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Review article

Smart cities software applications for sustainability and resilience

Donatus Ebere Okonta *, Vladimir Vukovic

School of Computing, Engineering and Digital Technologies, Teesside University, Middlesbrough, United Kingdom

A R T I C L E I N F O

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A B S T R A C T

To transform urban areas into smart cities, various technologies—including software, user interfaces, communication networks, and the Internet of Things (IoT)—must tackle complex sustainability and resilience issues. This study aims to investigate the challenges of rapid urban population growth and explore how Information and Communication Technologies (ICT) can be utilized to foster the development of smart cities. Specifically, it seeks to understand how the integration of ICT can contribute to enhancing urban resilience, promoting urban sustainability, and improving citizens' quality of life. The study relied on a literature review, appraisals of fifteen (15) different Smart City software applications and their characteristics (spanning various domains, including data analytics, the Internet of Things (IoT), urban mobility, energy management, and citizen engagement platforms, all related to sustainability and resilience), and thirty (30) case studies cutting across sustainability and resilience. Furthermore, thematic analysis from the case studies was used to evaluate the benefits of smart city applications mapped to the six (6) action areas of Smart City. Based on the findings from case studies and smart city software analysis, rapid urbanisation presents multifaceted challenges like traffic congestion, disaster management, environmental degradation, community engagement, economic disparities, and so on. However, adopting Smart City software applications and aligning with various domains, including data analytics, the Internet of Things (IoT), urban mobility, energy management, and citizen engagement platforms, play pivotal roles in addressing these challenges. Further findings reveal that the benefits of smart city software align with the action areas of smart cities, including Governance, Mobility, Economy, Environment, Living, and People. The research offers practical application of smart city software for Urban designs and planners. It highlights the influence of contextual factors across countries on Smart City effectiveness. The study advances ICT-driven urban transformation, enhancing the quality of life in fast-growing cities.

1. Introduction

There is no single, agreed-upon definition of an "urban area" or 'City', and they differ greatly from nation to nation. There are often no set criteria based on population for many countries. Instead, alternative measures like population density, infrastructure, or even pre-designated cities may be employed [1]. However, most of the world's population, economic activity, and created assets are concentrated in Urban areas. According to the UN, 68 % of the world's population will reside in urban areas by the year 2050, up from the current projection of 55 % in 2018 [2,3].

The 2018 Revision of World Urbanisation Prospects, released by the Population Division of the UN Department of Economic and

* Corresponding author.
E-mail address: d.okonta@tees.ac.uk (D.E. Okonta).

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Social Affairs (UN DESA), predicts that the future growth of the world's urban population will mainly occur in a select group of countries. According to the United Nations [2], India, China, and Nigeria are projected to account for 35 % of the expected global urban population increase between 2018 and 2050. By 2050, India is forecasted to add 416 million more urban residents, followed by China with 255 million and Nigeria with 189 million. The rise in urban population will result in increased demands for infrastructure and affordable housing [4,5], increased energy consumption and a 70 % increase in greenhouse gas emissions [6].

High levels of human activity brought on by a broad urban occupancy model have led to serious social and environmental issues, which have negative effects on sustainability and efficiency, and the resilience of cities [7] or their ability to absorb, recover and prepare for future shocks as a result of economic, institutional, environmental and social activities. The concepts of sustainability and resilience are viewed differently by different scholars; according to Refs. [8,9], sustainability and resilience differ in definitions, [10, 11], consider them fundamentally the same, while [9,12] consider resilience as the main determinant of sustainability. Irrespective of the mentioned disagreements, sustainability and resilience, although both complex, large, and crucial systematic issues, may rely on smart innovations or novel approaches to deal with challenges surrounding the built environment and to make cities more responsive and liveable by optimising traffic, waste, and energy management, and improving public health, education, and security. Planning for sustainable, smart and resilient cities has become paramount [13], especially with urban resilience [14]. Ref. [15] assessed and ranked the resilience of 187 smart cities in China using a Multi-criteria decision-making (MCDM) approach and found that these cities have a low level of resilience. The relationship between urban smartness and resilience was also investigated, and the findings revealed a strong positive correlation between the two. Evidence also supports the idea that increasing the intelligence of cities is somewhat helpful in enhancing urban resilience [15].

To make cities smart, various technologies, such as software, user interfaces, and communication networks alongside the Internet of Things (IoT), must solve complex sustainability and resilience issues. The IoT is a network of objects, such as automobiles, sensors, and household appliances that can exchange data and communicate [16,17]. The adoption of IoT infrastructure for application development in industrial contexts with a Cyber-Physical System as a key component has occurred recently in smart manufacturing and industries, which are all components of sustainable smart cities and societies [18]. Cloud servers store the data gathered by IoT sensors and devices. The interconnection of these devices and the utilisation of data analytics (DA) facilitate the merging of tangible and digital elements within urban settings. This fusion improves the efficiency of public and commercial sectors, leading to economic benefits and an enhanced quality of life for residents [19]. Smart City software is a technology solution that enables cities to use data, connectivity, and automation to improve operations, services, and quality of life for citizens [20]. Some of the fundamental features that define Smart City software are Data analytics platforms [21], IoT platforms [20], Urban mobility platforms [22], Energy management platforms [23], and Citizen engagement platforms [23].

- **Data Analytics Platforms** analyze large volumes of data generated by smart city sensors, devices, and systems and turn them into actionable insights to help city planners and administrators make more informed decisions.
- **Internet of Things (IoT) Platforms** enable cities to connect and manage various smart devices and sensors, such as traffic sensors, air quality monitors, and smart streetlights, and collect real-time data to improve city operations.
- **Urban mobility Platforms** aim to improve how people move around the city, such as traffic management systems, public transit apps, and bike-sharing platforms.
- **Energy Management Platforms** help cities optimize energy consumption and reduce carbon footprints, including smart grid management systems and building automation software.
- **Citizen Engagement Platforms** enable cities to engage with their citizens and involve them in decision-making processes such as online forums, social media platforms, and mobile apps.

The recognition of the necessity for smart city software is evident; however, research on Smart city software Applications for Sustainability and Resilience has often neglected to explore the applications themselves. For instance, Ref. [24], delved into how smart city technology enhances resilience and sustainability through improved performance, quality, and interactive urban services but provided minimal discussion on specific software. Lopez and Castro [25], who investigated sustainability and resilience in smart city planning, primarily conducted a bibliometric study, suggesting a need for a more in-depth examination of smart city technology and application. [26], In their exploration of smart city applications, they focused on the security of smart cities and the societal impact of artificial intelligence, with limited emphasis on the associated software. Other studies, such as [27] study on smart city ontologies [28], exploration of privacy in the smart city, and [29] investigation into security and privacy in smart city applications, share a similar gap. Consequently, this study concentrates on smart city applications and their valuable contributions to various cities' sustainability and resilience landscapes.

The current study appraises Smart City software along the described features to track, monitor, and manage urban infrastructure with IoT sensors with examples of their application in the built environment. The research objectives will seek to explore how smart city software applications contribute to the relationship between sustainability and resilience in urban areas and evaluate the effectiveness of smart city software applications in addressing urban infrastructure challenges, promoting sustainability, and enhancing resilience. It will seek to address the research problem of the absence of a comprehensive understanding of how smart city software applications, such as data analytics platforms, IoT platforms, urban mobility platforms, energy management platforms, and citizen engagement platforms, effectively address urban infrastructure challenges, promote sustainability, and enhance resilience in urban areas.

Consequently, the study's central research question will be: "How do smart city applications enhance the sustainability and resilience of diverse urban landscapes?". This study will explore several specific queries to address the central question of how smart city applications enhance the sustainability and resilience of diverse urban landscapes. Firstly, it will examine the various smart city software applications currently used. Secondly, it will investigate the specific advantages these applications offer regarding sustainability, highlighting their role in mitigating environmental impact and promoting resource efficiency. Thirdly, the study will explore how these applications contribute to the resilience of urban environments, considering their capacity to respond to and recover from various challenges, such as natural disasters or infrastructure disruptions. Lastly, it will analyze case studies or examples showcasing the tangible impact of smart city applications on urban sustainability and resilience, providing empirical evidence of their effectiveness in different contexts. Through this comprehensive exploration of specific queries, the research aims to deepen the understanding of how smart city technologies influence and contribute to urban landscapes' overall sustainability and resilience. The study is crucial in light of the increasing significance of smart city technologies in shaping the future of urban living. As cities worldwide embrace digital transformation, it becomes imperative to assess the specific contributions of smart city applications to the sustainability and resilience of urban environments. The research outcomes will not only enhance the comprehension of the role played by smart city technologies but also provide valuable insights to urban designers and planners aiming to create more sustainable and resilient cities. Overall, Smart City software should offer a comprehensive solution that helps cities increase safety and better health, give faster commutes, promote dialogue between the public and the government, and provide solutions for sustainability and resilience.

