholders depend on a solid network and strong partners to jointly develop individual solutions. However, there are no standard solutions available on the market	Green IS/IT research (e.g., Gholami et al. 2016; Malhotra et al. 2013; Watson et al. 2010) Digital ecosystems research (e.g., Adner 2017; Hannah and Eisenhardt 2018) Data sharing research (e.g., Melville et al. 2017; Zampou et al. 2022)
Partnership readiness	Data	The different *sources* of data can most likely not all be provided by a SUA organization itself. Especially in the case of air-based data, there is a high dependency on growing not only one's own SUA organization but also simultaneously the competitive market providing relevant air-based data points for operation	
Partnership readiness	Approach	Partnerships in SUA are diverse and can range from traditional farming companies providing crops to high-tech software firms. As a result, depending on the *type* and *end product,* SUA organizations must learn to build networks that deal with and leverage the diversity of required connections	
Regulatory readiness	Digital technology	Integrating various digital technologies differing in functionality or design (such as *interfaces*) also poses new regulatory concerns. Depending on the technologies selected, topics such as the ethical use of AI or prevention of digital stress/technostress and work accidents with robotics emerge as new tasks for SUA endeavors	AI research on ethical decision-making and responsibilities (e.g., Mikalef et al. 2022) Data privacy and protection research (e.g., Cichy et al. 2021) ntersection of IS and policy (e.g., Watson et al. 2022)
Regulatory readiness	Data	New regulations are required, with the emergence of new data giving rise to increased transparency and traceability related to food security and the climate status of cities. Simultaneously, existing regulatory requirements on data protection and security must be fulfilled, which is especially relevant in the case of employees as *data sources*	
Regulatory readiness	Approach	The regulatory framework of SUA is still evolving. When integrating SUA approaches into cities, there may be a mismatch between suitable business models and rigid policy regulations. For example, while a vertical farm or the integration of animals might be the best solution for an organization to provide food security in a city, regulations might not support this *type* and *end product* of urban agriculture	

nform each other on a practical level, we illustrate two use cases below: Considering two examples of SUA at the extremes of the different solutions' spectrum, we take a) a high-tech industrial vertical farm, and b) a miniature greenhouse for private balconies as the baseline. Looking at the taxonomy, use case a) would be classified as an enabler, with digital technologies being the backbone of the solution, technological functionality reaching to autonomous adaption, external interfaces being available at multiple touchpoints, process and environmental data being integrated, and different nutrient mediums used, depending on the specific end product. Use case b), in contrast, includes some smaller technological components as a supporter to give recommendations on when to water the plants, integrates a few data points on soil moisture, and a small solution-integrated display.

In terms of the relevance of different readiness factors depending on the taxonomic classification, our results summarize to several interpretations. While *resource readiness* is generally highly relevant to both use cases a) and b), the factors concerning *IT expertise* and *IT infrastructure* are more relevant to a) high-tech *enabler* industrial vertical farms than b) small private *supporter* SUA, as private consumer solutions are often stand-alone and intuitive to use. For *cultural readiness*, themes regarding openness to change are critical for use case a), where the respective SUA solution is often not selected by the employees but by management. In contrast, in use case b), the *fun factor* is predominant as motivation to decide on a SUA by oneself and to continue using it after its implementation, as no monetary incentives such as salaries are present. Lastly, regarding *regulatory readiness*, the requirements also strongly differ, depending on the selected *approach* and type of urban agriculture. For use case a), existing policies and their *adherence* are critical but simultaneously highly complex, given the many different regulatory concerns on food safety, employee rights, subsidy opportunities, or trade permits. A lack of adherence to such regulations bears the risk of both legal and reputational damage. For use case b) and private ground indoor approaches, few regulations on balcony usage might also exist. However, private endeavors are mostly free to choose what to do with their own living space, making this readiness category less critical.

Summarizing this study's findings, the readiness factors differ in relevance depending on the selected use case. Major differences emerge regarding the type of organization (e.g., small private versus large-scale professional endeavors), the technological advancement degree, and the approach selected. The visualization of the two use cases above does not claim comprehensiveness regarding the differences in the relevance of organizational readiness factors depending on SUA type. Rather, it demonstrates how classifying different SUA solutions and their underlying organization type through our taxonomy informs the relevance of the different readiness factors.

