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Sustainability-oriented innovations in smart cities: A systematic review and emerging themes

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ABSTRACT

The purpose of the paper is to clarify the relationship between sustainability-oriented innovations (SOI) and smart city development based on the systematic review of existing literature in the field. As an outcome of the review process, 159 articles were carefully selected for the in-depth analysis of the inter-linked concepts of smart city and sustainability-oriented innovations. The results show a growing trend of research papers in this field, especially in the last five years. The findings show the significance of a systemic multi-dimensional view of innovations for the smart sustainable development of cities. We have identified four main perspectives through which the scholars discourse the SOI dimensions in the smart city context: technology perspective, organizational perspective, social innovation perspective with citizen engagement, as well as system-level changes with innovation ecosystems. Second, we have recognized various focused themes under each main perspective. The various types of innovations also have impacts on different components of smart cities. Although the technological innovation perspectives dominate, and governance aspects are also paid attention to in recent studies, the increasing amount of research outputs also report on the developments of other components and perspectives, such as new human-centric approaches like citizen engagement.

1. Introduction

Cities are increasingly facing challenges due to rapid urbanization. It is estimated that by 2050, 66% of the global population will live in cities, which will also increase the amount of material consumption in cities (UNEP, 2018). As estimated already in the previous decade, cities consume 75% of the globally available natural resources such as primary energy, raw materials, water and food (UNEP, 2012). Growth, performance, competitiveness and residents' livelihoods are all aspects where cities are expected to face multiple challenges (McKinsey & Company, 2013). These challenges are related to waste management, scarce resources, pollution, traffic problems and the aging population, for example (Washburn et al., 2009). Furthermore, it remains to be seen what the effect of the COVID-19 pandemic on the global urbanization rate is, but at least some effects on migration have been seen already, and some of the above-mentioned challenges may be even more difficult to cope with, which calls for new approaches to city planning, infrastructure development and governance in the post-pandemic era (e.g., Panwar & Mishra, 2020).

The smart city as a concept provides a potential approach to find solutions to the various sustainability problems derived from rapid urbanization. The smart city is a concept that has multiple definitions that vary based on the elements a city needs to be viewed as smart, the resources that it needs, its characteristics, goals, purpose, and scope (Toli & Murtagh, 2020). In prior literature, smart city definitions range from sustainability-oriented definitions (e.g., Ahvenniemi et al., 2017; Bakici et al., 2010; Kourtit et al., 2012; Nam & Pardo, 2011; Toppeta, 2010) to definitions that merely focus on the importance of utilizing information and communication technologies (ICT) in combining resources to make cities more intelligent, interconnected, and livable (e.g., Batty et al., 2012; Chen, 2010). Another concept related to the common elements is the concept of the sustainable city, which presents a different research stream (D'Auria et al., 2018). Despite the conceptual confusion, the transition towards smart cities is seen as an essential way to reach the 11th UN Sustainable Development Goal of inclusive, safe, resilient, and sustainable cities (Toli & Murtagh, 2020; UN, 2018). Thus, a smart city can be viewed as an innovative urban development, aiming for sustainable development and high quality of life of its citizens (Lim et al., 2019; Toppeta, 2010; Washburn et al., 2009).

Lately, the smart city has also been increasingly linked to the concept

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of innovation (e.g., Beretta, 2018; Komninos, 2011; Ojasalo & Kauppinen, 2016; Zygiaris, 2013). This also raises questions regarding the relationship between smart cities, sustainable development, and innovation. Innovations in the smart city concept can in some contexts be mainly understood through technological development and operational optimization. However, sustainable development also calls for innovations that aim for (organizational) transformation and systems building, thus requiring innovations to make changes possible at an institutional and societal level. These types of innovations (ranging from operational optimization to systems building) that aim at economic, environmental, and social value creation are defined as sustainability-oriented innovations (SOI) (Adams et al., 2016). In other words, SOIs are innovations, that involve making intentional changes to (organization's) philosophies and values, surpassing the sustainability benefits of prior products, services, processes, practices and systems (Adams et al., 2016). As the prior literature shows, both smart city and sustainability-oriented innovation are developing concepts that lack conceptual clarity. In the context of smart city development, the development of SOI means the development of new collaborative products, services, processes, and business models that drive sustainable urban development. Sustainability can be integrated into smart city development to various degrees (scope, goals, and means) and levels of SOI processes can vary from light process adaptations to investments, including high risks and uncertainty.

While the concept of a smart city is relatively new and systemic understanding regarding it is still developing, some systematic literature reviews exist that have focused on various aspects of smart cities. However, these mainly focus on investigating the concept and its link to other related concepts (e.g., de Jong et al., 2015). For instance, the researchers have focused on investigating the links between smart cities and digital cities (Cocchia, 2014; Zheng et al., 2020), different domains of smart cities (Anthopoulos, 2015), smart urban governance (Meijer & Bolívar, 2016), and certain technologies and data in smart city context (e.g., Neves et al., 2020; Parmentola et al., 2021). Researchers have also focused especially on the emergence of the smart city concept (Komninos & Mora, 2018), analyzing the link between the smart city and sustainable development (Trindade et al., 2017, D'Auria et al., 2018, Toli & Murtagh, 2020; Yigitcanlar et al., 2019a, 2019b, 2019c), and examining the results of smart city development (Correira et al., 2020; Lim et al., 2019). These research streams help to understand the evolvement and emergence of the smart city concept and how it links to the digital economy and sustainable development. However, so far, the previous reviews have not focused on the nature and development of sustainability-oriented innovations in smart cities. It is still unclear to what extent sustainable development and SOIs are a strategy to aim for a smart city or to what extent smart city development enables the development of sustainability-oriented innovations. The available systematic literature reviews do not pay attention to the links between these two concepts. Thus, our guiding research question is: *What is the relationship between sustainability-oriented innovations and smart city development?* In the current literature, there is no overview and analysis of the levels and scope of these types of innovations and how the innovation perspective has been considered as part of sustainable smart city development. Furthermore, it is unclear what the main thematic (focus) areas of SOIs are in smart city contexts and what the main gaps revealed in the previous studies are, requiring future research in this area.

In order to understand the links between these concepts, the aim of this paper is to investigate the relationship between sustainability-oriented innovations and smart city development. We do this by using a systematic review (Petticrew & Roberts, 2008), which is aimed at carefully identifying all the relevant studies on the topic and creating an accessible synthesis based on the pieces of information from multiple studies (Tranfield et al., 2003). This systematic literature review aims to bring conceptual clarity but also help in decision-making with regard to innovations aiming for sustainable and smart urban development. The paper is organized as follows: First, we explain the conceptual background of smart city and sustainability-oriented innovations, which is followed by an explanation of the review agenda and the detailed research process. After this we move to the core characteristics of the literature. In the results section we consider the different thematic areas of how selected articles consider SOIs in a smart city context. Then the findings are also discussed through different smart city components identified from the literature. Finally, we conclude the study with a summary and discussion of the main findings highlighting the possible future research areas.

2. Conceptual background

2.1. Smart city

The understanding of the smart city concept ranges from sustainability-oriented to non-sustainability-oriented definitions (Toli & Murtagh, 2020). Although the definitions vary, a common feature is that the smart city is strongly linked to the use of ICT (such as sensors, real-time monitoring and digital knowledge sharing platforms) (Anthopoulos, 2017; Komninos, 2011; Lim et al., 2019; Yigitcanlar et al., 2018; Zygiaris, 2013) that helps in increasing the efficiency and effectiveness of urban systems and management, for instance in terms of intelligent optimization and collective intelligence (Komninos & Mora, 2018). According to UN Sustainable Development goal 11, sustainable city is a city that is dedicated to achieving green sustainability, social sustainability and economic sustainability (UN, 2018).

In addition, many smart city definitions also include the presence of high-quality human and social capital (i.e., soft capital) (e.g., Michelucci et al., 2016) and smart governance (e.g., Scholl & AlAwadhi, 2016). These present so-called sustainability-oriented definitions, where the focus is on combining soft and hard capital to deliver a sustainable, livable, and efficient city (Toli & Murtagh, 2020). The prior literature also uses the concept of the sustainable smart city (or smart sustainable city) to highlight the sustainability dimension (e.g., Ahvenniemi et al., 2017; Bibri & Krogstie, 2017c; Ibrahim et al., 2015). This type of sustainable smart city utilizes ICT to exploit the creativeness of citizens to improve quality of life (QoL) sustainably in the urban areas through innovation. According to these definitions, a city cannot be smart if it does not set goals for sustainable development. Especially recent literature links sustainable development as a natural part of smart city development (e.g., Correira et al., 2020; Yigitcanlar et al., 2019a, 2019b, 2019c). The definitions with an environmental or social focus mostly consider the integration of technologies with governance to improve QoL in cities and reduce the environmental impact of urbanism. On the other hand, the economic-focused definitions target the creation of competitive cities and boosting sustainable economic development (Toli & Murtagh, 2020).

Smart cities include multiple dimensions, characteristics, and components that may vary according to different researchers. For instance, Silva et al. (2018) divides the smart city into four categories of urbanization (technical, infrastructure, governance, and economics), smartness (economic, social, and environmental), sustainability (infrastructure & governance, energy & climate change, pollution & waste, social, economic, & health), and QoL (financial and economic well-being). On the other hand, Gil-Garcia et al. (2015) divide smart city components into the four dimensions of technology & data, physical environment, society, and government. More recently Das et al. (2019) identified eight smart city components of smart infrastructure, smart environment, smart services, smart governance, smart people, smart living, smart transportation, and smart economy. As an integrative viewpoint regarding this multi-dimensional systemic viewpoint to the concept of smart city, the authors also refer to the smart city as a complex "system of systems" (Khatoun & Zeadally, 2016; Naphade et al., 2011).