2. Smart city

A smart city is a technologically urban area that employs varying electronic methods and sensors to collect specific data, which are used to properly manage assets, resources, and services and improve city-wide operations [30]. Data collected include information from buildings and assets, which are processed and analyzed to monitor and manage various systems. Smart City systems include transportation, multiple buildings (schools, hospitals, libraries, etc.), utilities, and supply/waste networks [31]. According to Ref. [32], a Smart City integrates physical, digital, and human systems into the constructed environment to provide its residents with a sustainable, prosperous, and inclusive future [33]. Also, a Smart City is a location where traditional networks and services are improved for the advantage of residents and businesses by using digital and telecommunication technologies. The use of information and communication technology (ICT) for improved resource management and lower carbon emissions is a vital aspect of a Smart City in creating a municipal administration that is more responsive and interactive, making public areas safer and addressing the needs of an ageing population [34]. Aside from sustainability, smart cities' main goal is to minimise foreseeable environmental difficulties, costs, and complications related to urban growth [35].

In looking at the Smart City definition holistically, key thematic areas to consider are collaboration, energy savings, innovations, integration, participation, and simplification of services [36]. Smart cities require collaborative efforts from governments and key stakeholders within the built environment [36,37]. The aim of smart innovation should be to save energy and the environment from challenges that have existed over prolonged periods either by artificial actions or naturally [38]. More so, the innovation and integration of technology into smart cities are meant to translate urban architecture into environmentally responsive architecture that interacts freely with nature, culture, tradition, and emotions. Smart City further entails total participation of the entire public and professionals, ensuring the processes and methods of Smart City's operations are simple to comprehend [38]. For example, the world-changing effects of COVID-19 were also felt in many cities, spurring the international research community to use cutting-edge technologies to create safer measures for diagnosis, evaluation, and treatment procedures using the Internet of Things (IoT) as a ground-breaking technology [39]. New privacy and security problems have, however, emerged recently as the use of artificial intelligence (AI) and the Internet of Things (IoT) has increased, notably in cities [40]. Furthermore [40], showed how vulnerable smart cities are to cyberattacks, privacy risks, and other security threats. Also, it is essential to clarify between urban sustainability, urban resilience and the connections with smart cities.

Resilient cities are defined as cities that can absorb shocks, bounce back, and prepare for future shocks [41,42]. It denotes a system's capacity to recover from stresses brought on by any hazard and "bounce back" to a prior stable state [43]. Conversely, sustainable or green cities are planned to take into account the social, economic, and environmental effects and provide a stable environment for the current population, all without sacrificing the quality of life that future generations will be able to enjoy [43]. While the goal of urban resilience is the ability of individuals, communities, businesses, institutions, and systems within a city to survive, adapt, and grow in the face of stresses and shocks, the goal of urban sustainability is to improve the social, economic, and environmental conditions of cities for present and future residents [44]. However, according to Ref. [45], resilience and sustainability are complementary strategies that share several characteristics and are occasionally used interchangeably. For example, the concepts of urban resilience and sustainability, which focus on a city's adaptability and vulnerability, have similar but overlapping meanings [42,46], with both notions serving as tools for assessing urban systems' resilience and adaptation [47]. The smartness of a city potentially determines how sustainability and resilience interact [48]. This suggests that people living in cities would react more favourably to a city that can manage difficulties without raising any alarms than to a city that can't deal with pressures that endanger both present and future citizens. Smart cities, which pitch the interconnectivity of city systems and the speed at which information is shared and responded to across urban systems, may play a role in attaining urban resilience and sustainability [49]. Via its ability to link technology, smart cities empower and achieve smart mobility, governance, living, people, environment, and economy all within urban cities, boosting their resilience and sustainability [50].

It thus implies that treating the economic aspects of cities well will enable prosperity and profitability; better city mobility systems may decrease urban traffic congestion and accidents; faster information sharing can help people live smarter lives, creating a smarter environment. Nonetheless, by standardising data across different systems and acting as a regulator, the government may be able to make well-informed decisions that have a ripple effect throughout the city. Cities have to first become smart before they can become resilient and sustainable.

2.1. Action areas of smart cities

Given the crowded nature of some built environments, high-density cities should stimulate high-resolution disaster resilience assessments [51]. The development of a novel integrative model by Ref. [13], focusing on the domains of energy, environment, social, governance, and pandemic resilience, shows a strong correlation between the domains of smart management, energy, and environment while also emphasizing smart governance, smart society, and pandemic resilience as crucial elements in the creation of smart cities. However, one promise made in connection with smart cities is to use data to enhance the value obtained by citizens [52]. A Smart City is about using human-centred design principles to develop and deploy an ecosystem of solutions that contribute value and advance the common good [53]. Considering everyone's needs, particularly the needs of the citizens, is essential for success [54]. The road to evaluating a Smart City should be strategic, holistic, and systematic, along with certain Key Performance Indicators (KPIs) [55]. The KPIs for assessing the "smartness" of urban areas include Smart Governance, Smart Economy, Smart Environment, Smart People, Smart Mobility, and Smart living [56]. All six (6) indicators or factors of the Smart City can be viewed as a comprehensive plan for creating a Smart City [57,58], as illustrated in Fig. 1. They offer a holistic framework that considers urban life's economic, environmental, social, and governance aspects, guiding policymakers and planners in creating more sustainable, resilient, and livable cities for the future.

2.1.1. Smart governance

In a municipality, "Smart Governance" aims to improve communication and interaction between the government and all stakeholders, including residents, businesses, and other civil society groups [57,59]. Such governments provide open data and digital services through optimum tech adoption and effective data usage while integrating various mobility systems into city administration through skills and talent readiness. Using tri-sectoral partnerships between companies, government, and civil society organizations allows for effectively financing smart cities, leading to an innovative ecosystem [60].

2.1.2. Smart economy

All initiatives targeted at improving and transforming a municipality's economy are called "Smart Economy" initiatives [57]. The Smart City's atmosphere, which is safer and happier, attracts more talent, which increases the city's GDP and the overall economy. The most crucial objectives are to improve the enterprise and innovation culture, a city's appeal to start-ups, investors, businesses, and new (highly qualified) talent, and to grow the economy in a creative and sustainable to boost competitiveness [61]. Productivity through intelligent strategies and the effective use of (digital) technology create stable and beneficial circumstances for all parties involved. "Smart economic development" is crucial for creating local and global connections, actively engaging the government with opportunities, and creating environments that foster establishing, expanding, and growing new companies and jobs [62].

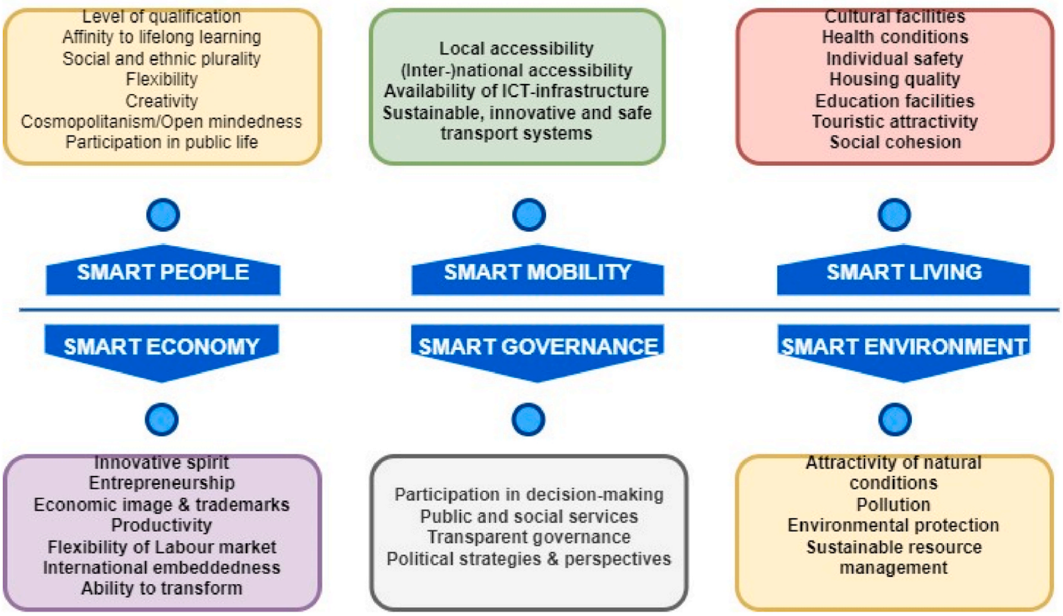

Fig. 1. Action areas of smart city.
Source: Compiled by Authors from [56].

2.1.3. Smart environment

A municipal government's management of the built and natural environments to enhance liveability for residents and tourists is called a "Smart Environment." [54]. Utilizing cutting-edge methodology and new technologies aids in executing cultural and regulatory changes that promote sustainable standards and practices [63]. Smart environments enable sustainable urban development through effective resource management and sustainable buildings, achieved through extensive and pervasive infrastructure and buildings that positively impact the environment [64].

2.1.4. Smart living

"Smart Living" seeks to improve the quality of life for residents and tourists by adopting a strategic plan inclusive of all age groups and demographics. Seeking to maximise benefits for the local government and its stakeholders, the concept facilitates liveability and optimises the management of the living environment [54,65]. Smart living tends to incorporate individuals' cultural health and safety into an artistic setting that embraces gender, race, religious belief, etc. It improves individuals' well-being through time efficiency, improved social environment and enhanced public safety [66]. Smart cities can improve residents' quality of life by as much as 30 % [67]. For example, the Internet of Health Things has the potential to create an all-encompassing connected health paradigm through the delivery of 5G-enhanced healthcare services, which enables health monitoring with quality of service, ultra-low latency, and deep learning processing of a sizable data repository daily generated as healthcare workflows and aids in decision-making processes [68].