6.1 Theoretical Implications

Summarizing the discussion above, a deep understanding about the contextual implications of how digital innovation in SUA can be *initiated, developed, implemented,* and fully *exploited* is required to unfold and leverage its full potential. Theoretical implications to both the broader literature on taxonomy development and readiness are threefold.

First, and in line with existing taxonomic IS research (Addas and Pinsonneault 2015; Böttcher et al. 2023), our taxonomy offers a common ground for conceptualizing the scattered nature of SUA by uniting terms from various domains and generalizing subtypes, as well as delivering high levels of knowledge regarding the possibilities for applying digital technologies to urban agriculture. In doing so, we build on prior taxonomic research that can be assigned to the research domains of either smart farming, or smart city and IT-enabled green city. First, we extend smart farming taxonomies (e.g.; Balafoutis et al. 2017) by referring to urban rather than traditional, rural farming contexts, and viewing smart agriculture from a BISE rather than from an agricultural or bio-economic perspective. Second, we extend smart city taxonomies analyzing various smart city projects and digital technologies (e.g., Perboli and Rosano 2020) by focusing on the urban agricultural sector. The provided classification scheme and thus demonstration of the scope of SUA serves as a starting point for theorizing: According to Gregor (2006), a taxonomy is a "theory for analyzing"; the most basic type of theory that describes and classifies by summarizing the commonalities in discrete observations. It enables the grouping of digital technologies in urban agriculture, allowing for relationships between the different groups to be hypothesized and tested. With our taxonomy, future researchers in this area do not have to analyze each SUA solution individually but can directly assess groups of such solutions. Our taxonomy helps to initiate and develop SUA innovations by offering the basis for more generalizable insights on digital technologies in urban agriculture.

Second, the identification of 20 SUA specific readiness factors provides theoretical understanding at the intersection of emerging literature on smart city and smart farming readiness (Yigitcanlar et al. 2022; Dewi et al. 2018). While some readiness factors directly build on previous research in smart farming (e.g., lack of data standards, or a deficit of digitally-savvy workers; Knierim et al. 2018; Giua et al. 2021) and smart city research (e.g., high connectivity through physical infrastructure, standards and interoperability; Dewi et al. 2018; Yigitcanlar et al. 2022), few new, SUA-specific readiness factors emerge. This includes, for example, factors of the category *strategic readiness* with *scale-up pace* and *scale* or categories such as *regulatory readiness* with *adherence* and *laws*. In terms of their contextualization, regulatory readiness is especially relevant in the SUA domain, because the shift from a long-standing traditional industry (i.e., farming) into the digital and urban realm brings massive changes to legal requirements which exceed normal changes during digital transformations. Second, readiness factors related to partnerships and strategic directions are particularly relevant in this context because of the novelty of SUA and the resulting lack of existing network partners. Overall, for the successful adaption of various SUA endeavors, some readiness factors are always relevant and important (e.g., *IT expertise* and *IT infrastructure*) while others play a less significant role (e.g., *appreciation* and *fun factor*). The readiness factors contribute to theories on opportunity exploitation and organizational readiness by offering a concrete list of factors relevant to the successful exploitation of SUA and potentially other domains (Kreuzer et al. 2022).

Third, by integrating the taxonomy and readiness factors through meta-inferences, we offer a theoretical lens for theorizing on the relationship between BISE, and urban agriculture as a particular instantiation thereof. In that regard, our study also answers questions posed by prime BISE and IS outlets asking how associated artifacts may foster more sustainable development (Gholami et al. 2016; Watson et al. 2010). Overall, the three central themes emerging from the meta-inferences comprise a) the need to jointly build a business ecosystem around SUA technologies in order for all partners to succeed, b) the significant differences in project execution depending on the level of technification, and c) the role of the social side – i.e., the development of skills and digital culture. For research, these results pinpoint relevant avenues for further advancing SUA knowledge, for example by analyzing the ecosystem dynamics in SUA or capabilities needed for SUA initiatives.

6.2 Practical Implications

Our results are meant to address all stakeholders aiming to leverage SUA's value: Professional urban agriculture organizations, housing associations, public administrations (e.g., city planners), or individual homeowners.