As a synthesis from the previous research, we can say that common smart city components are linked to technologies, economics, humans,

governance, public services, physical infrastructure, and the natural environment (e.g., Das et al., 2019; Gil-Garcia et al., 2015; Joshi et al., 2016; Nam & Pardo, 2011; Silva et al., 2018). Technological components include different types of smart, mobile, virtual, and digital technologies and networks such as the Internet of Things and the 5G network. From an economic perspective, the development of smart cities requires consideration of economic competitiveness, innovation activities, networks, and entrepreneurship, as well as working possibilities. From the human side, the role of education and social capital (knowledge and creativity) is also important. In addition, smart cities cannot be developed without the support of governance, policy, laws, and regulations representing institutional factors. All these previously-mentioned aspects work as enablers for smart city development. On the other hand, smart city development targets innovations in different areas. These areas include public services such as transportation, health and social services, and cultural services. The development also aims to increase sustainability and QoL by considering the development of physical infrastructure (e.g., energy and water networks, buildings, power lines, and streets) and the natural environment (e.g., by protecting natural resources, controlling pollution, and developing waste management).

2.2. Sustainability-oriented innovations and smart cities

Sustainable development, i.e., "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987), is increasingly linked to the context of urban development. It is acknowledged that to meet the sustainable development targets, urban development should be guided by sustainable planning and management vision (UN, 2018). The aim of sustainable urban development is to increase the QoL of citizens through sustainability-oriented innovations (SOIs) (e.g., Yigitcanlar & Teriman, 2014), meaning, for example, investments in housing, public transport, green public spaces, creation of business opportunities, and improving urban planning and management in participatory and inclusive ways (UN, 2018). In addition to increasing the quality of life of citizens, the recent research has also emphasized the significance of "more-than-human" and "post-anthropocentric" approaches in urban development, which would also enable the improved consideration of non-human elements in design, biocultural diversity and coping with complexity of long-term environmental sustainability (Clarke et al., 2019; Heitlinger et al., 2019; Yigitcanlar et al., 2019a).

Like other types of innovations, SOIs exist on various levels. SOIs are often understood through technological development and inventions, where the focus is on products, processes, and system infrastructure (Klewitz & Hansen, 2014). However, innovations also exist on other levels, including organizational (services, delivery, and business models) (Hansen & Große-Dunker, 2013), or institutional and social levels (considering production and consumption systems) (Jay & Gerard, 2015). In the previous literature, smart city innovations are seen as a combination of technology, organization, and policy innovation (Nam & Pardo, 2011). Technology innovation is seen as a mechanism to leverage transformation potentials of different technological tools and advanced ICTs. Organizational innovation refers to innovation management, i.e., a mechanism to create management and organizational capabilities for efficient and effective management to use technological innovations and work across organizational boundaries. Policy innovation refers to the redesigning of relationships, mechanisms to address urban problems, and the creation of an enabling environment for a smart city (Nam & Pardo, 2011). Similarly, SOIs can happen on different levels, focusing on operational optimization, organizational transformation and the building of entire systems (Adams et al., 2016; Hansen & Große-Dunker, 2013).

SOIs are needed at all levels of smart cities. Traditionally, the focus in sustainable urban development has largely been on technological innovations. Although these are very important from a sustainable development perspective, they are not enough to solve increasing sustainability challenges, but there is a need for change at the system level (Adams et al., 2016). Systemic innovation for sustainability requires cooperation among creative and aware individuals and organizations, and a shift in values to support collective intelligence in problem-solving process (e.g., Goodman et al., 2017; Hansen & Große-Dunker, 2013). Thus, a sustainable smart city approach could be an enabler for sustainable urban development. For example, building an effective waste management system requires technological innovations that make the sorting and recycling of waste possible. Additionally, products made with sustainable materials are easier to decompose and effective recycling requires planning of recycling infrastructure, including the location and capacity of sorting plants. From an organizational perspective, innovations are needed for example in establishing a product take-back program by the retailer or manufacturer. From an institutional and social perspective, an effective waste management system can only be built if consumers also have education, knowledge, and incentives to recycle their waste.

On all these levels, ICT and other smart technologies can help to make the system more effective. For instance, the sensors that are installed on recycling containers can help identify when certain plants need to be emptied and combined information can help in optimizing the logistics of waste transportation. Different technologies also help to build more effective sorting plants, reduce the use of energy, and increase the utilization rate of different raw materials. Technologies may also encourage consumers to reduce their waste production if they receive up-to-date information on the amount and composition of their waste, for instance. Despite all the benefits that technology can provide as an enabler, it is, however, important to note that the recent literature has also provided critical viewpoints towards "technology solutionism", which may lead, for example, to over-emphasizing "internet-centric" solutions and narrowly defined technology-based tools to all the complex problems that cities cope with (e.g. Mattern, 2021; Morozov, 2014). All in all, a connection between the smart city concept and sustainable urban development exists on several levels, and there is a need to further increase our understanding of the linkages between the various components of sustainability-oriented innovation in this context to enable systemic urban development in cities.

3. Methodology

As discussed, the purpose of this systematic literature review is to analyze the links between smart city development and SOIs. To achieve this, we focused on examining how SOIs are understood in a smart city context. The analysis focused on examining the given (SOI) innovation examples, types, scope, and scale of innovations and how they link to smart city and sustainable development. Our other main area of interest was examining the main thematic (focus) areas of how papers consider SOIs in smart city contexts and reveal possible future research areas.

As Lim et al. (2019) state, the results of current smart city research are scattered and fragmented, and a systematic literature review provides a tool to bring pieces of knowledge into more comprehensive understanding (Petticrew & Roberts, 2008). The aim of the systematic review methodology is to collect large volumes of information from multiple studies into a manageable synthesis (Tranfield et al., 2003). As argued by researchers, a systematic review is one of the most trustworthy, high-quality, and efficient methods for assessing a lot of literature (Cook, 1997; Denyer & Tranfield, 2006). As a methodology it is rigorous, transparent, exhaustive, and reproduceable (Cook, 1997; Tranfield et al., 2003).

3.1. The research process

The research followed the process illustrated in Fig. 1. First, the initial research objective for the research was set: "To investigate the

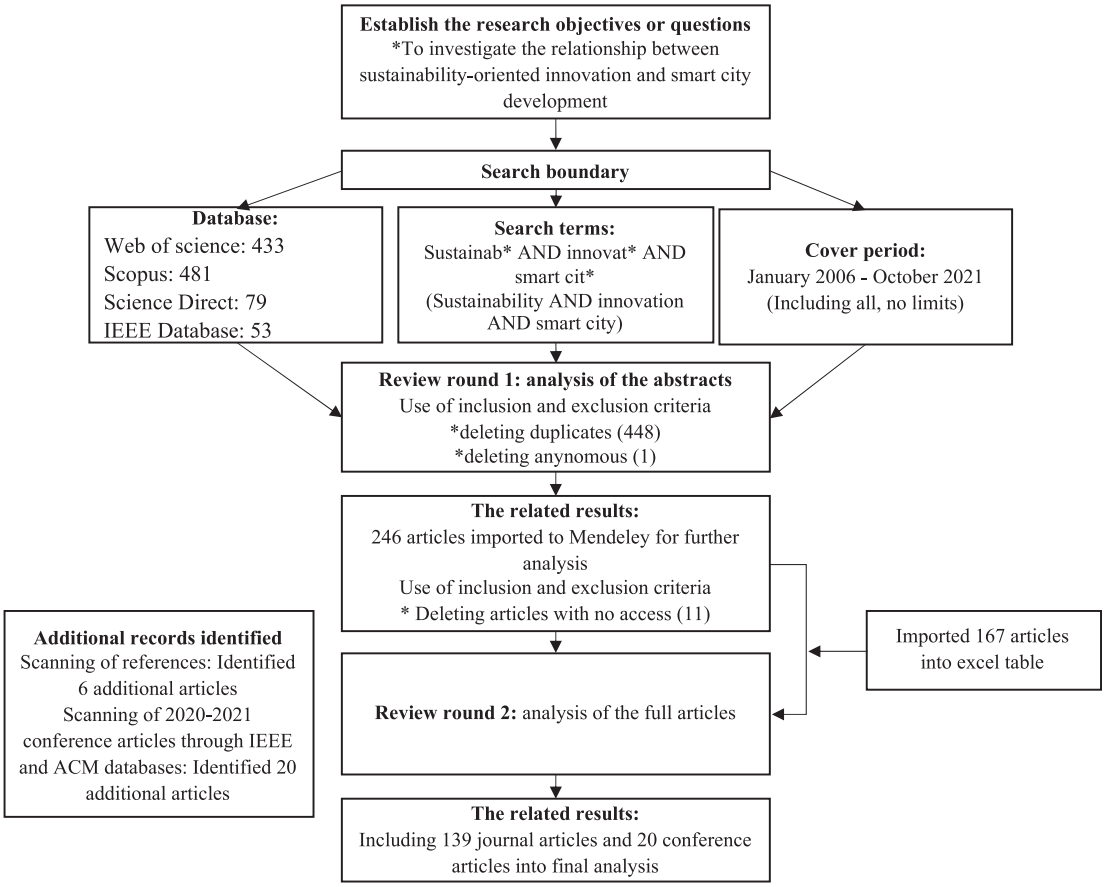

Fig. 1. The summary of the research process.