2.1.5. Smart mobility

To promote the use and adoption of new mobility solutions and boost people's mobility through effective mobility management and targeted infrastructure investments, "Smart Mobility" concentrates on improving urban transportation efficiency and service quality [54]. Transportation demand management (TDM) plays a key part in incorporating infrastructure and technology to boost transport efficiency, leading to lower emission levels while vehicles are interconnected. TDM also offers a combination of diverse, cleaner cars for transport, often on a single trip, known as multimodal mobility [22].

2.1.6. Smart society

The first goal of "Smart People" is to change how citizens engage with the public and private sectors as individuals or companies, either through providing information or services, as opined by Gupta, Mustafa, & Kumar [69]. Establishing social and digital inclusion/equality through educational opportunities should precede new technologies-based information and services to be delivered more effectively [63]. Individuals make up societies; hence, a creative, inclusive, and trained city is smart [70].

2.2. The role of technology in smart cities

Smart cities aim to put technology to work and achieve better decision-making while improving the quality of life, spurring economic expansion, and enhancing municipal management [71,72]. The components of a Smart City include several smart computing technologies. "smart computing" refers to hardware, software, and networks that provide real-time data and sophisticated analytics for better-informed decision-making [73]. Initiatives aimed at creating smart cities heavily rely on ICT. The degree of ICT integration in urban functions is frequently thought to distinguish Smart cities from other cities. The Smart City can thus be compared to a 'Lasagna' where three "layers" of technology overlay each other: software, infrastructure and digital data [36].

As illustrated in Fig. 2, the layers are organised in a hierarchical structure, from digital data at the bottom to software at the top, with connecting infrastructure in between. The lowest layer contains the main components of the Smart City, especially digital data,

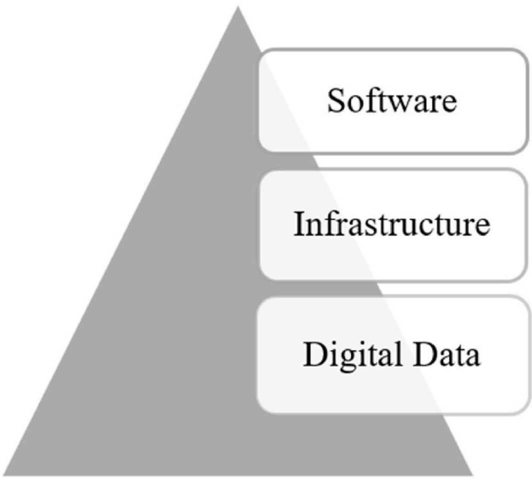

Fig. 2. The role of technology in smart cities.
Source: Compiled by Authors [36].

which are continually developing. Through "Big Data," the data are converted into new services instead of Open Data, where these services receive data from Smart City departments. Infrastructure enables the city to develop, deploy and promote sustainable development by integrating software with hardware [74].

Thanks to sensors, telecommunication networks (such as optical fibre and Wi-Fi) and data centres, the intermediate infrastructure layer assembles all the tools required to make the data collected from the urban environment available. The software is the top intelligent layer; it is the layer that generates information from data, such as a mobile application that compares public transportation timetables, locates a bus in gridlock, or a smartphone app that tells a user when their bus will arrive. Smart City software can be considered technology solutions designed to help cities manage and optimize their operations, infrastructure, and services more efficiently, sustainably, and effectively [20].

3. Methodology

The methodology employed in this study comprises three main components: literature review, case study selection, and case study analysis. Each element contributes to a comprehensive understanding to provide valuable insights into the practical applications of smart city technologies and inform decision-making in urban development practices worldwide.

3.1. Literature review

To begin with, an initial examination of existing literature was conducted to distil the core concepts and defining features of a Smart City. The approach can be broadly characterized as a systematic process of gathering and synthesizing prior research, as advocated by scholars like [75,76]. Such a review is essential for mapping and evaluating the research domain, providing a rationale for the study's objectives, and substantiating the research question and hypotheses, as explained by Ref. [77]. A comprehensive search was systematically carried out across various academic databases, including, but not limited to, PubMed, Scopus, Google Scholar, and pertinent journal databases. The search strategy incorporates keywords such as "smart cities", “smart building”, “the role of technology in smart cities”, “action areas of smart cities”, “sustainability and smart city”, “internet of things and smart city”, “ICT and smart cities”, “smart cities software”, “resilience and smart city”. The retrieved literature was then screened based on relevance to the research topic, and selected articles were critically reviewed and analyzed to identify key findings, trends, and insights related to the research topic.

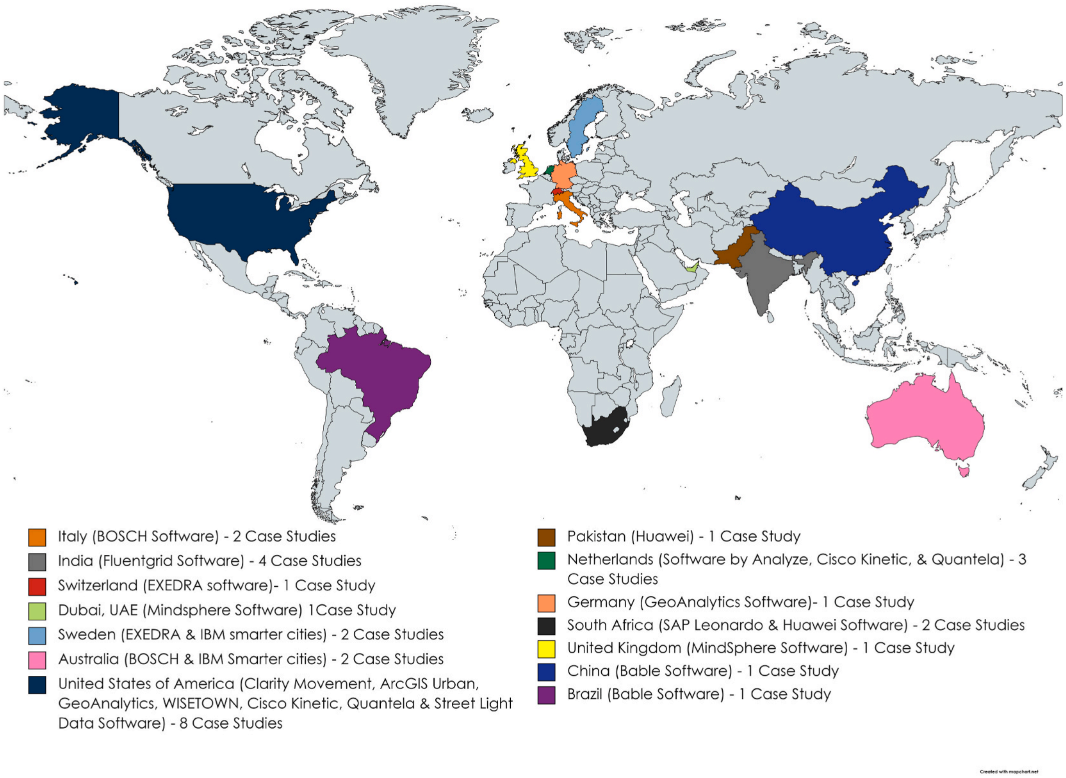

Fig. 3. Map showing various sustainability and resilience case studies in several countries.
Source: Created by Authors

Table 1
Smart city software for sustainability and resilience.