From the perspective of different actors involved in implementing SUA endeavors, our study will help plan and maintain SUA endeavors. The set of 20 readiness factors guides the actors in planning urban agriculture endeavors by providing a checklist of factors to consider before digital technology implementation. While fulfilling all readiness factors cannot ensure a success rate of 100%, it can reduce failure caused by financial troubles or lack of capabilities by increasing readiness. To name just two of the actionable suggestions following from our readiness factors, the factors *appreciation* and *trial-and-error mentality* (cultural readiness) serve as suitable illustrations. First, appreciation suggests that smart urban farmers actively communicate the value and benefits of the planned endeavor to the entire workforce to drive its acceptance. As a core component of successful change management, such communication needs to be included in the decision-making on the exact timeline of SUA endeavors to drive appreciation. Second, the readiness factor on trial-and-error mentality implies that smart urban farmers need to assess their current culture on the readiness to experiment. In case of low experimentation levels, the factor implies the need to increase experimentation through initiatives such as experimental laboratories or dedicated time for experimenting.

For policymakers, the regulatory readiness factors are also a call to develop regulations that reflect smart urban agriculture's peculiarities. Specifically, in terms of *adherence* to existing laws, policymakers need to closely monitor that data protection regulations are adhered to, as data is becoming increasingly important in smart (urban) agriculture. Concerning new laws and subsidies, our results are meant to motivate policymakers to develop appropriate tools for incentivizing sustainable practices in urban agriculture. This could include subsidies on the acquisition of high-tech soft- and hardware, machinery, or buildings (in the case of indoor vertical farming).

Finally, moving from individual actors to the portfolio of stakeholders representing a city, our results offer initial inspiration for integrating SUA in cities. Smart cities are a crucial prerequisite to attaining the UN's Sustainable Development Goal number 4, "Sustainable Cities and Communities" (United Nations). Cities striving to increase biodiversity, rewild, or use green spaces as carbon emission storage and food source, can use our taxonomy to review different urban agriculture approaches and identify potential use cases of digital technology through the proposed dimensions. Thus, users may find inspiration for SUA endeavors or increase their awareness of how digital technologies can improve cities beyond mere energy efficiency.

6.3 Limitations and Future Research

Our study has some limitations and highlights avenues for future research. Firstly, the evaluation sample of 32 real-life SUA technologies serves as a good starting point, as it comprises a wide variety of digital technologies. However, this sample does not represent a full market overview. As the industry matures and comprehensive databases of such digital technologies emerge, an extended demonstration using more real-life examples will become necessary to validate our initial findings and draw conclusions on the distribution of examples across characteristics. Secondly, we interviewed practitioners from Austria, Germany, Israel, and the Netherlands. While this sample covers different regions, it does not represent the global SUA industry. It would be interesting to assess local differences in SUA readiness, such as policies and regulations, resources, and skills, via a larger sample of interviews.

Our study yields interesting pathways for future research in the BISE community. Currently, the process of farmers' evolution from urban to smart urban is unknown. Becoming a SUA champion will not be a binary process from 0 to 1 but will involve various stages of development. For research and practice to understand this process, the development of a maturity model of SUA – including the readiness factors for each stage (e.g., readiness levels) – is a research endeavor that promises to strengthen conceptual understanding of the topic (Linhart et al. 2017).

Future investigations may also quantify the specific gains triggered by digital technologies in SUA contexts, to better explicate its value. Empirical research, for example, could conduct field studies that compare the outcome of different urban agriculture approaches – with and without digital technologies. Results may differ in terms of environmental sustainability (i.e., energy savings, efficiency of resources), societal (i.e., facilitation of work effort) and technical gains (i.e., creation of data sources, data transparency, monitoring and prediction options) or economic profitability. Similarly, future research can evaluate differences in gains based on the individual SUA dimensions and characteristics.

7 Conclusion

Mindful of the grand sustainability challenges we grapple with, they may constitute a "window of opportunity" for new organizational endeavors. We propose a multi-layer taxonomy that characterizes digital technologies helping to leverage opportunities in urban agriculture and suggest 20 organizational readiness factors for smart urban agriculture as a starting aid. Our work contributes to BISE research by providing a structuring tool to guide scholars working at the intersection of BISE, sustainability, and innovative digital opportunities in the urban realm. Overall, our study sets the scene for a thorough conceptual understanding of the nature of SUA technologies and requirements for leveraging their value, and, we hope, presents a further step toward creative ideas on how to turn crises into opportunities.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12599-024-00863-w.