relationship between sustainability-oriented innovation and smart city development". In order to cover as diverse a range of relevant high-quality publications as possible, we conducted the research for published journal articles in several leading databases. The main databases used were Web of Science and Scopus, representing commonly used digital archives for high-quality academic research in this multi-disciplinary field (see e.g., Correira et al., 2020; Lim et al., 2019). To ensure the coverage of relevant literature, the search was complemented with ScienceDirect, IEEE and ACM databases. Google scholar is also widely used database, but as it shows a variety of documents (such as commercial reports and news articles) and would have enlarged the number of irrelevant articles, it was excluded (see also Lim et al., 2019; Neves et al., 2020). The set search terms were: "Sustainab*" AND "innovat*" AND "smart cit*". The search was also done by using longer keywords (sustainability OR sustainable AND innovation AND smart city), but the results showed that the used combination covered the widest range of results. The search did not have any given timeframe or publication outlet restrictions. The document type was specified as journal articles published in academic journals. This was to ensure the accepted quality level of publications as a result of rigorous peer review processes. The language of the publications was specified as English. The database search was based on abstracts, keywords, and title. The initial search was done in in September 2020 and this research was complemented with the second round in October 2021 to cover more resent articles, available in the databases at that time. After removing duplicate entries, the search resulted in 598 articles from the time frame of 2006–2021. In addition, to cover the latest thinking in the scholarly field, the research was complemented with the search of latest conference articles (published in 2020–2021) by using IEEE and ACM databases.

The first round of analysis was performed for the abstracts, keywords, and titles of the articles. To ensure the relevance of the articles included in the study, we developed the inclusion and exclusion criteria, which are shown in Table 1. The titles, keywords, and abstracts were carefully and independently reviewed by two researchers. The use of the inclusion and exclusion criteria resulted in the inclusion of 246 articles that were imported to Mendeley software for further analysis. The second review round was based on the joint assessment of the abstracts, keywords, title, introduction, and conclusion. At this point, articles without access to the full texts were also removed. As a result, we ended up with 167 full-text articles to review. Based on the reading of 167 full texts, 32 articles were rejected. These included two virtual round table discussions and 30 articles that focused only on smart cities or sustainable development and did not have a clear connection to both concepts. After a joint assessment of the full texts, we ended up including 135 articles in the analysis. These articles were subsequently checked for references, resulting in the inclusion of two additional articles in the study (Naphade et al., 2011; Toppeta, 2010). The search was also supplemented with manual searches, focusing on the critical perspectives of the topic. This resulted in the inclusion of 4 articles. The search for the latest conference proceedings from IEEE and ACM databases resulted in

Table 1
Inclusion and exclusion criteria.

Inclusion	Exclusion
Article (research & review articles) Language: English Must relate directly to research themes of smart city, sustainable development, and innovation	Anonymous author No connection to smart city No connection to sustainable development Commentaries and discussions Full text not available

56 hits. After review of the articles, 24 articles were selected for the analysis of full papers, after which 20 articles were included to the study. The final data comprised 139 journal articles from the years 2010–2021 and 20 conference articles from the years 2020–2021. The identified publications are listed in Table 2.

Our systematic literature review identified 159 articles, which are presented in Table 2. In the following, we present a brief overview of the retrieved data.

3.2. Descriptive results

The identified articles are a highly diverse set of publications based on the authors, target journal, field of study, and publication year. This is similar to the other systematic reviews regarding smart cities (see e.g., Lim et al., 2019). Also, the research methods vary from theoretical papers to conceptual and empirical studies. As can be seen from Fig. 2, the identified journal articles are relatively new and the trend towards the topic has been growing. This evidences the growing scope and importance of the SOI perspective in smart city literature. The identified articles were published in 41 different journals and 20 different conference proceedings from different disciplines. We identified a total of 509 different authors. According to Web of Science (WoS) classification, approximately half of the journal publications were from technology disciplines (approximately 52%), including articles from computer science, energy, engineering, operations research, and management science. The social science articles (approximately 47%) were mainly from urban studies and included articles from business and economics, education, culture development studies, geography, women's studies, and futures studies. The articles also included some examples from life sciences (1%), from the fields of behavioral science, forestry, and medical science. This shows us the multidisciplinary nature of the topic (see also Chong et al., 2018).

The articles included theoretical, conceptual, and empirical studies. Some of the articles represented a combination of these with a focus on the development of conceptual models, for example, which was briefly discussed in a case context. The majority of the empirical studies represented some sort of case descriptions of certain smart city solutions, cities, innovations, or projects. The studies used multiple research strategies, approaches, and methods, including both qualitative, quantitative, and mixed methods, e.g., as single or multiple case studies, or with the help of the interviews or wider surveys. The case study countries also varied. Among 72 articles that conducted empirical studies, mostly single or comparative case studies, a total of 46 countries were identified. These included 22 countries from Europe, 17 from Asia, two from North America, two from South-America and three from Africa.

4. Findings

The results of our study show that innovations are indeed seen as a key for the development of sustainable smart cities, i.e., tackling the problems of sustainable urban development with the help of different smart (ICT) technologies. In prior literature, smart city innovations are often understood through the categorization by Nam and Pardo (2011) of technology innovation, organization innovation, and policy innovation. However, as the development and understanding regarding smart cities has evolved, the innovation aspect has also widened and smart cities are seen as innovation ecosystems (Mayangsari & Novani, 2015), including different innovation mechanisms ranging from technological solutions to process renewal and citizen engagement (Angelidou et al., 2018).

As Lim et al. (2019) state, smart city projects in general include multiple types and dimensions of innovations and initiatives that aim for city development and sustainability. Although many papers consider SOIs mainly from a technological perspective, tackling the different ecological, social, and economic problems on an urban scale also requires other types of innovations such as social, managerial, strategic,

Table 2
Identified publications.

	Author(s)/year	Article type	Journal
1	Aamir, M. et al. (2019)	Empirical (case study)	Wireless Personal Communications
2	Abu-Rayash, A. & Dincer, I. (2021)	Empirical (case study)	Sustainable Cities and Society
3	Agarwal, P. et al. (2020)	Conceptual	Fourth World Conference on Smart Trends in Systems, Security and Sustainability (WorldS4)
4	Akbarpour, N. et al. (2021)	Theoretical	Soft Computing
5	Al-Nory, M.T. (2019)	Theoretical	IEEE Access
6	Al-Saidi, M. & Zaidan, E. (2020)	Theoretical/ empirical (case study)	Energy Reports
7	Allam, Z. & Jones, D. S. (2021)	Theoretical	Land Use Policy
8	Alzaed, A., & Balabel, A. (2020)	Empirical (case study)	Environmental Research, Engineering and Management
9	Angelaki, M. et al. (2020)	Theoretical review	PCI 2020: 24th Pan-Hellenic Conference on Informatics
10	Angelidou, M. et al. (2018)	Empirical	Journal of Science and Technology Policy Management
11	Asteria, D. et al. (2020)	Empirical (case study)	Journal of International Women's Studies
12	Baena, B. et al. (2020)	Case study	IEEE International Smart Cities Conference (ISC2)
13	Baudier, P. et al. (2020)	Empirical	Technological Forecasting and Social Change
14	Belli, L. et al. (2020)	Theoretical/ empirical (case study)	Smart Cities
15	Benites, A.J. & Simões, A.F. (2021)	Conceptual/ empirical (case study)	Ecological Indicators
16	Beretta, I. (2018)	Empirical	Cities
17	Bertini, F. et al. (2018)	Theoretical/ empirical	Proceedings of the IEEE
18	Bibri, S.E. (2018)	Conceptual/ empirical	European Journal of Futures Research
19	Bibri, S.E. (2019)	Theoretical/ conceptual	Journal of Big Data
20	Bibri, S.E. (2020)	Theoretical/ empirical (case study)	Energy Informatics
21	Bibri, S.E. (2021a)	Empirical (case study)	Energy Informatics
22	Bibri, S.E. (2021b)	Theoretical	World Futures
23	Bibri, S.E. (2021c)	Empirical (case study)	European Journal of Futures Research
24	Bibri, S.E. & Krogstie, J. (2017a)	Theoretical	Journal of Big Data
25	Bibri, S.E. & Krogstie, J. (2017b)	Theoretical review/ conceptual	Sustainable Cities and Society
26	Bibri, S.E. & Krogstie, J. (2017d)	Theoretical	Sustainable Cities and Society
27	Bibri, S.E. & Krogstie, J. (2020a)	Empirical (case study)	Energy Informatics
28	Bibri, S.E. & Krogstie, J. (2020b)	Empirical (case study)	Energy Informatics
29	Bibri, S.E. & Krogstie, J. (2021)	Empirical (case study)	Future Cities and Environment
30	Birkeland, J. (2020)	Theoretical/ empirical (case study)	Routledge book: Net-positive design and sustainable urban development
31	Blagojević, D. et al. (2020)	Theoretical	DETUROPE
32	Bosich, D. et al. (2020)	Project description	Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)
33	Bolz, K. (2018)		ORBIT Journal

(continued on next page)

Table 2 (*continued*)

