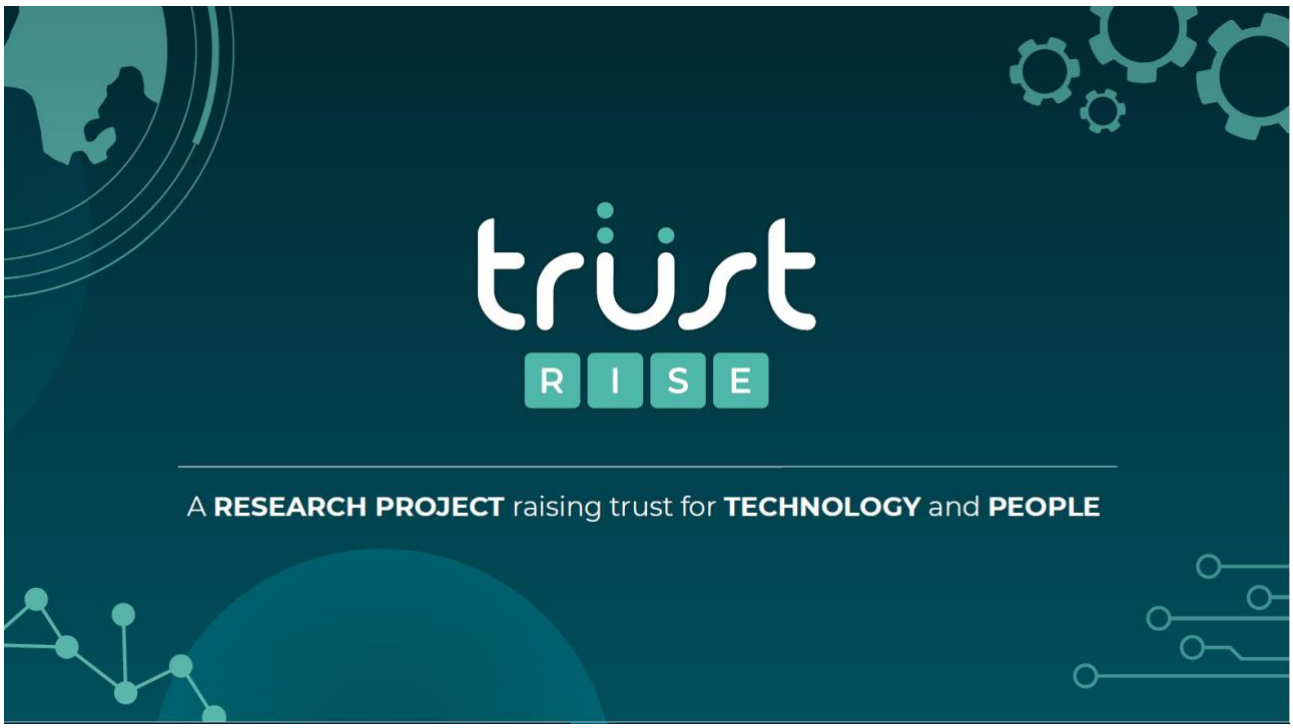

TRUST - digital TuRn in EUrope: Strengthening relational reliance through Technology

BCTs to deliver public services – D5.3

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TRUST - digital TuRn in EUrope: Strengthening relational reliance through Technology

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Authors	Massimo Biasin (Unimc); Andrea Delle Foglie (Unimc) [Co-Author Sections 3,4,5]; Manuel Ignacio Feliu Rey (Universidad Carlos III de Madrid) [legal Box]; Chiara Iorio (Unimc), Beatrice Baldoni (Unimc) [Annex 2]
Task leader	Massimo Biasin (Unimc)
Nature[1]	**R**
Dissemination[2]	**PU**
Abstract	The present report investigates the impact of Blockchain technology (BCT), also from an economic and financial perspective, on urban environment for developing «Smart Cities» defined as metropolitan areas where technological solutions, both private and public, improve the management and efficiency of traditional networks for the benefits of their residents and business. Starting from the paramount role of urban spaces worldwide, we performed a two-step analysis. The first step was a survey and systematisation of the existing literature on blockchain applied to the urban context in combined term; the analysis first considers applications from a broad spectrum of scientific areas, and then focuses on economic and, finally, financial issues, using a progressive selection approach. Moreover, specific *focus* is devoted to