Funding Open Access funding enabled and organized by Projekt DEAL.

References

Addas S, Pinsonneault A (2015) The many faces of information technology interruptions: a taxonomy and preliminary investigation of their performance effects. Inf Syst J 25(3):231–273. https://doi.org/10.1111/isj.12064

Adner R (2017) Ecosystem as Structure. J Manag 43(1):39–58. https://doi.org/10.1177/0149206316678451

Alter S (2020) Making sense of smartness in the context of smart devices and smart systems. Inf Syst Front 22(2):381–393. https://doi.org/10.1007/s10796-019-09919-9

Amalia B, Kapoor S, Sharma R, Fu M, Fernández E, Rana JS (2020) Online sales compliance with the electronic cigarettes ban in India: a content analysis. Int J Publ Health 65(8):1497–1505. https://doi.org/10.1007/s00038-020-01480-6

Ampatzidis Y, De Bellis L, Luvisi A (2017) iPathology: robotic applications and management of plants and plant diseases. Sustain. https://doi.org/10.3390/su9061010

Azunre GA, Amponsah O, Peprah C, Takyi SA, Braimah I (2019) A review of the role of urban agriculture in the sustainable city discourse. Cities 93:104–119. https://doi.org/10.1016/j.cities.2019.04.006

Balafoutis AT, Beck B, Fountas S, Tsiropoulos Z, Vangeyte J, van der Wal T, Soto-Embodas I, Gómez-Barbero M, Pedersen SM (2017) Smart farming technologies – description, taxonomy and economic impact. In: Pedersen SM, Lind KM (eds) Precision agriculture: technology and economic perspectives. Springer, Cham, pp 21–77

Battistella C, Dangelico RM, Nonino F, Pessot E (2021) How social start-ups avoid being falling stars when developing social innovation. Creativity Innov Manag 30(2):320–335. https://doi.org/10.1111/caim.12431

Benbasat I, Zmud RW (2003) The identity crisis within the IS discipline: defining and communicating the discipline's core properties. MIS Q 27(2):183–194. https://doi.org/10.2307/30036527

Bharadwaj A, Es Sawy OA, Pavlou PA, Venkatraman N (2013) Digital business strategy: toward a next generation of insights. MIS Q 37(2):471–482

Boell SK, Cecez-Kecmanovic D (2015) On being 'systematic' in literature reviews in IS. J Inf Technol 30(2):161–173. https://doi.org/10.1057/jit.2014.26

Böttcher TP, Empelmann S, Weking J, Hein A, Krcmar H (2023) Digital sustainable business models: using digital technology to integrate ecological sustainability into the core of business models. Inf Syst J. https://doi.org/10.1111/isj.12436

Broad GM, Marschall W, Ezzeddine M (2021) Perceptions of high-tech controlled environment agriculture among local food consumers: using interviews to explore sense-making and connections to good food. Agric Hum Values 39:417–433. https://doi.org/10.1007/s10460-021-10261-7

Carolan M (2020) "Urban farming is going high tech": digital urban agriculture's links to gentrification and land use. J Am Plan Assoc 86(1):47–59. https://doi.org/10.1080/01944363.2019.1660205

Chang M, Morel K (2018) Reconciling economic viability and socio-ecological aspirations in London urban microfarms. Agron Sustain Devel. https://doi.org/10.1007/s13593-018-0487-5

Chen Y, Wang Y, Nevo S, Benitez-Amado J, Kou G (2015) IT capabilities and product innovation performance: the roles of corporate entrepreneurship and competitive intensity. Inf Manag 52(6):643–657. https://doi.org/10.1016/j.im.2015.05.003

Cichy P, Salge TO, Kohli R (2021) Privacy concerns and data sharing in the internet of things: mixed methods evidence from connected cars. MIS Q 45(4):1863–1892. https://doi.org/10.25300/MISQ/2021/14165