	Author(s)/year	Article type	Journal
		Empirical (case study)	
34	Bucchiarone, A. et al. (2020)	Theoretical/ empirical (case study)	IEEE Transactions on Intelligent Transportation Systems
35	Budrin, A. et al. (2020)	Descriptive	IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)
36	Cao, S.. et al. (2020)	Conceptual	5th International Conference on Universal Village (UV)
37	Canli, H., & Toklu, S. (2021)	Theoretical/ empirical (case study)	IEEE Access
38	Carli, R. et al. (2016)	Theoretical/ empirical (case study)	IEEE transactions on systems, man, and cybernetics: systems
39	Casado-Mansilla, D. et al. (2018)	Empirical (project-based)	IEEE Access
40	Casini, M. (2020)	Empirical (case study)	Renewable Energy,
41	Catarinucci, L. et al. (2020)	Theoretical	IEEE Sensors Journal
42	Ceccarini, C. et al. (2020)	Empirical (project description)	FRUGALTHINGS'20
43	Cheela, V.S. et al. (2021)	Empirical (case study)	Journal of Urban Management.
44	Chen, Y.-T. (2011)	Conceptual	Environmental Science and Engineering
45	Chen, Y., & Silva, E. A. (2021)	Empirical	Transportation Research Interdisciplinary Perspectives
46	Chong, M. et al. (2018)	Empirical (case study)	Government Information Quarterly
47	Correira, D. et al. (2020)	Theoretical review	WIT Transactions on Ecology and the Environment
48	Corsini, F. et al. (2019)	Theoretical review	Technological Forecasting and Social Change
49	Cravero, S. (2020)	Theoretical review	Valori e Valutazioni
50	Cugurullo, F. et al. (2020)	Empirical (case study)	Urban Geography
51	D'Amico, G. et al. (2020)	Theoretical review/empirical (case study)	Sensors
52	D'Auria, A. et al. (2018)	Theoretical review	Sustainability
53	Das, A. et al. (2020)	Theoretical review	IEEE International Women in Engineering (WIE) Conference on Electrical and Computer Engineering (WIECON-ECE)
54	de Oliveira, J. R. et al. (2021)	Theoretical review/empirical	Sustainable Cities and Society
55	Doost Mohammadian, H. & Rezaie, F. (2020)	Theoretical/ empirical (case study)	Inventions
56	Dos Santos, M.J.P.L. (2016)	Theoretical	Urban Forestry and Urban Greening
57	Errichiello, L. & Micera, R. (2018)	Conceptual/ empirical (case study)	Sustainability
58	Ferraris, A. et al. (2018)	Empirical	Journal of Business Research
59	Foth, M. (2018)	Conceptual	Smart and Sustainable Built Environment
60	Fraske, T., & Bienzeisler, B. (2020)	Empirical (case study)	Sustainability: Science, Practice and Policy
61	Freudendal-Pedersen, M. et al. (2019)	Empirical (case study)	Sustainability
62	Galvão, J.R. et al. (2017)	Empirical (case study)	Management of Environmental Quality: An International Journal
63	García-Fuentes, M.Á. & de Torre, C. (2017)	Empirical (project-based)	Entrepreneurship and Sustainability Issues

Table 2 (*continued*)

	Author(s)/year	Article type	Journal
64	Giampietro, M. & Mayumi, K. (2018)	Conceptual	Frontiers in Energy Research
65	Giourka, P. et al. (2020)	Empirical (case study)	Smart Cities
66	Giourka, P. et al. (2019)	Theoretical/ conceptual	Energies
67	Girard, L.F. (2013)	Conceptual	Sustainability
68	Gómez-Expósito, A. et al. (2018)	Theoretical review/empirical (case study)	Proceedings of the IEEE
69	Gonzales-Gil, P. et al. (2021)	Descriptive	IEEE International Conference on Smart Internet of Things (SmartIoT)
70	Gutiérrez, V. et al. (2017)	Empirical (project-based)	IEEE Internet of Things Journal
71	Haarstad, H. & Wathne, M.W. (2019)	Empirical (project-based)	Energy Policy
72	Haque, A. B. et al. (2021)	Theoretical review	Expert Systems
73	Hildebrandt et al. (2018)	Conceptual/ empirical (case study)	Business and Information Systems Engineering
74	Horbliuk, S., & Dehtiarova, I. (2021)	Theoretical	Baltic Journal of Economic Studies,
75	Hou, L. et al. (2020)	Conceptual	International Conference on Intelligent Design (ICID)
76	Hsiao, Y.C. et al. (2021)	Empirical (case study)	IEEE Transactions on Engineering Management
77	Icasiano, C. D. A., & Taeihagh, A. (2021)	Empirical (case study)	Sustainability
78	Kahya, A. et al. (2021)	Theoretical review	International Conference on Computer Communications and Networks (ICCCN)
79	Khanjanasthiti, I. et al. (2021)	Empirical (case study)	Sustainability
80	Khatoun, R. and Zeadally, S. (2016)	Theoretical review/ conceptual	Communications of the ACM
81	Kraus, S. et al. (2015)	Empirical	Creativity and Innovation Management
82	Kwak, Y.H. & Lee, J. (2021)	Empirical (case study)	IEEE Transactions on Engineering Management
83	Laiolo, P. et al. (2021)	Empirical (case study)	IEEE 6th International Forum on Research and Technology for Society and Industry (RTSI)
84	Lawrence, S. et al. (2017)	Empirical	Field Actions Science Report
85	Lim, Y. et al. (2019)	Theoretical review	Cities
86	Linde, L. et al. (2021)	Empirical (case study)	Technological Forecasting and Social Change
87	Lindhult, E. et al. (2016)	Empirical (project-based)	Energy Procedia
88	Lopez-Carreiro, I. & Monzon, A. (2018)	Conceptual/ empirical (case study)	Sustainable Cities and Society
89	Malheiro, B. et al. (2019)	Empirical (project-based)	International Journal of Engineering Pedagogy
90	Mann, M. et al. (2020)	Conceptual/ empirical (case study)	Journal of the Association for Information Science and Technology
91	Marciano, C. (2013)	Theoretical	International Journal of Interdisciplinary Environmental Studies
92	Masseck, T. et al. (2017)	Empirical (project-based)	Energy Procedia
93	Matyushenko, I. et al. (2021)	Empirical (project-based)	2nd International Conference on Internet and E-Business
94	Mayangsari, L. & Novani, S. (2015)	Conceptual/ empirical (case study)	Procedia Manufacturing
95	Michelam, L. D. et al. (2021)	Empirical (case study)	Sustainability

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Table 2 (*continued*)

	Author(s)/year	Article type	Journal
96	Michelam, L. D. et al. (2020)	Theoretical review	Revista de Gestão Ambiental e Sustentabilidade
97	Miller, T.R. (2020)	Empirical (case study)	Science as Culture
98	Monachesi, P., & Witteborn, S. (2021)	Empirical (case study)	Telematics and Informatics
99	Mora, H. et al. (2021)	Theoretical review	Computers in Human Behavior
100	Mora, L. et al. (2021)	Theoretical	Journal of Urban Technology
101	Mulero et al. (2018)	Empirical (project-based)	IEEE Access
102	Muñoz, L. A., & Bolívar, M. P. R. (2021)	Theoretical/ empirical	Sustainability
103	Mutule et al. (2021)	Theoretical/ empirical	Energies
104	Naphade et al. (2011)	Empirical (case study)	Computer
105	Nesti, G. (2020)	Empirical (case study)	International Review of Administrative Sciences
106	Neves et al. (2020)	Theoretical review	Cities
107	Newman, A. O. (2020)	Theoretical	Urban Science
108	Nick, G. et al. (2018)	Theoretical review	DETUROPE
109	Nughara, Y. (2020)	Empirical (case study)	International Conference on ICT for Smart Society (ICISS)
110	Okafor, C. C. et al. (2021)	Empirical (case study)	Journal of Construction Management
111	Olszewski, R. et al. (2018)	Empirical	Sensors
112	Ortega-Fernández, A. et al. (2020)	Empirical (case study)	Sustainability
113	Pan, S. et al. (2021)	Theoretical review	International Journal of Production Research
114	Pardo-García, N. et al. (2019)	Conceptual/ empirical	Journal of Cleaner Production
115	Parlina, A. et al. (2021)	Theoretical review	Sustainability
116	Parmentola, A. et al. (2021)	Theoretical review	Business Strategy and the Environment
117	Paseto, L. et al. (2021)	Empirical (project-based)	IEEE International Smart Cities Conference (ISC2)
118	Paskaleva, K. et al. (2021)	Empirical (case study)	European Urban and Regional Studies
119	Peponi, A., & Morgado, P. (2021)	Conceptual	Land
120	Pereira, G. et al. (2020)	Theoretical review	13th International Conference on Theory and Practice of Electronic Governance
121	Polderman, A. et al. (2020)	Empirical	Sustainability
122	Popescu, A. I. (2020)	Conceptual/ empirical (patent analysis)	Sustainability
123	Qaed, F. (2020)	Theoretical review/empirical	Proceedings of the 3rd IET International Smart Cities Symposium, September 21–23, Bahrain
124	Radulescu, C.M et al. (2020)	Theoretical/ empirical (field investigation)	Sustainability
125	Radziejowska, A., & Sobotka, B. (2021)	Theoretical/ conceptual	Energies
126	Rehm, S.V. et al. (2021)	Empirical (case study)	Smart Cities
127	Robaeyst, B. et al. (2021)	Empirical (case study)	Sustainability
128	Romanelli, M. (2018)	Theoretical review	Systems Research and Behavioral Science
129	Sabatini-Marques, J. et al. (2020)	Empirical	Sustainability
130	Sánchez, L. et al. (2020)	Empirical (case study)	Wireless Personal Communications
131	Sarosh, P. et al. (2021)	Empirical	Sustainable Cities and Society
132	Şerban, A. C., & Lytras, M. D. (2020)	Theoretical review	IEEE Access
133	Shi, F. et al. (2018)	Conceptual	IEEE Transactions on Intelligent Transportation Systems
134	Shin, S.Y. et al. (2021)	Empirical	Sustainability
135	Siljanoska, J. & Korobar, V.P. (2017)	Empirical (case study)	Prostor
136	Simunic D. et al. (2021)	Theoretical review	4th International Convention on Information, Communication and Electronic Technology (MIPRO)
137	Soeiro, D. (2021)	Empirical (project-based)	Fennia
138	Song, T. et al. (2021)	Theoretical/ empirical	Journal of the Knowledge Economy
139	Soutullo, S. et al. (2020)	Empirical (case study)	Energies
140	Tantau, A., & Şanta, A. M. I. (2021)	Empirical (case study)	Smart Cities
141	Toppeta, D. (2010)	Conceptual	Think! The Innovation Knowledge Foundation
142	Trencher, G. & Karvonen, A. (2019)	Empirical (case study)	Local Environment
143	Treude, M. (2021)	Theoretical review	Sustainability
144	Uzumaki, T. (2014)	Empirical (case study)	Fujitsu Scientific and Technical Journal
145	Valdez, A.-M. et al. (2018)	Empirical (case study)	Technology Analysis and Strategic Management
146	Van den Buuse, D. et al. (2021)	Theoretical	Journal of urban technology
147	Vinci, G. et al. (2019)	Empirical	International Journal of Innovative Technology and Exploring Engineering
148	Wang, Y. et al. (2019)	Theoretical/ empirical (case study)	Technological Forecasting and Social Change
149	Yang, J. et al. (2020)	Empirical (case study)	IEEE Access
150	Yang, Z. et al. (2021)	Theoretical/ conceptual	Complexity
151	Yeasmin, S. et al. (2020)	Conceptual	International Conference on Artificial Intelligence & Modern Assistive Technology (ICAIMAT)
152	Yigitcanlar, T. et al. (2021)	Theoretical review	Journal of Urban Technology
153	Yigitcanlar, T. et al. (2019c)	Theoretical review	Journal of Open Innovation: Technology, Market, and Complexity
154	Zaballos, A. et al. (2020)	Conceptual/ empirical (case study)	Sustainability
155	Zeng, L. et al. (2021)	Conceptual	International conference on intelligent transportation, big data & smart city (ICITBS)
156	Zhang, Q. et al. (2020)	Technological	Sustainability
157	Zheng et al. (2020)	Theoretical review	Journal of Cleaner Production
158	Zhuang, H. et al. (2020)	Theoretical	Sustainability
159	Zygiaris, S. (2013)	Conceptual	Journal of the Knowledge Economy