[1] Nature: R: Document, report; DEM: Demonstrator, pilot, prototype; DEC: Websites, patent fillings, videos, etc; OTHER; ETHICS: Ethics requirement; ORDP: Open Research Data Pilot

[2] Security Class: PU: Public; CO: Confidential, only for members of the consortium (including the Commission Services); EU-RES Classified Information - restraint UE; EU-CON: Classified Information - confidential UE; EU-SEC: Classified Information - secret UE

	the studies related to the context of transportation and urban planning as relevant services of public interest. The second step was to identify the key topics and future pioneer research agenda for addressing policy and governance interventions. The same recommendations are the subject of the concluding remarks. The analysis is supported by a series of case studies of smart cities worldwide, with particular *focus* on BCT-applications to mobility services as well as to urban planning and development. Part of the present deliverable has been submitted and approved for publication in Sustainability, with open access (https://www.mdpi.com/2071-1050/16/15/6669).
Date	25/08/2024

BCTs to deliver public services (Smart Cities and Blockchain).
Report on Smart Cities & BCT: Potential Impacts, Literature Review, Case Studies and Policy Recommendations.

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1. Introduction and Objectives of the Analysis

The present analysis aims at investigating the impact of Blockchain (BCT) as a distributed ledger technology on urban environments for developing «Smart Cities» defined as metropolitan areas where technological solutions, both private and public, are expected to improve the management and efficiency of traditional networks for the benefits of their residents and business. This in terms of both the production of activities and services as well as social, political and economic processes in light of the citizen participation and cooperation in the urban governance.

Starting from the paramount role of urban spaces worldwide, we performed a two-step analysis.
The first step was a survey and systematisation of the existing literature on Blockchain applied to the urban context in combined term especially from an economic and financial perspective; moreover, specific *focus* is devoted to the studies related to BCT projects applied to the context of (urban) transportation and planning as relevant urban services in view of their public externalities.
The second course was to identify the key topics and future pioneer research agenda, especially from an economic and financial perspective as well as with *focus* on mobility and urban development issues, for addressing policy and governance interventions on the basis of the results of the analysis referred to in the previous step.
The report is supported by a series of case studies of smart cities worldwide, with a particular concentration on BCT-applications to mobility services as well as to urban planning and development. This as empirical evidence of BCT-uses to urban contexts as a counterpoint to theoretical indications.

The results show a fundamental lack in the aggregate comprehension of potential Blockchain applications within the urban context in combined terms from a general perspective. Overall, despite the potential of Blockchain – as a distributed ledger technology – of conveying secure and trusted information across sites and market participants (and so potentially reducing transaction costs), the existing literature appears to be still limited and almost absent focusing on pure financial applications within cities (even if benefitting from increased academic attention). Crucial knowledge about Smart Cities remains scattered on several fronts and following a fragmented approach of smaller, transversal application areas, largely driven by technical analysis.
Moreover, what seems to be missing, are investigations regarding BCT applications specifically targeted to the urban context from an aggregate economic perspective (*i.e.* studies do not depict a comprehensive framework for the economic implementation of BCT to Smart Cities missing a measuring capability of the performance gains of Blockchain technology compared to conventional information systems). In that perspective, there is great potential for further studies in order to develop (economic and financial) applications specifically intended for Smart Cities that might commonly be used for shared micro- and macro-constructs also in the logic of related policy and governance interventions considering the public externalities of most urban services.

In that sense, stronger public commitment by the relevant authorities from an overall perspective capable of coordinating different development projects and initiatives in order to share potential synergies in the joint production of services and activities by ensuring adequate accessibility to certified information, possibly of public origin, is desirable. This would also facilitate the participation and cooperation of citizens and stakeholders at large in the urban governance in terms of both actions and processes.