Corbett J, Mellouli S (2017) Winning the SDG battle in cities: how an integrated information ecosystem can contribute to the achievement of the 2030 sustainable development goals. Inf Syst J 27(4):427–461. https://doi.org/10.1111/isj.12138

Corbin JM, Strauss A (1990) Grounded theory research: procedures, canons, and evaluative criteria. Qual Sociol 13(1):3–21. https://doi.org/10.1007/BF00988593

De Bon H, Parrot L, Moustier P (2010) Sustainable urban agriculture in developing countries a review. Agron Sustain Devel 30(1):21–32. https://doi.org/10.1051/agro:2008062

Deserti A, Rizzo F (2020) Context dependency of social innovation: in search of new sustainability models. Eur Plan Stud 28(5):864–880. https://doi.org/10.1080/09654313.2019.1634005

Dewi MAA, Hidayanto AN, Purwandari B, Kosandi M, Budi NFA (2018) Smart city readiness model using technology-organization-environment (TOE) framework and its effect on adoption decision. In: Proceedings of the 22nd Pacific Asia conference on information systems

Diehl JA, Sweeney E, Wong B, Sia CS, Yao H, Prabhudesai M (2020) Feeding cities: Singapore's approach to land use planning for urban agriculture. Glob Food Secur 26:100377. https://doi.org/10.1016/j.gfs.2020.100377

Dorr E, Goldstein B, Horvath A, Aubry C, Gabrielle B (2021) Environmental impacts and resource use of urban agriculture: a systematic review and meta-analysis. Environ Res Lett. https://doi.org/10.1088/1748-9326/ac1a39

Egerer MH, Wagner B, Lin BB, Kendal D, Zhu K (2020) New methods of spatial analysis in urban gardens inform future vegetation surveying. Landsc Ecol 35(3):761–778. https://doi.org/10.1007/s10980-020-00974-1

El Bilali H, Allahyari MS (2018) Transition towards sustainability in agriculture and food systems: role of information and communication technologies. Inf Proc Agric 5(4):456–464. https://doi.org/10.1016/j.inpa.2018.06.006

Farhangi MH, Turvani ME, van der Valk A, Carsjens GJ (2020) High-tech urban agriculture in amsterdam: an actor network analysis. Sustain 12(10):3955. https://doi.org/10.3390/su12103955

Félix MJ, Santos G, Barroso A, Silva P (2018) The transformation of wasted space in urban vertical gardens with the contribution of design to improving the quality of life. Int J Qual Res 12(4):803–822. https://doi.org/10.18421/IJQR12.04-02

Galdon F, Hall A, Wang SJ (2021) Designing trust in highly virtual assistants: a taxonomy of levels of autonomy. In: Dingli A, Haddod F, Klüver C (eds) Artificial Intelligence in Industry 4.0. Springer, Cham, pp 199–211

Ghandar A, Ahmed A, Zulfiqar S, Hua Z, Hanai M, Theodoropoulos G (2021) A decision support system for urban agriculture using digital twin: a case study with aquaponics. IEEE Access 9:35691–35708. https://doi.org/10.1109/ACCESS.2021.3061722

Gholami R, Watson R, Hasan H, Molla A, Bjorn-Andersen N (2016) Information systems solutions for environmental sustainability: how can we do more? J Assoc Inf Syst 17(8):521–536. https://doi.org/10.17705/1jais.00435

Gimpel H, Graf V, Graf-Drasch V (2020) A comprehensive model for individuals' acceptance of smart energy technology – a meta-analysis. Energy Policy. https://doi.org/10.1016/j.enpol.2019.111196

Gimpel H, Graf-Drasch V, Hawlitschek F, Neumeier K (2021) Designing smart and sustainable irrigation: a case study. J Clean Prod. https://doi.org/10.1016/j.jclepro.2021.128048

Giua C, Materia VC, Camanzi L (2021) Management information system adoption at the farm level: evidence from the literature. Br Food J 123(3):884–909. https://doi.org/10.1108/BFJ-05-2020-0420

Goldstein B, Hauschild M, Fernández J, Birkved M (2016) Urban versus conventional agriculture, taxonomy of resource profiles: a review. Agron Sustain Devel. https://doi.org/10.1007/s13593-015-0348-4