and policy innovations (e.g. Zeng et al., 2021). The review results show that the development of SOIs in a smart city context are also increasingly linked to the creation of innovation networks, open innovation practices, and citizen engagement. As the SOI literature highlights (e.g., Adams et al., 2016), the need for achieving change at the system level

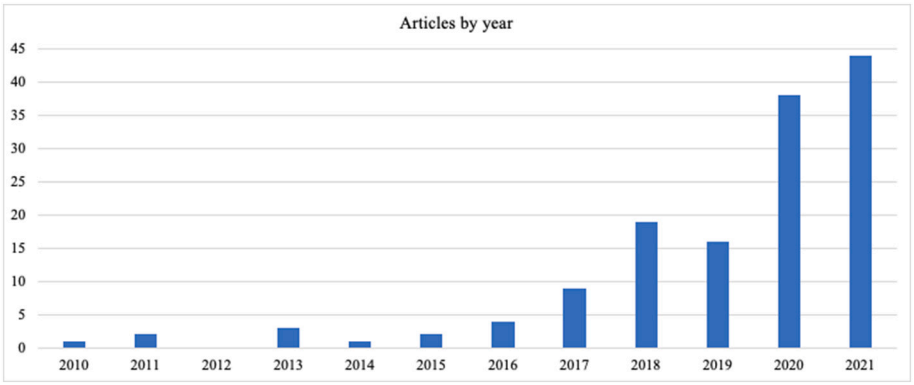

Fig. 2. Journal articles by year.

exists and as Toppeta (2010) states, innovative solutions are important in the management of a complex system like a smart city project.

Based on the extensive analysis of the literature, we first identified four main perspectives through which scholars discourse the SOI dimensions in a smart city context: the technology perspective, the organizational perspective, the social innovation perspective with citizen engagement, and system-level changes with innovation ecosystems. Second, we recognized various focused themes under each main perspective. These are described in Table 3, with references to the related literature sources and with practical examples of SOIs.

4.1. Technology perspective on SOI

In our data set, many of the articles (104 out of 159) included technology-oriented innovations as one essential dimension of sustainability-oriented innovation. More specifically, many authors see the development of SOIs in smart cities from the perspective of the use of different ICTs and applications (Bibri, 2019; Bibri & Krogstie, 2017a, 2017b, 2017c; Bolz, 2018; Gonzalez-Gil et al., 2021; Khatoun & Zeadally, 2016; Kraus et al., 2015; Lawrence et al., 2017; Marciano, 2013; Nick et al., 2018; Olszewski et al., 2018; Yeasmin et al., 2020). In addition, some authors highlight the implementation of different environmental technology innovations (eco-/green innovations) (Beretta, 2018; Chen, 2011; Yang et al., 2021), and process innovations (Galvão et al., 2017; Zhuang et al., 2020). In general, technological innovations bring information and provide tools to support measurement and management activities for more sustainable cities (e.g., low-carbon energy systems) (D'Amico et al., 2020; Pardo-García et al., 2019; Uzumaki, 2014). They also provide opportunities and possibilities for innovations to encourage citizens towards sustainability actions (Kahya et al., 2021).

Technology and innovation are seen as key enablers in sustainable and smart cities (D'Auria et al., 2018; Lopez-Carreiro & Monzon, 2018). By integrating new technology into the management and operation of cities, smart cities are seen to offer innovative solutions to the challenges of sustainability, equity, and economic growth in cities and urban regions (Haarstad & Wathne, 2019; Pereira et al., 2020; Toppeta, 2010). As Miller (2020) states, smart cities are entangled with techno-political projects related to innovation, economic development, and commitments to sustainability. In other words, innovation is seen as a tool (software) that helps city managers to integrate urban policies and measures with sustainability (for example, controlling air quality, land use and water use at a city level) (Pardo-García et al., 2019). More recently, technological innovations (such as IoT and 6G network) have been discussed in the context of increasing pandemic resiliency of cities as the COVID-19 pandemic has brought a need for several types of digital and smart services e.g. for tracking people and allowing remote work (Allam & Jones, 2021; Khanjanasthiti et al., 2021; Newman, 2020; Nugraha, 2020).

Technological innovations are also seen as a basis for system-level innovation (Zhang et al., 2020), including the development of transportation systems (Angelaki et al., 2020; Bosich et al., 2020; Valdez et al., 2018; Yigitcanlar et al., 2019c), food systems (Baena et al., 2020) and low-carbon energy systems (Pardo-García et al., 2019; Galvão, 2017; Zhuang et al., 2020), for example.

In addition to the papers describing the opportunities enabled by new technologies, there are also papers discussing the other sides of the coin, the darker sides, and risks related to new data-driven technologies adoption in smart city contexts. Technologies are seen to solve many problems, but in reality, as Cao et al. (2020) notes, the technology developing at highspeed but lacking human consideration is leading to more and more eco-challenges. The short technological innovation cycles also cause the generation of a lot of e-waste, creating sustainability challenges (Das et al., 2020). Bibri (2021a, 2021b, 2021c) provides critical perspectives on data-driven smart urbanism in terms of the associated risks and implications, raising several critical questions involving technocentric policies and technocratic governance, as well as other aspects of social and environmental sustainability. Allam and Jones (2021) identified challenges related to the use of 6G technologies, like infrastructure capacity limitations, network security, energy efficiency, high price tag, and so on. As Treude (2021) mentions, a Smart city does not always lead to sustainability as digitalization may improve e.g., energy efficiency, but the opposite impact is also possible. Data security issues have been raised in connection to many novel technologies in cities (e.g., Budrin et al., 2020), such as autonomous vehicles (Cugurullo et al., 2020), real-time monitoring, and cloud computing (D'Amico et al., 2020; Haque et al., 2021), to mention a few. Technologies like blockchain may also include issues related to social acceptance (Belli et al., 2020; Mora et al., 2021) and sustainability in terms of energy consumption (Parmentola et al., 2021). Shin et al. (2021) also emphasize the so-called digital divide as a gap related to user engagement in new technologies. Based on their survey results in Korea (Shin et al., 2021), socio-demographic factors like age, income and region may explain the digital divide in cities. Furthermore, regarding technology sovereignty and its issues, Mann et al. (2020) suggested advancing it by emphasizing public and common interests rather than private interests in smart urban development.

4.2. Organizational and managerial perspective on SOI

In the literature, the development of SOIs in smart cities are also considered from the organizational innovation perspective. In this paper, organizational perspective for SOI means implementing a new organizational method for internal practices, ways of working or external relations.