Smart City Software	Sustainability Case Studies	Resilience Case Studies
Fluentgrid – Fluentgrid Actilligence's Smart City platform enables real-time monitoring of renewable energy generation and surveillance with sensors, automatic workflow task conversion, service level agreement tracking and escalation, and web or mobile-based issue resolution. https://fluentgrid.com/	**Background:** Integrated city management solution for Lodha Group's Palava Smart City, India. The Palava City of the Lodha Group is reportedly India's first and fastest-growing greenfield smart city. **Problems:** The issues of creating a world-class smart city with a centralized administrative team, accessibility, and minimal intervention in running all city services. **Method:** Implementation of a CRM[a] tool-integrated CIS system for multi-service enrolment and billing **Solution:** Fluentgrid provided a CIS system for multi-service enrolment and billing, integrated with various CRM tools, resulting in a better citizen engagement experience [80].	**Background:** Lucknow Smart City Command Center's response to COVID-19. **Problems:** Being the second largest city in north and central India, its command and control centre had to be transformed overnight into a COVID-19 command and response centre. **Method:** Fluentgrid used the 3TMEM[b] strategy, which involved monitoring, engagement, and resource mobilisation to Test, Trace, and Treat victims efficiently. **Solution**: An 80 % citizen grievance response and closure rate with a drastic SLA adherence from 70 to 90 % [81].
ArcGIS Urban - ArcGIS Urban is a 3D tool for better urban planning and decision-making. It enables collaboration and evaluation of development projects using a web-hosted 3D tool. https://www.esriuk.com/en-gb/arcgis/products/arcgis-urban/overview	**Background:** City and County of Honolulu in the USA Planners Visualize Housing Patterns with an Eye on Affordability and encouraging development. **Problems:** One of the worst traffic situations in the nation is a problem. Additionally, there has been a lack of reasonably priced long-term housing since most locals have switched to short-term accommodations due to the heavy influx of tourists. **Methods:** ArcGIS is used for city mapping, databases, and 3D visualization to investigate and visualize suggested solutions. **Solutions**: Zoning modifications to solve the housing shortage included limiting the size of residential units and extending the height limit for low-rise buildings from three to five stories [82].	**Background:** San Francisco City in the USA engages in Smart planning as an effective response to the growth challenge. **Problems:** The unprecedented growth of the city has created the need for long-range planning as the city is growing past its current zoning capacity, hence the need for city planning to accommodate growth. **Methods:** use of GIS for 3D modelling and visualization of urban and regional systems as a whole rather than parcel by parcel **Solution:** Findings reveal that smart planning could have a dual pathway, with most of its processes automated and applied in public planning meetings, policy development, and design scenarios, creating capacity for urban planning growth [83].
Smart Cities Software by Bosch Canada - Better quality of life for residents and users. Connected devices, services and smart living solutions from Bosch. Bosch is active in the solutions for energy, security, mobility and E-governance. https://www.bosch.ca/	**Background:** Device management for connected agriculture- An Australian IoT project helps oyster farmers reduce the risk of unnecessary harvest closures caused by weather. **Problem:** Through rainwater runoffs, contamination of waterways can cause oyster infections. Additionally, the risk of unnecessary harvest closures caused by weather would significantly harm farmers' livelihoods. **Method:** Use of Bosch ProSyst IoT Platform **Solution:** It pinpoints the precise time for oyster farming. The Australian oyster business could save several million dollars annually if unnecessary closures were reduced by up to 30 % [84].	**Background:** Vitesty Smart Planter, Vienna, Italy, addresses ventilation needs in Vienna. Italy is exposed to numerous contaminants from furniture, construction materials, cleaning sprays, cooking, and more because users spend 90 % of their time indoors. **Problem:** Poor Indoor Air Quality (5x less) **Method:** Work with the firm "Vitesy" in utilizing IoT to nimbly power sensors to improve plants' ability to purify themselves **Solution**: The flowerpot technology freshens 36 cubic metres of space, and the surrounding area has 96 % fewer environmental pollutants [85].
Smart Cities Software by Schréder- EXEDRA is the most sophisticated and easy-to-use remote management system for controlling, monitoring and analyzing urban lighting. https://www.schreder.com/en/products/schreder-exedra-smart-city-control-system	**Background**: Malmö inner ring road- Malmö, Sweden. The European Green Capital network, which includes the most forward-thinking cities in the battle against climate change, counts Malmo among its members. **Problem:** High energy consumption and increased carbon footprint. **Method:** Relighting the 12 km Inner Ring Road using an IZYLUM-fitted LensoFlex®4 photometrical engine to provide the necessary lighting levels for streets and roads, adding Zhaga-D4i nodes and using the Schréder EXEDRA system to regulate it, **Solution:** Smart lighting saves energy and preserves the environment along the busy motorway. The colour temperature adaptation of LEDs ensures safety, efficiency and environmentally friendly lighting [86]. **Background:** The local community uses Martigny's Octodure Stadium, which is home to FC Martigny-Sports, a team that competes in the Swiss 1 Liga, for a range of sports.	

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Table 1 (*continued*)

Smart City Software	Sustainability Case Studies	Resilience Case Studies
	Problem: need for improving energy saving **Method:** using ECOBLAST floodlights with 37-m high adjustable masts holding 9 floodlights. **Solution:** The installation's overall power consumption has decreased by over 50 % thanks to the new LED lighting, from 102 kW to 57.44 kW [87].	
Clarity Movement - offers an inclusive air quality monitoring software, hardware, and service package. This makes it simpler to measure air pollution reliably and cost-effectively. https://www.clarity.io/	**Background:** The Denver Department of Public Health and Environment (DDPHE) made significant strides toward improving air quality and conducting impact assessments at highly targeted locations in Denver, USA **Problem:** Air pollution events, including wildfires, industrial disruptions, traffic congestion, and building projects, frequently threaten Denver's air quality, ranking as one of the ten worst US cities. **Method:** A co-location was set up with a reference monitoring station for data assessment **Solution:** The Clarity Nodes enable Ogletree to react quickly to unusual air quality events and conduct impact analyses in carefully chosen areas [88].	**Background:** The Monterey Bay Air Resources District (MBARD) manages the air quality in the North Central Coast Air Basin (NCCAB), which comprises the counties of Monterey, San Benito, and Santa Cruz, USA, using Clarity. **Problem:** Increasing levels of concern about air quality **Method:** Building a sensor network to provide real-time granular data for extreme air quality events **Solution**: The results indicate an enhanced calibration model for addressing wildfires. Utilizing the Clarity Dashboard, which provides network administrators with a powerful interface to access both current and past air quality data, all of which is stored in the Clarity Cloud, the MBARD team can generate reports and conduct analyses on the unprocessed and adjusted data from their air sensor network [89].
Smart Cities Software by Analyze (part of KBenP) Smart data solutions for the realization of social tasks and organizational objectives. https://analyze.nl/	**Background:** Smart City Digital Twin Alkmaar, Netherlands - The aim is to provide transparent, unambiguous, and up-to-date insight to residents, entrepreneurs, and other stakeholders regarding the plans and projects to be implemented. **Problem:** The need for appropriate and effective decision-making based on available data to manage traffic flow and help residents stay healthy **Method:** Creating smart city requirements and transcription into the architectural plate for smart city digital twin. **Solution:** The Alkmaars Kanaal's many programme areas served as the foundation for the information products developed by smart cities. This product comprises an easy-to-use web application and a website that provides details and information on the pertinent subject [90].	**Background**: Smart bridges through data and deep learning - South Holland, Netherlands**.** By operating and maintaining bridges, the province of South Holland plays a significant part in regional transportation flow while managing several rivers. **Problem:** Increased traffic along waterways and roads. **Method:** Smart Shipping partnerships for knowledge and innovation exchange **Solution:** The company developed a smart dashboard for the bridge control centre, the 'Web Application Impact Monitor Bridge Opening', to prevent road traffic from being affected [91].
GeoAnalytics - **Smart Cities Software by WiseTown**. GeoAnalytics is a customizable decision support system for city administrations that integrates data from various sources, including IoT sensors, SIT data, and city portals, to support the city's intervention strategy. https://wise.town/en/	**Background:** Perugia, Italy Smart City- integration with various systems to effectively optimize costs and resources, harmonise technologies, and achieve service quality levels in line with the policies of large European cities. **Problem:** Perugia's vast territory necessitates the provision of prompt, effective services as well as ongoing public-citizen communication channels. Hence, a need for effective data management and gathering for the city. **Method:** Integration of software infrastructure with existing systems **Solution:** Equipped with a variety of already-approved solutions at the European level, the integration standardises and optimises costs and resources, harmonises technology, and achieves service quality standards consistent with the regulations of major European cities [92].	**Background:** The DoNotFear app is part of a participatory security project promoting citizens' collaboration to manage and improve security at **Technical University, Berlin**. **Problem:** feelings of insecurity and danger regarding various means of transportation, hence limiting the use of public transportation. **Method:** A mobile application, **Wizgo,** was created **Solution:** captures in-vehicle security employees with real-time passenger reports for the transport firm to view [93].
Siemens- MindSphere - Smart City Solutions essential for Geo-location system for parking offences, a Monitoring system for dumpster and collection container refuse levels, Alert capability based on weather events, shock or damage, heat or smoke, etc. https://siemens.mindsphere.io/en	**Background:** MindSphere Smart City App in the Dubai Expo 2020 to create a smart environment **Problem**: to create a more intelligent, liveable, and sustainable world. **Method:** By gathering, observing, comparing, and analysing data from the Expo site in the cloud **Solution:** To help drive the Expo's ambitious sustainability goals and KPIs, the Smart City app	**Background:** Yorkshire Water: Clean waterways with artificial intelligence and IoT to locate blockages before they can occur- UK **Problem:** Blockage of sewer pipe systems **Method:** Data approach through (Sensors & Cloud systems) and analysis using SIWA Blockage Predictor Application running on the Siemens industrial IoT

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Table 1 (*continued*)