Graf-Drasch V, Kauffeld L, Kempf L, Oberländer AM, Teuchert A (2023) Driving twin transformation - the interplay of digital transformation and sustainability transformation. In: Proceedings of the 31st European conference on information systems

Gravalos I, Avgousti A, Gialamas T, Alfieris N, Paschalidis G (2019) A robotic irrigation system for urban gardening and agriculture. J Agric Eng 50(4):198–207. https://doi.org/10.4081/jae.2019.966

Hanelt A, Busse S, Kolbe LM (2017) Driving business transformation toward sustainability: exploring the impact of supporting IS on the performance contribution of eco-innovations. Inf Syst J 27(4):463–502. https://doi.org/10.1111/isj.12130

Hannah DP, Eisenhardt KM (2018) How firms navigate cooperation and competition in nascent ecosystems. Stratg Manag J 39(12):3163–3192. https://doi.org/10.1002/smj.2750

Harada Y, Whitlow TH, Walter MT, Bassuk NL, Russell-Anelli J, Schindelbeck RR (2018) Hydrology of the Brooklyn Grange, an urban rooftop farm. Urban Ecosyst 21(4):673–689. https://doi.org/10.1007/s11252-018-0749-7

Hess T, Matt C, Benlian A, Wiesböck F (2016) Options for formulating a digital transformation strategy. MIS Q Exec 15(2):123

Hong W, Chan FKY, Thong JY, Chasalow LC, Dhillon G (2014) A framework and guidelines for context-specific theorizing in information systems research. Inf Syst Res 25(1):111–136

Khan RRA, Ahmed V (2017) Building information modelling and vertical farming. Facilities 35(13–14):710–724. https://doi.org/10.1108/F-03-2016-0026

Kinelski G, Stęchły J, Bartkowiak P (2022) Various facets of sustainable smart city management: selected examples from Polish metropolitan areas. Energies 15(9):2980. https://doi.org/10.3390/en15092980

Knierim A, Borges F, Kernecker ML, Kraus T, Wurbs A (2018) What drives adoption of smart farming technologies? Evidence from a cross-country study. In: Proceedings of the 13th European international farm systems association symposium

Kohli R, Melville NP (2019) Digital innovation: a review and synthesis. Inf Syst J 29(1):200–223. https://doi.org/10.1111/isj.12193

Köksal Ö, Tekinerdogan B (2019) Architecture design approach for IoT-based farm management information systems. Precis Agric 20(5):926–958. https://doi.org/10.1007/s11119-018-09624-8

Kreuzer T, Lindenthal A-K, Oberländer AM, Röglinger M (2022) The effects of digital technology on opportunity recognition. Bus Inf

Syst Eng 64(1):47–67. https://doi.org/10.1007/s12599-021-00733-9

Kundisch D, Muntermann J, Oberländer AM, Rau D, Röglinger M, Schoormann T, Szopinski D (2022) An update for taxonomy designers: methodological guidance from information systems research. Bus Inf Syst Eng 64:421–439. https://doi.org/10.1007/s12599-021-00723-x

Langemeyer J, Madrid-Lopez C, Mendoza Beltran A, Villalba Mendez G (2021) Urban agriculture – a necessary pathway towards urban resilience and global sustainability? Landsc Urban Plan 210:104055. https://doi.org/10.1016/j.landurbplan.2021.104055

Langendahl P-A (2021) The politics of smart farming expectations in urban environments. Front Sustain Cities. https://doi.org/10.3389/frsc.2021.691951

Lee AS (2010) Retrospect and prospect: information systems research in the last and next 25 years. J Inf Technol 25(4):336–348. https://doi.org/10.1057/jit.2010.24

Li L, Li X, Chong C, Wang C-H, Wang X (2020) A decision support framework for the design and operation of sustainable urban farming systems. J Clean Prod 268:121928. https://doi.org/10.1016/j.jclepro.2020.121928

Linhart A, Klaus C, Röglinger M (2017) Maturing maturity models – a methodological extension using the analytical hierarchy process and Google PageRank. J Decis Syst 26(4):307–327. https://doi.org/10.1080/12460125.2017.1422317

Lokuge S, Sedera D, Grover V, Dongming X (2019) Organizational readiness for digital innovation: development and empirical calibration of a construct. Inf Manag 56(3):445–461. https://doi.org/10.1016/j.im.2018.09.001