The report is structured as follows.

Section 2 is dedicated to the topic's comprehension highlighting the absolute relevance of cities for Blockchain applications based on some basic but paramount observations related to the urban environment and considering how Blockchain might impact on the urban environment for developing Smart Cities by enhancing the quality and types of urban governance and services (*e.g.* transportation, security, connections, etc.) by applying Blockchain solutions to their production and management processes.
Section 3 reports an original bibliometric and systematic literature review of Smart Cities and Blockchain in combined terms in order to gain a comprehensive overview of what we know, followed by a specific *focus* on transportation and urban development studies, respectively, highlighted in Section 4. The analysis follows a progressive selection approach, considering first applications from a broad spectrum of scientific areas, and then focusing – also in light of the academic background of the main authors – on economic and, finally, financial issues, followed by the *focus* on mobility and urban planning aspects.
Section 5 contains summary considerations of the results of the bibliometric review. For those interested in in-depth research into the various aspects, the related relevant bibliographical references are listed in Annex 1.
An information *Box* reports preliminary but relevant legal considerations with regard to the production and access of shared certified data in light of privacy concerns on the basis of the European Union's regulatory framework in place.
The analysis also includes an international selection of use case sheets, sorted by country, of BCT applied to urban environments at international stage using a largely common reporting matrix (Annex 2). The reported cases are judged to be particularly significant in terms of breadth in the use of BCT, maturity of the context from the point of view of openness to the use of technologies, and relevance for other EU contexts in the adoption of BCTs for building smart and inclusive cities.
Based on the analysis of the existing literature and identified BCT-application cases, the main conclusions are outlined in the concluding remarks also drafting some policy recommendations to improve the efficiency of Blockchain to urban environments from a governance perspective (Section 6). The same conclusions also report the main directions for future researches.

2. The Relevance of Cities & Blockchain for the Urban Environment

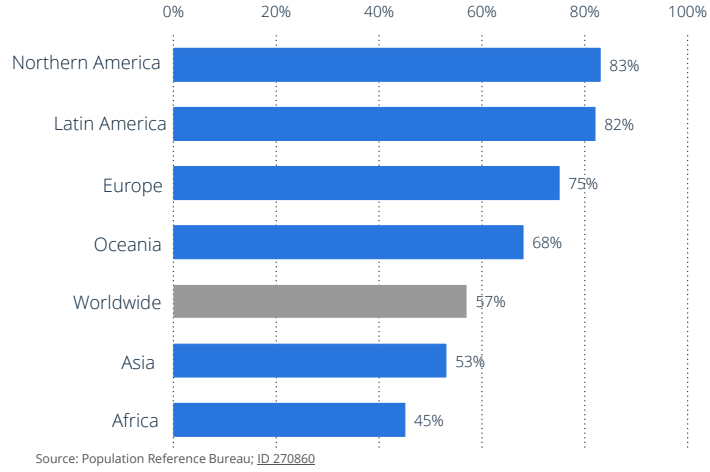
Cities can fundamentally be interpreted along two dimensions closely interlinked. As a collection of real estate assets represented by buildings and infrastructures located within a geographically delimited urban space; as a set of related governance structures and services like transportation, security, connections, waste management, etc., for allowing residents to use the same spaces either for living or working.

In that perspective, cities have a terrific impact on three stages:

i) on the quality of life of the residents (considering sociological factors along with financial variables) because it largely depends on the amenities and opportunities in the place where the largest part of (European) people lives (European Commission, 2023). In turn, the urban