Smart City Software	Sustainability Case Studies	Resilience Case Studies
	provides Expo organisers access to metrics across the entire Expo infrastructure and serves as a single source of truth [94].	**Solution**: It is 3x more successful in predicting blockages. Findings reveal a 2-week advance notice of blockages and 10 potential issues [95].
SAP Leonardo Creating Smart cities through cross-industry collaboration in healthcare, higher education, travel and transportation, automotive, etc. https://news.sap.com/2017/07/what-is-sap-leonardo-2/	**Background:** Middle River Aerostructure Systems (MRAS)- US. For more than 90 years, Middle River Aerostructure Systems (MRAS), an ST Engineering firm, has supplied thrust reversers, composite aerostructures, and jet engine nacelle systems globally. **Problem:** We need to achieve design sustainability, cut waste, reduce cycle time, and increase the production of components made of composite materials. **Method:** To combine the operational, manufacturing, engineering, and cutting systems, use SAP S/4HANA®. **Solution:** an 80 % reduction in material waste and 96 % "First-time-right" yield for composite nacelle structures [96].	**Background:** Cape Town, the second most populated city in South Africa, has little under four million residents. The city administration's transport department, which is in charge of maintaining the infrastructure for roads and stormwater, wanted to automate and streamline the procedures that its maintenance teams used. **Problem:** Need for maintenance of 21 roads and road operations. **Method:** Integrating a user-friendly SAP Fiori®app with the SAP®ERP application **Solution:** Real-time reports on task completion data, compared to the 4 weeks that manual reporting previously required Training the maintenance personnel to use the fix takes 3 h [97].
IBM Smarter Cities Smart City software helps leaders provide services that support the social, health and educational needs of citizens – https://www.ibm.com/smarterplanet/us/en/smarter_cities/solutions/human_solutions/	**Background**: Stockholm, Sweden, implemented a first-of -its-kind traffic management system, easing congestion, increasing revenue and improving the environment. **Problem:** Traffic Congestion **Method:** Create an inner-city 24-square-kilometer road pricing system with 18 barrier-free control points outfitted with cameras and various payment methods. **Solution:** The project reduced morning traffic delays by 50 %, increased the daily ridership of 60,000 people on public transit, and enhanced the quality of life for Stockholm's citizens [98].	**Background:** Melbourne Water – Sustainability through IoT technology- Melbourne water improves stormwater management with IBM Maximo Solutions. **Problem:** Severe Rainfall events due to climate change led to more coastal flooding, increasing the need for stormwater drainage inspection and cost. **Method:** Automation of visual inspection integrating still image camera to Melbourne waters IoT platform **Solution**: Findings show less cost, reduced maintenance time and increased building sustainability [99].
Huawei Smart City- Huawei focuses on ICT infrastructure and partners with companies to develop open, customer-centric solutions to build sustainable Smart City ecosystems. https://e.huawei.com/uk/solutions/industries/government/smart-city	**Background:** The City of Ekurhuleni (COE) in Gauteng, South Africa, is the fourth largest metropolitan area in South Africa with a population of 3,37 million people. **Problem:** need to further address health, education, transportation, and security sectors through technology. **Method**: use of Huawei opens digital platforms using its cloud-based data systems. **Solution**: Huawei worked with the city to develop specialized "connected city," "efficient city," and "Smart City" plans. Powerful cloud data centres, a wide-wired and wireless network, and centralised government apps [100].	**Background:** Improving Traffic Conditions in Lahore, Pakistan, with Huawei's ITMS - Huawei's big data platform has slashed response times for universal queries to under 1 s. **Problem:** Traffic congestion as a result or rapid urbanization concerning economic growth. **Method:** Creating an ITMS system with 900 sets of e-police facilities, 200 traffic checkpoints, and 100 traffic signal sites. **Solution:** Improved, faster, safer roads within one year of deploying the Huawei ITMS [101].
Bable Smart Cities- BABLE Smart Cities is dedicated to accelerating change for a better urban life, aiming to be a driving force in holistic and urban innovation, utilizing clean tech and innovation to elevate the standard of living in cities, towns, and regions. https://www.bable-smartcities.eu/connect/companies/company/citymatica.html	**Background:** An integration of street lighting solutions in Huanggang, China that combines real-time monitoring and energy management, transforming Huanggang into a smart city. **Problem:** to address national carbon goals by tackling emission levels **Method:** Integrative Street lighting combining real-time monitoring and management plus aesthetics. **Solution:** A seamless blend of urban, scalable and modular design that is easy to manage, transforming the city into a smart city [102].	**Background:** Elliot Water helps Sabesp manage the water resources network in São Paulo **Problem:** The adoption and upkeep of integrated automation solutions **Method:** Data analysis and communication of integrated automation sensors. **Solution:** Improved maintenance and operation procedures, lowering direct costs and providing customers with a better, more affordable service while eliminating losses, leaks, and water thefts, managing assets intelligently, monitoring water quality, and managing energy [103].
Cisco Kinetic for Smart Cities Cisco Kinetic is an open, extensible city data tool consolidating devices, applications, and solutions. It helps communities efficiently collect data, foster constituent engagement, and generate job opportunities and new revenue. https://developer.cisco.com/docs/cisco-kinetic-for-cities/	**Background:** Transforming the Citizen Experience in Cary- North Carolina. **Problem:** the need to use technology to fulfil and surpass citizen expectations of great service while better preparing for possibly adverse occurrences. **Method:** A wide range of communications, network, and security technologies were deployed, maintained, and watched via Cisco Kinetics for Cities. **Solution:** Through this smart-city system, the town of Cary could view and manage data on a single	**Background:** Transforming the port of Rotterdam, Netherlands, leveraging IoT and advanced analytics to transform the port's operational environment and drive greater efficiencies **Problem:** To support 3000 businesses and thousands of employees while ensuring the safe passage of 130,000 vessels and millions of tonnes of cargo before 2050, the port must reduce its footprint by 95 %. **Method:** The use of Cisco 800 Series industrial integrated routers.

(*continued on next page*)

Table 1 (*continued*)

Smart City Software	Sustainability Case Studies	Resilience Case Studies
	pane of glass for parking, traffic signal automation, crowd counting, facility usage, video analytics, and more [104].	**Solution:** There is now a standardised, plug-and-play IoT ecosystem. Better traffic planning, inspections, and security through digitising vessel travel Route optimisation improves air quality, cuts emissions, and increases fuel efficiency [105].
Quantela delivers the AI-based urban solution Atlantis, which has machine-learning models perfect for advancing the digitization cycle. It strives to make autonomous and resilient cities. https://www.quantela.com/about-us	**Background:** The Smart City Mission, which aims to stimulate economic growth and enhance people's quality of life through local area development and the application of technology, has designated RSCL (Raipur Smart City Limited) as the entity responsible for carrying out priority initiatives. **Problem:** encircled traffic management, including congestion, violations, vehicle conditions, etc **Method:** Building an integrated command and control centre using the Quantela platform **Solution:** encompassed improved citizen participation and experience, effective traffic management, and increased levels of citizen safety [106].	**Background:** Gurugram has had tremendous growth during the past three decades, with a sevenfold increase in population between 1991 and 2011. Almost three million people are living there now. **Problem:** The rapid urbanisation that stressed city infrastructure impacted the provision of public services. **Method**: The Quantela platform is used by the Integrated Control and Command Centre (ICCC) to gather, combine, and analyze data from various sources across the city. **Solution:** aided to enhance citizen engagement and experience, smarter lighting, and improve water supply and mobility [107].
StreetLight Data uses smartphones as sensors to measure foot, bike, vehicle, and transit traffic remotely. As a key piece of the best public transportation software solutions available today, it gets counts, O-D, and other transportation standards for any road, location, or timeframe. To date, it has been helping 1000 professionals manage transportation. https://www.streetlightdata.com/	**Background:** To gain a complete view of the regional traffic movement, Shreveport, Louisiana, had to discover areas of serious traffic congestion and build a plan to mitigate it. **Problem:** Traffic congestion and public safety **Method:** Mobility Analysis **Solution:** The results showed volumetrics and speed for reducing traffic congestion while illuminating a regional picture of regional traffic movement for all modes of transportation [108]. **Background:** Transportation Demand Management for Snowbowl Traffic, Arizona, USA **Problem:** Traffic Congestion to key destinations **Method:** Pinpointing accurate metrics for Snowbowl traffic through big data. **Solution:** With the right analysis, decisions were taken to enlarge highways, increase transit services, create alternate routes, and offer parking and carpool incentives [109].	

[a] Customer Relationship Management.
[b] ″Test, Trace, and Treat, Monitor, Engage, and Mobilize."
Source: Created by Authors

3.2. Case study selection

The adoption of the case study method in this study stems from its capacity for in-depth, multi-faceted exploration of intricate issues in real-life settings. This approach proves particularly valuable when there is a need to gain a profound understanding of an event or phenomenon within its natural context [78]. The case study methodology is employed as a research approach to investigate a phenomenon within a specific context, utilizing diverse data sources. This method uses various perspectives to thoroughly explore the phenomenon, revealing multiple dimensions [79]. Case study findings carry implications for both theory development and testing, potentially allowing for theoretical generalization beyond the specific cases under examination. The study delved into an analysis of thirty (30) case studies, encompassing two (2) instances for each smart city software originating from fourteen countries. The investigation focused on instances where smart city software was successfully implemented within the built environment. This examination was visually represented in Fig. 3, crafted using MapChart software for its design. Including diverse case studies from various countries ensures a globally representative perspective on implementing smart city software in real-world settings. This methodological approach provides a rich and varied dataset that facilitates a nuanced understanding of smart city technologies' practical applications, challenges, and successes across different geographic and socio-economic contexts. MapChart software not only enhances the visual representation of the global distribution of case studies but also adds a layer of geographical insight to the findings, enriching the overall depth and scope of the study. The study evaluated the smart city software applications or platforms by exploring thirteen (13) resilience case studies and seventeen (17) sustainability case studies. The authors employed a meticulous case study data selection method that directly accessed the company's websites to extract the practical implementation of the case studies and their blog posts where applicable. This approach involved choosing case studies from diverse continents, including North America, Asia, Europe, the Middle East, Africa, and South America, to ensure a global perspective representative of a general approach. Data collection prioritized cases addressing a wide array of urban challenges such as traffic, environment, economy, quality of life, planning, and resilience, allowing for a comprehensive analysis of smart city strategies.