Lüttge U, Buckeridge M (2020) Trees: structure and function and the challenges of urbanization. Trees 37:9–17. https://doi.org/10.1007/s00468-020-01964-1

Malhotra A, Melville NP, Watson RT (2013) Spurring impactful research on information systems for environmental sustainability. MIS Q 37(4):1265–1274

Maye D (2019) Smart food city: conceptual relations between smart city planning, urban food systems and innovation theory. City Cult Soc 16:18–24. https://doi.org/10.1016/j.ccs.2017.12.001

Melville NP, Saldanha TJ, Rush DE (2017) Systems enabling low-carbon operations: the salience of accuracy. J Clean Prod 166:1074–1083. https://doi.org/10.1016/j.jclepro.2017.08.101

Mikalef P, Conboy K, Lundström JE, Popovič A (2022) Thinking responsibly about responsible AI and 'the dark side' of AI. Eur J Inf Syst 31(3):257–268. https://doi.org/10.1080/0960085X.2022.2026621

Molla A, Licker PS (2005) Perceived e-readiness factors in e-commerce adoption: an empirical investigation in a developing country. Int J Electron Commer 10(1):83–110. https://doi.org/10.1080/10864415.2005.11043963

Nadal A, Alamús R, Pipia L, Ruiz A, Corbera J, Cuerva E, Rieradevall J, Josa A (2017) Urban planning and agriculture. methodology for assessing rooftop greenhouse potential of non-residential areas using airborne sensors. Sci Total Envir 601–602:493–507. https://doi.org/10.1016/j.scitotenv.2017.03.214

Nair AS, Nof SY, Bechar A (2021) Emerging directions of precision agriculture and agricultural robotics. In: Bechar A (ed) Innovation in agricultural robotics for precision agriculture. Springer, Cham, pp 177–210

Nambisan S, Lyytinen K, Majchrzak A, Song M (2017) Digital innovation management: reinventing innovation management research in a digital world. MIS Q 41(1):223–238

Nickerson RC, Varshney U, Muntermann J (2013) A method for taxonomy development and its application in information systems. Eur J Inf Syst 22(3):336–359. https://doi.org/10.1057/ejis.2012.26

Niemöller C, Metzger D, Berkemeier L, Zobel B, Thomas O (2019) Mobile service support based on smart glasses. J Inf Technol Theor Appl 20(1):77–108

Nwankpa JK, Datta P (2017) Balancing exploration and exploitation of IT resources: the influence of digital business intensity on perceived organizational performance. Eur J Inf Syst 26(5):469–488. https://doi.org/10.1057/s41303-017-0049-y

Oberländer AM, Lösser B, Rau D (2019) Taxonomy research in information systems: a systematic assessment. In: Proceedings of the 27th European conference on information systems

Ofori M, El-Gayar O (2021) An approach for weed detection using CNNs and transfer learning. In: Bui T (ed) Proceedings of the 54th Hawaii international conference on system sciences

O'Sullivan CA, Bonnett GD, McIntyre CL, Hochman Z, Wasson AP (2019) Strategies to improve the productivity, product diversity and profitability of urban agriculture. Agric Syst 174:133–144. https://doi.org/10.1016/j.agsy.2019.05.007

Padilla M, Mok S, Raj H, Latypov V, Bescansa M (2018) Urban farming in the city of tomorrow: assessing the global landscape on urban food and resource production with the focus on indoor plant and microalgae cultivation. Fraunhofer IAO, Stuttgart. https://publica.fraunhofer.de/handle/publica/299209

Perboli G, Rosano M (2020) A taxonomic analysis of smart city projects in North America and Europe. Sustain 12(18):7813. https://doi.org/10.3390/su12187813

Püschel LC, Röglinger M, Brandt R (2020) Unblackboxing smart things – a multilayer taxonomy and clusters of nontechnical smart thing characteristics. IEEE Trans Eng Manag. https://doi.org/10.1109/TEM.2020.2988981

Qureshi I, Pan SL, Zheng Y (2021) Digital social innovation: an overview and research framework. Inf Syst J 31(5):647–671. https://doi.org/10.1111/isj.12362