In general, the concept of the smart city is even seen to emerge as a strategic innovation to limit the issues arising from the growth of the urban population (sustainable development and QoL) and meeting urban challenges (Mayangsari & Novani, 2015).

Table 3
Summary of findings.

Themes	Examples of SOIs	Other literature sources under the theme
Technology perspective to SOI		
Eco-efficiency: (environmental) technology and process innovations as a basis for SOI.	A model for an energy system for a public services building (mix of energy production processes based on PV panels and biomass boilers) (Galvão et al., 2017). A methodology/model applying multi-objective function and considering several supply chain architectures to optimize total cost and energy variation in the electricity grid (Al-Nory, 2019) GreenSoul project: an innovative energy-efficient platform which enhances traditional public-use buildings with various smart technologies (Casado-Mansilla et al., 2018) ReStart4Smart, an energy positive smart home (Casini, 2020) Solatube daylight system in sustainable buildings to lower energy consumption (Alzaed & Balabel, 2020) The Plastic Bank: blockchain incentive for sustainable behavior. Rewarding users for recycling plastics with blockchain tokens that are convertible with respective local fiat currencies or exchangeable with goods and services such as water, food and tuition. (Kahya et al., 2021)	Akbarpour et al., 2021; Beretta, 2018; Chen, 2011; D'Auria et al., 2018; Gonzalez-Gil et al., 2021; Khatoun & Zeadally, 2016; Lopez-Carreiro & Monzon, 2018; Ş erban & Lytras, 2020; Yang et al., 2021; Yeasmin et al., 2020; Zhuang et al., 2020
Infrastructure technologies and socio-technical solutions: technological innovations as tools for the measurement, management, and operation of cities towards SOI.	Retrofitting: installing energy-efficient solutions and digital solutions for energy management and visualization of energy consumption and water usage in public housing apartments. The aim is to reduce emissions and upgrade living standards (Haarstad & Wathne, 2019). Open data portal: availability of Geographic Information System data on the council's Open Data Portal for public use. Including information on council administration, local environment, parks and recreation, planning and building, stormwater, transport, and water and sewerage services (Khanjanasthiti et al., 2021) The framework of sensor cities: integrating various sensors and big data analysis technologies to optimize urban infrastructures and services, and turning the urban system into a smart one (D'Amico et al., 2020) Inteli.gente platform: a system for diagnosing and assessing the level of maturity in the various themes for cities to become smart (Paseto et al., 2021)	Al-Saidi & Zaidan, 2020; Belli et al., 2020; Bibri, 2021b; Canli & Toklu, 2021; Das et al., 2020; Gómez-Expósito et al., 2018; Laiolo et al., 2021; Miller, 2020; Neves et al., 2020; Okafor et al., 2021; Polderman et al., 2020; Pardo-García et al., 2019; Popescu, 2020; Song et al., 2021; Tantau & Șanta, 2021; Toppeta, 2010; Uzumaki, 2014
ICT and data-enabled solutions: IoT technologies and applications as a basis for SOI. Smart technology innovations to increase pandemic resiliency	Big data, IoT, Wireless Network Technologies, data analytic systems and techniques, etc. as a basis for innovations to monitor and manage environmental emissions, parking, traffic intensity, and parks and gardens irrigation, for example (Sánchez et al., 2020). Motion Maps, smart transportation app (Valdez et al., 2018). Improved public transportation through smart cards and real-time route information (Lawrence et al., 2017). Autonomous vehicles (Cugurullo et al., 2020; Yigitcanlar et al., 2019c) and Autonomous Shuttles-as-a-Service (Bucchiarone et al., 2020) System-intelligent automatic waste removal, including several innovative technologies, utilization of IoT, ROS route robot operating system and RRT path planning algorithm (Zhang et al., 2020). A smart campus' digital twin (Zaballos et al., 2020)	Allam & Jones, 2021; Bibri and Krogstie, 2017a, b, c, 2020a, b, 2021; Bibri, 2019, 2021a, 2021c; Bosich et al., 2020; Bolz, 2018; Catarinucci et al., 2020; Khanjanasthiti et al., 2021; Khatoun & Zeadally, 2016; Kraus et al., 2015; Marciano, 2013; Mora et al., 2021; Mutule et al., 2021; Newman, 2020; Nugraha, 2020; Olszewski et al., 2018; Parmentola et al., 2021; Shin et al., 2021; Sarosh et al., 2021; Shi et al., 2018; Yigitcanlar et al., 2021
Organizational and managerial perspective to SOI		
Managerial solutions: innovations in planning, assessment, management, and operations for the development of sustainable smart cities. Innovations in supporting regulations, policies and governance	DROMS (a demand response optimization and management system—controlling and predicting distributed energy sources) (Angelidou et al., 2018). SureCity Platform (the Sustainable and Resource Efficient Cities—Holistic simulation and optimization for smart cities) (Pardo-García et al., 2019). Urban Experimentation platform (Rehm et al., 2021) The triangular Pyramid Trunk: the three Smart City Axes – a smart city assessment tool (Correira et al., 2020)	Abu-Rayash & Dincer, 2021; Agarwal et al., 2020; Baena et al., 2020; Benites & Simões, 2021; D'Amico et al., 2020; de Oliveira et al., 2021; Fusco Girard, 2013; Fraske & Bienzeisler, 2020; Hsiao et al., 2021; Horbliuk & Dehtiarova, 2021; Icasiano & Taeihagh, 2021; Naphade et al., 2011; Pan et al., 2021
Strategic service innovations in cities: strategic innovations for management, design, and governance of sustainable smart cities. Implementation of different technologies, services, and business approaches.	Remourban project: the purpose of urban transformation towards the smart city (Garcia-Fuentes & de Torre, 2017). VioSIn (Vision-Oriented service innovation, sketching technology roadmap for service innovation) (Chen, 2011).	Bibri, 2018, 2019; Blagojević et al., 2020; Carli et al., 2016; Cheela et al., 2021; Doost Mohammadian & Rezaie, 2020; Chen & Silva, 2021; Garcia-Fuentes & de Torre, 2017; Kwak & Lee, 2021; Matyushenko et al., 2021; Nesti, 2020; Yang et al., 2020
Business model innovations for	Smart city business model canvas as a framework to support creative development,	Garcia-Fuentes & de Torre, 2017; Hou et al., 2020; Khatoun

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Table 3 (*continued*)

Themes	Examples of SOIs	Other literature sources under the theme
sustainable smart city development.	visualization, and communication of sustainable smart city business model innovations (Giourka et al., 2019). Multi-agent smart city framework (including IS-enabled bonus scheme system that significantly motivated consumers to reduce reckless and wasteful driving) (Hildebrandt et al., 2018).	& Zeadally, 2016; Tantau & Şanta, 2021
Dynamic capabilities: innovation management capabilities are needed in the planning and management of smart cities towards sustainability, especially for the development of a capability for radical/ disruptive innovation.		Chong et al., 2018; Linde et al., 2021; Lindhult et al., 2016; Mayangsari & Novani, 2015; Nick et al., 2018; Ortega-Fernández et al., 2020; Pan et al., 2021; van den Buuse et al., 2021
Social innovation and citizen engagement		
Well-being and healthcare in cities: social innovation actions supported by ICT solutions: including citizens in the process of building SOIs.	Safe and self-determined life project—users provided with services ordered through touchscreen terminal at home. Aim to support (older) people to live longer in their own homes (Bolz, 2018). Pressure Tel—home-based telemonitoring solution for patients suffering from high blood pressure (Bolz, 2018). City4Age platform: a Smart City oriented infrastructure for unobtrusively collecting and managing data related to elderly people behavior patterns (Mulero et al., 2018)	Corsini et al., 2019; Olszewski et al., 2018; Sánchez et al., 2020; Trencher & Karvonen, 2019; Zheng et al., 2020
Citizen inclusion: need for the inclusion of individuals and communities in the development of SOI. Citizen engagement is key for networked value creation and creating capacity to innovate. Need for innovative methods for citizen education and participation in sustainable urban development and diffusion of innovations.	London as a living lab (Miller, 2020). Creating collaborative sustainability maps with citizens in Barcelona (Lawrence et al., 2017). Serious games for sustainable urban development (Cravero, 2020). Gamification that incentivizes carpooling (Olszewski et al., 2018). FruGar: a responsive web app to facilitate casual citizen when gardening (Ceccarini et al., 2020)	Asteria et al., 2020; Baudier et al., 2020, Chong et al., 2018; D'Auria et al., 2018; Bolz, 2018; Gutierrez et al., 2018; Malheiro et al., 2019; Monachesi & Witteborn, 2021; Muñoz & Bolívar, 2021; Nugraha, 2020; Radziejowska & Sobotka, 2021; Robaeyst et al., 2021; Siljanoska & P Korobar, 2017; Simunic et al., 2021
Innovation ecosystems and system-level changes		
Innovation ecosystems to foster SOI: collaborative innovation and innovation networks aiming for "smart citizenship". Knowledge-based	The smart open innovation of MuseoTorino (Errichiello & Micera, 2018). Experimentation-As-A-Service (EaaS) platform: Mobilizing the ecosystem (Gutierrez et al., 2018) Billy, a smart billboard for	Asteria et al., 2021; Bibri, 2019; Ferraris et al., 2018; Giourka et al., 2020; Kwak & Lee, 2021; Masseck et al., 2017; Michelam et al., 2021; Rădulescu

Table 3 (*continued*)