Moreover, the authors included cases utilizing various smart city solutions such as Geographic information systems (GIS), IoT, AI, and urban planning, thereby capturing a range of innovative approaches. The selected cases were sourced from credible publications, government documents, and reputable news sources, enhancing the accuracy and reliability of the collected data. The carefully designed data selection method empowers the research to provide valuable insights for informed decision-making in urban development practices worldwide.

3.3. *Case study analysis*

The data analysis was designed to extract comprehensive insights from the selected cases, enabling a thorough examination of each smart city initiative's strategies, technologies, and outcomes. The case study analysis unfolds through several systematic steps. First, the study establishes a contextual understanding of each software and the case study within its unique geographic, socioeconomic, and urban setting. The foundation ensures that the analysis is attuned to each city's challenges and opportunities. In analysing the case study, the study attempted to explore the challenges in the context of the case study, the method that was followed, and the solutions

Table 2
Domains of smart city Software.

Smart City Software	Traffic Control, Vehicle Security, logistics	Air pollution	Health Care	Disaster Prevention/public safety	Energy Management	Waste Management	Urban Planning/Zoning	Agriculture	Communication, Decision making & Privacy	Water Management	Manufacturing & Maintenance
Fluentgrid			*X*		*X*						
ArcGIS Urban	*X*			*X*		*X*	*X*				
Smart Cities Software by Bosch Canada	*X*	*X*						*X*			
Smart Cities Software by Schréder- EXEDRA					*X*						
Clarity Movement		*X*									
Smart Cities Software by Analyze (part of KBenP)	*X*						*X*				
GeoAnalytics	*X*								*X*		
Siemens-MindSphere										*X*	*X*
SAP Leonardo	*X*					*X*					*X*
IBM Smarter Cities	*X*			*X*							
Huawei Smart City	*X*				*X*				*X*	*X*	
Bable Smart Cities					*X*						
Cisco Kinetic for Smart Cities	*X*	*X*			*X*				*X*		
Quantela	*X*								*X*	*X*	
StreetLight Data	*X*									*X*	

Legend

Green: Most Versatile software (>/= 4 domains)
Yellow: Versatile software (3 domains)
Blue: Average software (2 domains)
Red: Specialized Software (1 domain)

Source: Created by Authors

that were derived from implementing the software and summarized in section 4. Also, the authors attempted to classify the various case studies according to the implementations related to sustainability and resilience. The Smart City software was categorized based on applications for sustainability and resilience, using the definition obtained from the literature review. Each software had a corresponding application for sustainability and resilience, except the Smart City software by Schréder and Street Light software, which did not have corresponding case studies for resilience. Such discrepancy may be caused by the unavailability of the case study on the website, or it has not been implemented. Following this procedure, the study endeavoured to categorize their applications to comprehend which software was commonly utilized for specific purposes in urban environments.

Furthermore, the study employed thematic analysis to extract key phrases from each case study, specifically focusing on expressions that elucidated the benefits of using various smart city software for sustainability and resilience, as outlined in section 5.1. Thirty-one key phrases were meticulously extracted from the table and mapped using thematic analysis. The objective was to align each keyword with a smart city's six pivotal action areas, namely smart economy, smart people, smart governance, smart mobility, smart environment, and smart living, according to Ref. [56]. The approach aimed to provide a nuanced understanding of how different smart city software contribute to sustainability and resilience across various facets of urban life, shedding light on their multifaceted impacts and potential applications.

In the final step of the analysis, the smart city software was categorized into diverse platforms, aligning with the frameworks outlined in the desk study. The inclusion criteria were based on meeting fundamental platform features defining smart city software, as delineated in the literature review from Refs. [20–23]. These features encompassed data analytics platforms, IoT platforms, urban mobility platforms, energy management platforms, and citizen engagement platforms. Fifteen software solutions successfully met the stipulated inclusion criteria, expounded upon and categorized in Fig. 3. This methodical categorisation ensures a comprehensive understanding of each software's diverse functionalities and features. It establishes a structured framework for further analysis and comparison within smart city technologies.

4. Results

Table 1 provides a list of various Smart City Software examples such as Fluentgrid Actilligence, ArcGIS Urban, Smart Cities Software by Bosch, Smart Cities Software by Schréder, Clarity Movement, Smart Cities Software by Analyze, GeoAnalytics, Siemens-MindSphere, SAP Leonardo, IBM Smarter Cities, Huawei Smart City, Bable Smart Cities, Cisco Kinetic for Smart Cities, Quantela, and StreetLight software. The table briefly presents the results of the analysis and a range of possible applications in the form of a summary.

5. Discussions

Table 1 provides basic software descriptions and links to the company websites. The links are essential to obtain authentic information concerning each software's characteristics, functionality, cost, case studies, and customer support so that any potential user can access the help needed.

Table 2, summarize the domains various smart city software solutions cover. Notable findings include ArcGIS Urban's high versatility across six domains, while Fluentgrid focuses on traffic control and vehicle security. Smart Cities Software by Bosch Canada addresses air pollution, waste management, and urban planning. Cisco Kinetic for Smart Cities demonstrates versatility in traffic control and disaster prevention. Huawei Smart City covers health care, disaster prevention, energy management, and communication. Specialized software solutions include Clarity Movement for traffic control, Bable Smart Cities for disaster prevention, and Quantela for disaster prevention, water management, and communication. The legend provides a colour-coded classification, with green indicating the most versatile software, yellow for versatile software, blue for average software, and red for specialized software, providing a clear visual representation of each software's domain coverage.

It is noteworthy that smart city software addresses different livelihood domains, making life easier, more connected and safer. For instance, areas of mobility entailing traffic control, vehicular security, and logistics, amongst others, can be addressed by numerous potential drivers for smart mobility and smart city software development. Table 2 reveals that software such as ArcGIS Urban, Smart Cities Software by Bosch Canada, Smart Cities Software by Analyze, GeoAnalytics, IBM Smarter Cities, Huawei Smart City, Cisco Kinetic for Smart Cities, Quantela and StreetLight Data all address mobility. The importance of smart mobility to smart city software was bolstered by Ref. [110], revealing that it can be applied in route optimisation, parking, lighting, traffic control, road anomalies, accident detection and building transport infrastructure, all while having a simple framework. Furthermore [111], concurred with this finding by stating that smart mobility is potentially one of the major ways to address the current climate crisis, hence a keen focus on this direction.

Air pollution and air quality management in smart cities are primarily addressed by three major software solutions, namely Smart Cities Software by Bosch Canada, Clarity Movement, and Cisco Kinetic for Smart Cities. According to Ref. [112], Clarity Movement is one of the top software options for monitoring air quality a closer examination. Table 2 indicates that only a limited number of software solutions offer the functionality to monitor air quality effectively. Furthermore, the healthcare domain is the least addressed area within smart city software, with Fluentgrid being the sole software covering this aspect. This observation is consistent with the findings of [113, p. 6], who noted in their study on future smart cities that there is a lack of smart city software or applications specifically designed for healthcare. The recognition of Fluentgrid as the only software addressing healthcare needs is attributed to its proficiency in quick data interchange and aggregation within the Internet of Things systems, as highlighted by Ref. [113]. This emphasizes the importance of addressing healthcare concerns within smart city development and highlights Fluentgrid's capabilities in facilitating data management for healthcare applications.

ArcGIS Urban and IBM Smart Cities emerge as the two primary software solutions with the potential to effectively manage disasters and enhance overall public safety, particularly in disaster response scenarios. These software platforms possess investigative capabilities that directly contribute to public safety by predicting potential disasters, facilitating the creation of early warning systems, and promoting smarter governance, as noted by Refs. [114–116]. There is a notable concentration of software solutions in energy management, including Fluentgrid, Smart Cities Software by Schréder-EXEDRA, Huawei Smart City, Bable Smart Cities, and Cisco Kinetic for Smart Cities, all playing significant roles in energy management. Monitoring energy consumption in real-time is central to addressing the global energy crisis and mitigating climate change. Therefore, the focus of these software solutions on providing real-time monitoring of energy generation and sensor-based surveillance is a key factor driving their prominence in the energy management domain, as highlighted by Refs. [117,118].

In waste management and urban zoning and planning, key software solutions such as ArcGIS Urban, SAP Leonardo, and Smart Cities Software by Analyze play crucial roles. ArcGIS Urban, known for its exceptional city visualization capabilities [119], is utilized in waste management, urban zoning, and planning, highlighting its versatility and significance. SAP Leonardo stands out in waste management due to its unique features, including the ability to link objects to business processes, automatic inventory replenishments, and IoT-based cycle counting, making it an effective tool for efficient waste management practices [120]. The integration of these functionalities contributes to streamlined processes and enhanced operational efficiency in waste management.