Riera C, Iijima J (2019) The role of IT and organizational capabilities on digital business value. Pac Asia J Assoc Inf Syst 11(2):67–95. https://doi.org/10.17705/1pais.11204

Roundy PT (2017) "Doing Good" while serving customers. J Res Mark Entrep 19(2):105–124. https://doi.org/10.1108/JRME-03-2017-0009

Salmimaa T, Hekkala R, Pekkola S (2018) Dynamic activities for managing an IS-enabled organizational change. Bus Inf Syst Eng 60(2):133–149. https://doi.org/10.1007/s12599-018-0524-6

Smit J, Nasr J, Ratta A (2001) Urban agriculture: food, jobs and sustainable cities. UNDP, New York

Specht K, Weith T, Swoboda K, Siebert R (2016) Socially acceptable urban agriculture businesses. Agron Sustain Devel. https://doi.org/10.1007/s13593-016-0355-0

Steininger DM, Kathryn Brohman M, Block JH (2022) Digital entrepreneurship: what is new if anything? Business Info Sys Eng 64(1):1–14. https://doi.org/10.1007/s12599-021-00741-9

Stoiber C, Stöter M, Englbrecht L, Schönig S, Häckel B (2023) Keeping your maturity assessment alive. Bus Inf Syst Eng (in Press). https://doi.org/10.1007/s12599-023-00805-y

Surantha H, Surantha N (2020) Smart hydroculture control system based on IoT and fuzzy logic. Int J Innov Comput Inf Contr 16(1):207–221. https://doi.org/10.24507/ijicic.16.01.207

United Nations (2015) The 17 Goals. https://sdgs.un.org/goals. Accessed 6 Jun 2021

Venkatesh V, Brown S, Sullivan Y (2016a) Guidelines for conducting mixed-methods research: an extension and illustration. J Assoc Inf Syst 17(7):435–494. https://doi.org/10.17705/1jais.00433

Venkatesh V, Thong J, Xu X (2016b) Unified theory of acceptance and use of technology: a synthesis and the road ahead. J Assoc Inf Syst 17(5):328–376. https://doi.org/10.17705/1jais.00428

Walczuch R, Lemmink J, Streukens S (2007) The effect of service employees' technology readiness on technology acceptance. Inf Manag 44(2):206–215. https://doi.org/10.1016/j.im.2006.12.005

Watson RT, Boudreau MC, Chen AJ (2010) Information systems and environmentally sustainable development: energy informatics and new directions for the IS community. MIS Q 34(1):23–38. https://doi.org/10.2307/20721413

Watson RT, Ketter W, Recker J, Seidel S (2022) Sustainable energy transition: intermittency policy based on digital mirror actions. J Assoc Inf Syst 23(3):631–638. https://doi.org/10.17705/1jais.00752

Weidner T, Yang A, Forster F, Hamm MW (2022) Regional conditions shape the food–energy–land nexus of low-carbon indoor farming. Nature Food 3(3):206–216. https://doi.org/10.1038/s43016-022-00461-7

Wolfswinkel JF, Furtmueller E, Wilderom CPM (2013) Using grounded theory as a method for rigorously reviewing literature. Eur J Inf Syst 22(1):45–55. https://doi.org/10.1057/ejis.2011.51

Wood J, Wong C, Paturi S (2020) Vertical farming: an assessment of Singapore city. Electron J Stud Tropics 19(2):228–248. https://doi.org/10.25120/etropic.19.2.2020.3745

World Economic Forum (2020) Climate emergency: how our cities can inspire change. https://www.weforum.org/agenda/2020/01/smart-and-the-city-working-title. Accessed 28 Jul 2023

Yigitcanlar T, Degirmenci K, Butler L, Desouza KC (2022) What are the key factors affecting smart city transformation readiness? Cities, Evidence from Australian Cities. https://doi.org/10.1016/j.cities.2021.103434

Zampou E, Mourtos I, Pramatari K, Seidel S (2022) A design theory for energy and carbon management systems in the supply chain. J Assoc Inf Syst 23(1):329–371. https://doi.org/10.17705/1jais.00725

Zhang R, Indulska M, Sadiq S (2019) Discovering data quality problems. Bus Inf Syst Eng 61(5):575–593. https://doi.org/10.1007/s12599-019-00608-0