Themes	Examples of SOIs	Other literature sources under the theme
urban development to innovation and sustainability. *Open innovation*: open models and collaborative development of knowledge-sharing platforms and smart city services to achieve sustainability goals.	monitoring urban areas and displaying real-time information regarding the air in public green spaces as well as recommendations to citizens on how to improve local air quality (Malheiro et al., 2019). Triangulum project: a model for smart city innovation ecosystem (Paskaleva et al., 2021)	et al., 2020; Romanelli, 2018; Sabatini-Marques et al., 2020; Soeiro, 2021; Tantau & Şanta, 2021; Vinci et al., 2019; Zygiaris, 2013
Systemic transition: cities transition towards sustainability (and energy smart cities) is a complex, systemic innovation journey. System innovations need integration of managerial and technological innovations.	Smart transportation system as a system-level innovation integrating different smart technologies (IoT, WSN) and services (e.g., big data analytics), require political actions (Aamir et al., 2019). City-to-share and EASYRIDE—automatized driving (Freudendal-Pedersen et al., 2019). Systemic solution maps and generic roadmaps—systemic approach to future energy solutions (Masseck et al., 2017). Aquaponics as an innovative smart and sustainable production system for integrating aquaculture with hydroponic vegetable crops (Dos Santos, 2016).	Cheela et al., 2021; Garcia-Fuentes & de Torre, 2017; Lindhult et al., 2016; Mora et al., 2021; Peponi & Morgado, 2021; Soutullo et al., 2020, Wang et al., 2019

In addition to technological innovations, the transformation towards sustainable smarter cities is seen to require innovation in planning, management, and operations of cities (Agarwal et al., 2020; Angelidou et al., 2018; Fusco Girard, 2013; Naphade et al., 2011). Some of the authors emphasize strategic innovations for management, design, and governance in particular (Bibri, 2018, 2019) to implement different technologies, services and business approaches for favoring the transition to smart cities (Chen, 2011; Garcia-Fuentes & de Torre, 2017), and to achieve sustainable development goals (Doost Mohammadian & Rezaie, 2020). The others highlight the need for supporting regulations, policies and governance towards SOIs in smart cities (Fraske & Bienzeisler, 2020; Kwak & Lee, 2021).

Lindhult et al. (2016) emphasize the need for considering innovation management capabilities in smart city planning and development towards sustainability. These capabilities can be categorized through the five dimensions of strategy, organization, processes, linkages, and learning, also used in innovation management and SOI literature (e.g., Adams et al., 2016; Tidd & Bessant, 2018). Furthermore, the researchers identify the importance of dynamic capabilities (Chong et al., 2018; Linde et al., 2021) and the need for the development of the capability for radical and disruptive innovation to take advantage of ICTs (Nick et al., 2018; Ortega-Fernández et al., 2020).

On more practical levels, the SOIs in smart cities are also considered through the need for the development of business model innovations (Garcia-Fuentes & de Torre, 2017; Giourka et al., 2019; Hou et al., 2020; Khatoun & Zeadally, 2016), for instance from the perspective of combining sustainable technologies with sharing business models (Hildebrandt et al., 2018; Hou et al., 2020).

4.3. Social innovation and citizen engagement

Although most of the analyzed articles consider SOI particularly

from the environmental perspective, some authors emphasize the role of social innovations in the creation of smart cities. Authors speak about responsible innovation (Bolz, 2018) and innovations considering health-related issues (Sarosh et al., 2021), frugal innovation (Ceccarini et al., 2020), community building, educational and behavioral development (Trencher & Karvonen, 2019) for example. The different (ICT) technologies are seen to support the creation of social innovations, but these need to be co-created in close collaboration with citizens (Corsini et al., 2019; Olszewski et al., 2018; Sánchez et al., 2020). As Zheng et al. (2020) summarize, ICT innovations enable a sustainable future for citizens, but they are only tools, and the people and socio-technical aspects also have to be emphasized for real "smartness", i.e., social innovations are also important. In their study on the digital divide on smart city innovations, Shin et al. (2021) emphasize that diverse social groups should be engaged, and that the necessity factor is important. If there is no real need for using new technologies, this may negatively affect citizen engagement and sustainability in a smart city.

In addition to technology-connected innovations, smart cities include human and participatory aspects (D'Auria et al., 2018). As Malheiro et al. (2019) mention, urban equipment (e.g., for sensing and displaying information) need to become smarter, meaning these should be connected, interactive, and involve the people. Qaed (2020) even introduce a concept of human smart city, where people, rather than technology, are major players of urban smartness. Many authors highlight the need for the inclusion of individuals and communities in the development of SOI (Miller, 2020; Nugraha, 2020; Siljanoska & P Korobar, 2017), i.e., the need for bottom-up approaches (Chong et al., 2018) and inclusion of citizens in urban decision-making (e.g., Asteria et al., 2020). Foth (2018) also emphasizes the transition of city governments' roles regarding smart urban development. Moving from administrator and service provider roles to a facilitator and collaborator also means that citizens are not only passive residents or consumers but participators and co-creators in innovative urban development. Including citizens in innovations projects is a basis for networked value creation (Bolz, 2018) and is seen as key in creating capacity to innovate (Lawrence et al., 2017). On the other hand, citizen engagement also needs innovative methods for citizen education and participation for sustainable urban development (Cravero, 2020). For example, Simunic et al. (2021) introduce a concept of Smart creative city to enable and support pilot projects to introduce a new way of holistic thinking and the use of creativity of the citizens.

4.4. Innovation ecosystems and system-level changes

As the results show, lately the literature has started to emphasize the importance of innovation networks and ecosystems in the building of sustainable smart cities (e.g., Gutiérrez et al., 2017; Paskaleva et al., 2021; Rehm et al., 2021) A strong innovation ecosystem is seen to have a leading role in fostering sustainable innovation (Ferraris et al., 2018) and creating new business models and smart growth (Zygiaris, 2013). Authors emphasize the need for collaborative development and public-private partnerships (Rădulescu et al., 2020; Tantau & Şanta, 2021; Vinci et al., 2019), shared resources (Bibri, 2021a, 2021b, 2021c), and open innovation models of smart city services to achieve sustainability goals (Errichiello & Micera, 2018; Giourka et al., 2020; Malheiro et al., 2019; Masseck et al., 2017). As Giourka et al. (2020) note, an open innovation environment aligned well with the market needs and strategic collaboration of stakeholders such as public authorities, industrial leaders, investors, research organizations, and citizen communities are critical enablers in the development of smart cities meeting the various needs of different actors. These allow the creation of knowledge-sharing platforms (Bibri, 2019) and sustainable digital ecosystems (Romanelli, 2018) that work as a basis for smart sustainable cities as innovation labs or, more ambitiously, as urban experimentation platforms (Rehm et al., 2021).

On a large scale, the transition of cities towards sustainability (and energy smart cities) is seen as a complex, systemic innovation journey (Lindhult et al., 2016). Technological innovations (and ICT) and the creation of integrated infrastructures and processes are the basis for the development of different smart and sustainable systems in cities (Garcia-Fuentes & de Torre, 2017), but we should not too much rely on "solutionism" and technology-centrism (Mattern, 2021; Morozov, 2014). Instead, the aim should be to have a system-level understanding, which is also balanced in terms of sustainability. Furthermore, different innovations, such as automatized vehicles, challenge entire industries and thus drive system-level changes (Freudendal-Pedersen et al., 2019). SOIs in smart cities can consider entire production systems, being a combination of managerial and technological innovations (Dos Santos, 2016). Smart system-level transformation requires the integration of smart technologies, smart decision-making and management, a market-oriented approach, and strengthening environmental awareness in cities (Wang et al., 2019).

The results show that many of the articles in the review include multiple dimensions of SOI and can also fit under several themes. In practice, all the articles in the analysis are relatively new, i.e., published between 2010 and 2021. Within this period many themes under the perspective of technology-related solutions, for example, have remained strong, although some new emphasized areas can also be noted. At the same time, certain themes like emerging innovation ecosystems and citizen engagement have attracted increased attention in recent years regarding SOIs in smart city contexts. In the following Discussion chapter, the findings from our observations and analyses are discussed in more detail by reflecting on them in relation to prior literature on the smart city dimensions and components.

5. Discussion: SOIs in smart cities

In the majority of the publications, sustainable development was seen as a natural part of smart city development. Despite most of the studies acknowledging the three sustainability dimensions of SOIs (the aim for economic, environmental, and social value creation), the premises of considering SOIs in a smart city context varied. In the following, the SOI application areas are considered through the seven smart city components, four of which can be considered to enable the development of sustainable smart cities (technology, governance, economic, and human components) and three of them working as a target for innovations (public services, natural environment, and physical infrastructure).

In most of the studies, the *technological aspect* was considered as a natural part of smart city development and definition. In some studies, sustainable smart city development was considered purely from a technological perspective (e.g., application of ICT technologies, IoT, big data, and related applications). For example, Bibri and Krogstie (2017a, 2017b, 2017d) studied the core enabling technologies of big data analytics and context-aware computing for smart sustainable cities. Even if the technologies were not the core focus of the paper, technological solutions were seen as tools and being a basis for the innovations and the development of smart governance (e.g., Pardo-García et al., 2019), economics (e.g., Khatoun & Zeadally, 2016), environment (e.g., Malheiro et al., 2019), living (e.g., Casini, 2020; Lawrence et al., 2017), and mobility (e.g., Garcia-Fuentes & de Torre, 2017).