As seen in Fig. 4, on the other hand, the agriculture domain, similar to healthcare, exhibits a scarcity of smart city software solutions. In this context, the Smart Cities Software by Bosch Canada stands alone as an application that applies its expertise specifically to the field of oyster farming. This limited focus on agriculture within the realm of smart city software emphasizes the potential for further development and integration of digital solutions in agriculture-related practices. The identification of Bosch Canada's software as the sole application addressing oyster farming underscores the need for expanding smart city technologies into diverse sectors, including agriculture, to foster innovation and sustainable practices in food production.

Four software solutions address communication, decision-making, privacy, and water management domains, contributing to comprehensive solutions in these crucial areas. The relevant software solutions for communication, decision-making, and privacy include GeoAnalytics, Huawei Smart City, Cisco Kinetic for Smart Cities, and Quantela. Siemens-MindSphere, Huawei Smart City, Quantela, and StreetLight Data are the software solutions identified for water management. The study by Ref. [121] supports the precise decision-making capabilities of GeoAnalytics, validating its significance in this domain. Moreover [122], research highlights Huawei Smart City's integration of high network and security support compliance, justifying its multifaceted use in communication, decision-making, privacy, and water management.

Additionally [119], findings affirm implementing information management using Cisco Kinetic for Smart Cities, aligning with the software's applicability in communication, decision-making, privacy, and water management. Furthermore [123], statements emphasize Quantela's ability to interconnect services and enhance water quality monitoring, providing a rationale for its communication and water management utilisation. This comprehensive utilisation of software solutions across these critical domains demonstrates the interconnectedness and synergy between communication, decision-making, privacy, and water management, as supported by various research findings.

Siemens-MindSphere and SAP Leonardo are pivotal software solutions in smart manufacturing and maintenance. Manufacturing has witnessed transformative innovations throughout the Industrial Revolution, progressing from Industry 1.0 to 5.0. With a focus on large-scale manufacturing characterized by minimal pollution and heightened profitability, software solutions like Siemens-MindSphere assume a central role. Siemens-MindSphere, as noted by Ref. [124], exhibits the capability to transform an entire factory into an intelligent manufacturing sector. Additionally [125], highlights its proficiency in maintaining a single database for assembling industries securely and for extended periods, further establishing Siemens-MindSphere as a key software in addressing manufacturing and maintenance domains. This dual functionality underscores the significance of Siemens-MindSphere in driving efficiency and innovation within the dynamic landscape of modern manufacturing.

It is crucial to acknowledge that the development of smart city applications often encounters challenges, as highlighted by Ref. [126]. The complexity inherent in meeting numerous intricate requirements may contribute to the limited functionality observed

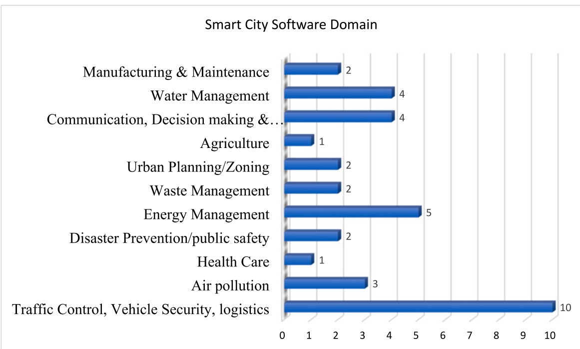

Fig. 4. Smart city software domain.
Source: Created by Authors

in smart city software. For instance, healthcare-oriented software faces the formidable challenge of requiring a high degree of accuracy, coupled with the need for robust policy support and operational efficiency, as noted by Ref. [127]. However, this complexity can also position healthcare-focused software as optimal solutions for emergencies and disasters, showcasing their potential resilience and adaptability in critical scenarios. This underscores the imperative for expediting the digitization processes of smart city software, thereby reshaping the roles and services of enterprises within the framework of sustainable smart cities, as emphasized by Ref. [128]. Recognizing and addressing the challenges associated with complexity in smart city applications will be pivotal in advancing their capabilities and ensuring their effectiveness in meeting diverse urban needs and challenges.

As illustrated in Fig. 5, a closer examination of individual smart city software reveals a spectrum of versatility and specialization within each solution. ArcGIS Urban, Huawei Smart Cities, and Cisco Kinetic for Smart Cities are the most versatile software solutions, demonstrating their utility in at least four domains. Software solutions like Smart Cities Software by Bosch Canada, SAP Leonardo, and Quantela exhibit notable versatility by addressing three domains each, showcasing their capacity to serve diverse functions within a smart city context. This multifaceted nature allows these software solutions to be effectively applied in more than two domains, enhancing their adaptability and usefulness. Furthermore, software solutions such as Fluentgrid, Smart Cities Software by Analyze, GeoAnalytics, Siemens-MindSphere, IBM Smarter Cities, and StreetLight Data demonstrate dual-purpose functionality by addressing two domains each. This dual capability underscores their ability to contribute to multiple aspects of smart city management. Lastly, software solutions dedicated to a singular domain can be considered specialized. Examples include Smart Cities Software by Schréder-EXEDRA, Clarity Movement, and Bable Smart Cities, emphasizing their specific focus within a particular domain. This classification provides a nuanced understanding of the diverse roles and functionalities of different smart city software solutions, contributing to smart city technologies' dynamic and integrated landscape.

Furthermore, using the results from Table 1 and Fig. 2, the study considered different countries where the Smart City software was implemented to understand how the product performed in various legal, cultural, technical, and market contexts. The differences in laws (a software product that is compliant in one country may not be so in another), culture (a software tool's effectiveness in one country doesn't guarantee its success in another), technical infrastructure (some countries may have better internet connectivity or more advanced hardware than others), and market demand (a product that is in high demand in one country may not be in another) can influence the effectiveness of a software product in different countries. Analysing case studies from various countries provides insights into the mentioned differences and may help understand the product's performance in multiple contexts.

5.1. *Benefits of smart city software*

Also, the study attempted to extract from the case study in Table 1 and paraphrased key phrases in line with each case study to express the benefits of smart city software in the Urban environment. The paraphrased key phrases were tabulated in Table 3. The study attempted to map each keyword in Table 3 to the smart city's six (6) action areas. Aligning the phrases to key action areas helps to provide a clear understanding of how each word contributes to specific aspects of a smart city.

As seen in Table 4, by categorizing the selected key phrases expressing the benefits of Smart City software, it becomes easier to identify the focus areas and the corresponding technologies or solutions that support them. The alignment may help organize and structure the information, making it more accessible and meaningful for analysis or decision-making. The categorisation also enables better comprehension of the diverse initiatives and solutions implemented in a smart city context. It highlights the multidimensional nature of smart city development, where various sectors and domains intersect to create a holistic and integrated urban environment. Furthermore, aligning the phrases to key action areas helps stakeholders, policymakers, and urban planners identify the areas in which advancements are being made. It allows them to prioritize and allocate resources based on the identified needs and objectives of the city, facilitating targeted and efficient decision-making.

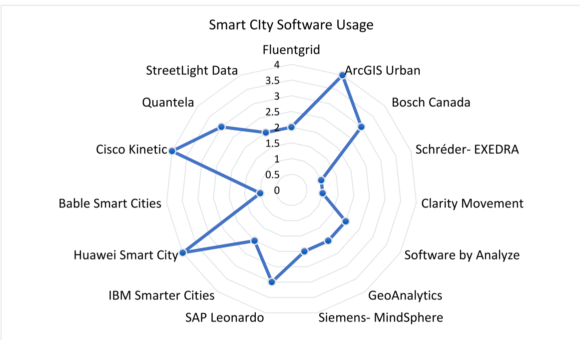

Fig. 5. Smart city software usage.
Source: Created by Authors

Table 3
Selected key phrases expressing the benefits of Smart city software to be categorized into the action areas of Smart Cities.

Key Phrases	
"Improved indoor air quality through IoT technology and plant-based air purification"	*"Sustainable solutions for energy savings and environmental impact reduction"*
"Improved citizen grievance response and closure rate"	*"Integrated city management solution"*
"Improved traffic management effectiveness and citizen safety"	*"Service level agreement tracking and escalation"*
"Transparent and up-to-date insight for effective decision-making"	*"Improved citizen experience and preparation for potential challenges"*
"Improved yield and income for oyster farming through IoT device management"	*"Advancement in sustainable development and reduction of environmental footprint"*
"Improved water resource network management and elimination of losses"	*"Collaboration and evaluation of development projects"*
"Web or mobile-based issue resolution"	*"Open digital platforms and cloud-based data systems for smart city development"*
"Real-time and historical air quality data analysis"	*"Remote management system for controlling, monitoring, and analyzing urban lighting"*
"Intelligent traffic management system for traffic congestion reduction and safer roads"	*"Large-scale project tackling emissions and promoting digital transformation."*
"Accurate measurement of traffic patterns and informed decision-making for transportation management"	*"ICT infrastructure for a connected city and efficient government applications"*
"Centralized administrative team"	*"Energy-efficient lighting with colour temperature adaptation"*
"Inclusive air quality monitoring software and hardware"	*"Better urban planning and decision-making"*
"Visualization of housing patterns and exploration of potential solutions"	*"Streamlined maintenance procedures and reduced costs"*

Source: Created by Authors

Table 4
Mapping of Key benefits from case studies to the action areas of Smart Cities.

Action Areas of Smart Cities	Benefits of Smart City Software
Smart Governance	*"Customizable decision support system integrating IoT sensors and city portals."*
(7 Key Phrase linked)	*"ICT infrastructure for a connected city and efficient government applications"*
	"Large-scale project tackling emissions and promoting digital transformation."
	"Transparent and up-to-date insight for effective decision-making"
	"Remote management system for controlling, monitoring, and analyzing urban lighting."
	"Service level agreement tracking and escalation".
	"Open digital platforms and cloud-based data systems for smart city development"
Smart Mobility	*"Collaboration and evaluation of development projects"*
(7 Key Phases linked)	*"Visualization of housing patterns and exploration of potential solutions"*
	"Improved traffic management effectiveness and citizen safety"
	"Intelligent traffic management system for traffic congestion reduction and safer roads"
	"Improved maintenance and operation procedures"
	"Optimisation of operational efficiency in port management"
	"Accurate measurement of traffic patterns and informed decision-making for transportation management"
Smart People	*"Centralized administrative team"*
(4 key phrases linked)	*"Improved citizen grievance response and closure rate"*
	"Inclusive air quality monitoring software and hardware"
	"Improved indoor air quality through IoT technology and plant-based air purification"
Smart Environment	*"Better urban planning and decision-making"*
(5 key phrases linked)	*"Energy-efficient lighting with colour temperature adaptation"*
	"Real-time and historical air quality data analysis"
	"Sustainable solutions for energy savings and environmental impact reduction"
	"Improved water resource network management and elimination of losses"
Smart Economy	*"Improved yield and income for oyster farming through IoT device management"*
(2 key phrases linked)	*"Integrated city management solution"*
Smart Living	*"Web or mobile-based issue resolution"*
(6 key phrases linked)	*"Smart city surveillance, access control, and parking management"*
	"Improved citizen experience and preparation for potential challenges"
	"Enhanced citizen engagement and experience"
	"Streamlined maintenance procedures and reduced costs"
	"Advancement in sustainable development and reduction of environmental footprint"

Source: Created by Authors

5.2. Smart city software categories

Despite the thorough analyses conducted in this study, determining a singular "best" smart city software for the built environment proved challenging. This challenge arises from the inherent complexity of software evaluation, which depends on many factors, including users' unique needs and goals, specific applications, budget considerations, and other requirements. Recognizing the diversity of these influencing factors, it becomes evident that selecting the most suitable software is a subjective and context-dependent decision. The optimal software for a given application is contingent upon the nuanced interplay of user-specific requirements and the distinctive features of each software solution. Smart city software offerings vary widely in their capabilities, functionalities, and

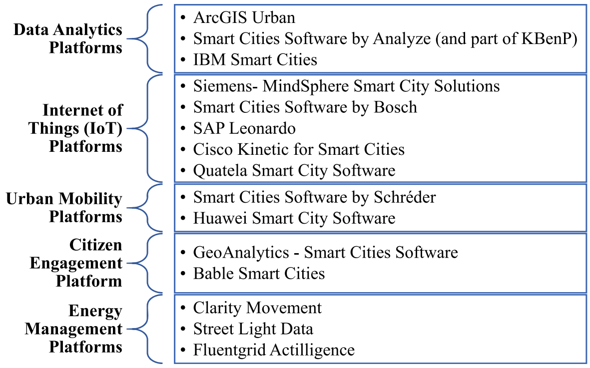

Fig. 6. Smart City Software categories based on use.
Source: Created by Authors

advantages, catering to different use cases and scenarios. Acknowledging this diversity, the study refrained from prescribing a one-size-fits-all solution but sought to provide a comprehensive understanding of the landscape.

The study adopted a method of evaluation to facilitate a meaningful comparison within the confines of this complexity. This involved categorizing the considered software based on smart city features derived from an extensive desktop review, as illustrated in Fig. 6. This categorisation served as a valuable guide, allowing the study to specify which software solutions excel in particular features by delving into their descriptions, characteristics, and real-world case study applications. By embracing this nuanced and feature-specific evaluation approach, the study aimed to assist stakeholders in making informed decisions tailored to their unique needs and requirements within the dynamic realm of smart city technology.

6. Conclusions and recommendations

The emergence of smart city software has revolutionized the planning and management of the city. The unique contributions of the research lie in its comprehensive analysis and case studies of various Smart City Software applications aimed at enhancing sustainability and resilience and categorizing their benefits into the action areas of smart city. The research was driven by the overarching aim of comprehensively exploring the contributions of various Smart City Software applications to the sustainability and resilience landscapes of diverse cities. The central research question, "How do smart city applications contribute to the sustainability and resilience landscapes of diverse cities?" guided the investigation, leading to an in-depth analysis of several prominent software solutions and their implications for urban development. The study meticulously examined key Smart City Software applications, including Fluentgrid's real-time monitoring platform, ArcGIS Urban's 3D urban planning tool, Bosch's smart living solutions, and Quantela's AI-based urban solution, among others. Each software showcased unique features and capabilities, contributing to specific aspects of urban sustainability and resilience. Fluentgrid's platform, for instance, demonstrated its efficacy in addressing issues such as centralized city management and service accessibility, providing a valuable solution for enhancing citizen engagement in Lodha Group's Palava Smart City.

Similarly, ArcGIS Urban's 3D tool proved instrumental in visualizing housing patterns in Honolulu and aiding smart planning initiatives in San Francisco. Bosch's smart living solutions showcased applications in agriculture, air quality monitoring, and energy efficiency, highlighting the diverse ways in which technology can enhance the quality of life. Quantela's AI-based urban solution showcased notable success in traffic management in Gurugram and urban area development in Raipur.

The thematic analysis of the case studies played a pivotal role in distilling essential insights and identifying key patterns that underscore the advantages of employing Smart City software across diverse action areas within the Smart Cities framework. This analytical approach involved a systematic examination of the case studies to discern recurrent themes and central ideas related to the impact of Smart City software. Through the thematic analysis, the study discerned key phrases that serve as focal points in elucidating the benefits realized in different facets of urban development. The delineation of action areas within Smart Cities, namely smart people, smart environment, smart mobility, smart economy, smart living, and smart governance, provided a structured framework for understanding the varied dimensions influenced by Smart City software applications.

Also, the study acknowledges challenges in comparing software and determining a one-size-fits-all tool used in the built environment. However, simplifying software comparison by categorizing the considered tools according to the included features leads to identifying prominent software in each feature. A limitation of the study was related to accessing information about various case studies, as many do not have updated examples of software implementations.

Furthermore, Table 4 and Fig. 3 highlighted the key benefits of smart city software from the case studies and mapped them to the action areas of Smart Cities, providing a comprehensive understanding of how the software contributes to different aspects of urban development. The research article contributes to understanding Smart City software applications and their potential benefits for sustainability and resilience. Further research and evaluation are necessary to delve deeper into the effectiveness and performance of specific software applications in various urban contexts.

As smart city software continues to evolve, future efforts will consider effective implementation, requiring collaboration between city planners, technology providers, and citizens to identify the needs and concerns of the community. A possible study may investigate the potential challenges and limitations associated with implementing Smart City Software in the built environment and develop strategies to overcome such challenges. In conclusion, the study analyses various examples of Smart City Software, their applications for sustainability and resilience, and a method of evaluation to simplify the process of software comparison for specific user needs and requirements. Further studies could explore much more. While numerous platforms exist to facilitate the creation of smart city applications, most fail to integrate the provided services with geographical information, lack support for executing semantic queries on the accessible data, and come with restrictions that could pose challenges in the development process. Based on the study's findings, the following policy recommendations are proposed: Invest in training and capacity-building programs for city planners and technology providers. Ensuring stakeholders are well-equipped with the necessary skills and knowledge will facilitate the effective implementation and management of smart city solutions. Establish mechanisms for ongoing monitoring and evaluation of smart city initiatives. Regular assessment of the effectiveness and performance of smart city applications will provide valuable feedback for continuous improvement. Ensure that smart city initiatives are inclusive and address socio-economic disparities. Policies should focus on making smart city benefits accessible to all citizens, regardless of their socio-economic status.

The global significance extends to the practical implications for city planners, technology providers, and policymakers. City planners, equipped with insights from the research, can leverage practical examples to enhance urban planning strategies, ensuring that technology aligns with sustainability goals. By understanding the specific needs addressed in diverse urban contexts, technology providers can tailor their solutions more effectively, contributing to the creation of intelligent and resilient cities. Armed with knowledge about the benefits and limitations of Smart City Software applications, policymakers can formulate informed regulations and policies, fostering an environment conducive to adopting technologies that enhance urban living globally.

Data availability statement

Data included in article/supp. Material/referenced in the article.

Ethics statement

The authors declare the research did not involve human or animal experiments.

CRediT authorship contribution statement

Donatus Ebere Okonta: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Vladimir Vukovic:** Writing – review & editing, Supervision, Project administration.

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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