As indicated in the previous chapter, SOIs with the technology dimension may be related to more operational level eco-efficiency, ICT-enabled solutions, or more system-level infrastructure solutions. Regarding the efficiency-focused approaches, which have seemed to dominate quite widely, it is also essential to notify the big picture in addition to lower-level efficiency gains. As proposed by Birkeland (2020), the focus should be on net-positive design, which may require a transition to more open systems with strong ecological and ethical perspectives rather than focusing on trade-offs between the elements of the sustainability triple bottom line in a closed system. Yigitcanlar et al. (2019b) also remind us that there are empirical studies, which show that

the "smartness" has not too often positively influenced on the environmental sustainability, although the quality of life of citizens and economic prosperity would have been improved. Thus, they suggest paying attention to decentralizing human in the center of urban development to move towards truly post-anthropocentric and "more-than-human" cities, which are at the same time smart and sustainable (Yigitcanlar et al., 2019b). Another issue that needs to be considered regarding the efficiency-focused innovations in smart cities is the phenomenon known as the Jevons Paradox (e.g., Giampietro & Mayumi, 2018), which means that the efficiency in using resources may eventually lead to an increase in resource consumption rather than a decrease.

In addition to the technology perspective, many studies focused on the *governance* of smart cities (i.e., the development of smart governance) (Das et al., 2019; Kwak & Lee, 2021). It is essential that the sustainable smart city development is addressed by looking at the big picture and identifying opportunities for development and innovation. As Yigitcanlar et al. (2019b) note, the development of smart and sustainable cities requires the use of a healthy mixture of smart technologies, people, and policies. Cities need to develop a high-level agenda and strategies for the smart city to push sustainability achievements (Haarstad & Wathne, 2019) and more concrete management actions to fight against the challenges in innovation and the transition work of cities towards sustainability (Lindhult et al., 2016). There is a need for changes towards smart governance. However, as Belli et al. (2020) acknowledge, the changes in government models, which are needed for smart city development, still present challenges. The governance models face the challenge of combining top-down policies with bottom-up approaches, i.e., welcoming citizen engagement and collaboration. This requires actions of increasing flexibility and informality as well as increasing transparent communication actions to lower the gap between citizens and government and address, for example, territorial cohesion.

From an *economic* (and social) city development perspective, there is a need to focus on business models (Giourka et al., 2019), business opportunities, and entrepreneurs (Kraus et al., 2015). These work as a basis for smart growth, the creation of economic well-being, and improving quality of life (e.g., Zygiaris, 2013), i.e., the development of a smart economy (Das et al., 2019). Cities should support the development of integrated business and economic models (how organizations should deliver and reap benefits from their services) to support sustainable smart city development (Khatoun & Zeadally, 2016; Tantau & Şanta, 2021).

From a *human* perspective, it is evident that citizen engagement at multiple levels is the key for higher-level SOI and achieving sustainable development goals at a city level. This means providing opportunities for people to participate in the development of city life and enabling the development of smart citizenship (e.g., Asteria et al., 2020; Vinci et al., 2019). Human and social capital (i.e., smart people, Das et al., 2019) plays a key role in developing new or improved smart city services (i.e., smart innovation) for sustainability goals (e.g., Errichiello & Micera, 2018). However, the development of more impactful SOIs require cities to create premises for high-level education and the development of social capital (knowledge and creativity) (Malheiro et al., 2019; Simunic et al., 2021; Trencher & Karvonen, 2019), as well as developing new knowledge-sharing possibilities (Michelam et al., 2021; Zaballos et al., 2020). Furthermore, the necessity factor (a real need for engagement) and inclusion of diverse groups of citizens in technology usage need to be taken into account to avoid possible negative consequences for citizen participation (Shin et al., 2021). Although our review reveals the increased importance of citizen engagement in smart sustainable urban planning, the cities should, however, be careful in using the engagement methods and not lean too much on top-down approaches that do not lead to a real change. Otherwise, there may be a pitfall of drifting to undesirable situations, which are discussed as "tokenism" or "engagement theater" by scholars in these fields (Kamols et al., 2021; Mattern, 2020; Monno & Khakee, 2012). To cope with these types of challenges, Fredericks et al. (2019) suggest a "middle-out approach" (between top-down and bottom-up) to community engagement, including, for example, a series of "pop-up interventions" to enable continuous systemic change.

In the papers, SOIs are also considered through the more concrete development of different types of *public services* (i.e., the development of smart services, smart transportation and smart living) (e.g., Das et al., 2019; Song et al., 2021). Many of the authors consider different solutions for the development of smart mobility and transportation systems (e.g., Chen & Silva, 2021; Freudendal-Pedersen et al., 2019; Lopez-Carreiro & Monzon, 2018), as well as cultural, health, and social services (e.g., Bolz, 2018). The aim of these innovations is to improve living conditions, create social well-being and reduce negative impacts on the environment. For example, a carpooling system for smart transportation addresses both social and environmental problems faced in cities (Olszewski et al., 2018). However, like for example Chen and Silva (2021) note, smart transportation systems are uncertain and complex due to the inclusion of rapidly developing technological innovations. In addition, previously mentioned data security and data ownership issues (Icasiano & Taeihagh, 2021; Khanjanasthiti et al., 2021) must be seriously coped with in systems planning.

Sustainable urban development and SOIs are often easily understood as solutions to environmental problems. This aspect was also visible in the analyzed literature. SOIs in smart cities that target the well-being of the *natural environment* include solutions for energy management (driving energy system transformation and the development of a low-carbon economy) (Polderman et al., 2020), eco and green innovations to protect natural resources (Beretta, 2018), different solutions to control pollution (Angelidou et al., 2018; dos Santos, 2016), and developing waste management (Akbarpour et al., 2021; Catarinucci et al., 2020; Zhang et al., 2020). Some of these solutions also consider the development of *physical infrastructure* such as energy and water networks (Doost Mohammadian & Rezaie, 2020), power networks (e.g., Gómez-Expósito et al., 2018; Naphade et al., 2011), and energy-efficient buildings (Casado-Mansilla et al., 2018; Zhuang et al., 2020). These innovations aim for the development of a smart environment, smart infrastructures, and smart living (Das et al., 2019).

6. Concluding remarks

This study has managed to uncover several of the linkages between sustainability-oriented innovation and smart city development. A systematic literature review was conducted and based on a thorough analysis of 159 selected articles, we identified four main perspectives from which the scholars discourse the SOI dimensions in the smart city context:

- technology perspective
- organizational and managerial perspective
- social innovation perspective with citizen engagement
- system level changes with innovation ecosystems.

Under each of these dimensions, we have also revealed several themes with multiple SOI examples reported in the reviewed articles.

In addition to recognizing the dimensions with the themes, it has also been essential to reflect the review results on our existing understanding of different smart city components, i.e., the enablers and the targets of the sustainable smart city development. As expected, quite a lot of research has been done with a particular focus on the technological development perspective of smart city development—this also with the sustainability-oriented aspect. At the same time the review has also revealed the wide variety of viewpoints on how innovation is—or should be—considered regarding the components of governance, economic, and human aspects in this complex entity targeting the improved development of city infrastructures and public services in a sustainable way.

As theoretical implications, this study has increased our

understanding of the interconnections between the recognized SOI dimensions and the smart city development components. Due to the relatively novel phenomenon that we aimed to address in this review, the analyzed data concerns relevant existing research articles from the last eleven years. However, during this period there are already some SOI-related themes that are worth mentioning as they appear in several articles, and on the other hand, there are certain themes that can be considered more as emerging ones, potentially affecting future research in this context. For example, based on the analysis of this study, we can derive a tendency towards a need for more research into social dimensions, human-centric approaches, and citizen inclusion/engagement in smart city development. It would be interesting to look for citizen participation in public decision-making regarding SOI by executing qualitative research among citizens as well as public decision-makers. Another potential theme for the increasing amount of research can be related to cities' capabilities in terms of the development of SOI. Finally, rather than considering data-related digital transformation and sustainable development as separate but complementary areas of development, it may be relevant to consider these viewpoints as a parallel development perspective, i.e., considering the so-called twin transition in the smart city context.

Furthermore, in addition to theory-related implications, the findings of this study can also be valuable in terms of city governance, management, and policy-level implications. The increased interest in interdisciplinary viewpoints for development including SOI development may help policy-makers and managers to establish collaborative platforms and innovation ecosystems that support focusing on relevant viewpoints in the development of sustainable smart cities.

This study is limited to the fact that it does not cover empirical data, but instead, the analysis was only based on the peer-reviewed articles, conference articles and book chapters in selected databases. Although the database selection confirms the high quality and wide coverage of the selected articles, there may also be additional relevant articles in other types of literature sources, e.g., in government reports, or project evaluation reports. Finally, the complexity and the systemic nature of the studied concepts, i.e., smart city and sustainability-oriented innovation, may cause variation in the interpretation of the research results. An attempt was made to ensure that the internal and external validity of the derived results are at a high level, however, by using the systematic iterative review process in this research. Essential future research areas can also be related to more focused bibliometric analyses about the evolution of this currently still developing topic, and citation and co-citation analyses on the most influential themes within this field.

CRediT authorship contribution statement

Nina Tura: conceptualization, methodology, validation, investigation, data curation, writing - original draft preparation, writing – review & editing, visualization, project administration **Ville Ojanen**: conceptualization, methodology, validation, data curation, writing – original draft preparation, writing – review & editing

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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