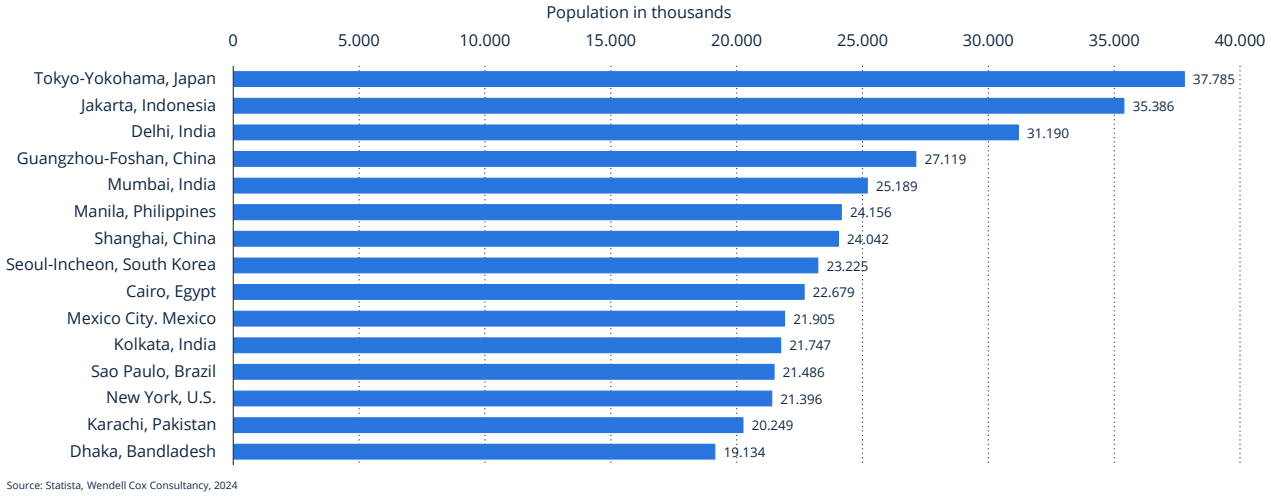
environment affects sociological behaviours in a cause-effect relationship. Recent surveys (World Bank, 2023; Statista, 2024) show that worldwide almost 57% of the population – 4.4 billion inhabitants – resides in cities, with higher percentage shares in Europe (75%) and North (83%) and Latin America (82%) [Table 1].

Table 1
Urban population as share of total population by continent, 2023 (Statista, 2024)



The dynamic is expected to grow further, with the urban population foreseen to increase by between 2.5 to 3 billion by 2050 (>70% of the total population) and the growth envisaged to occur primarily in Asia and Africa, which continents already host the largest megacities [Table 2].

Table 2
Largest urban agglomerations worldwide in 2023



ii) on sustainability and climate change, considering that metropolitan areas contribute circa 75% of the total greenhouse gas emissions worldwide (Seto K. et al., 2021);

iii) on the overall economy because urban areas represent between 3-6% of the total land use in geographical terms but roughly 90% of the overall land/real estate values in financial terms (where,

in turn, real estate represents almost 55-57% of the overall wealth of households' portfolios (University of Michigan, 2023; De Bondt et al., 2020). In addition, over 80% of the worldwide GDP is generated in urban areas (World Bank, 2023).

In that context, "Smart" Cities may be defined as metropolitan areas where technological solutions, both private and public, help improve "the management and efficiency of traditional networks for the benefits of their residents and business" (European Commission, 2023) (*i.e.*, the type and quality of the above mentioned urban governance and services like transportation, security, etc. are enhanced by applying digital advancements and new technologies to their production and management processes and overall urban governance). Such implementations aim to reduce metropolitan climate and environmental impact and improve urban vividness by boosting positive externalities at societal and governance levels.

3. Blockchain Applications to Smart Cities: a Review[3]

Following that perspective, the present section aims to analyse the literature and the advance in the body of knowledge on Smart Cities research, focusing on how Blockchain technology impacts the urban environment and may contribute to constructing inclusive and sustainable communities, including, below others, financial systems with the same characteristics to serve these societies. In fact, Blockchain as a DLT has immense potential for urban settings because it is perfectly suited to conveying secure and trusted information spread across sites and market participants from various perspectives that might be used for micro and macro-level constructs. At the micro-stage, *e.g.* for incorporating legal, Environmental, Social and Governance (ESG), technical, and financial data on urban real estate assets and development projects; at the macro-level, for integrating reliable and certified information in traditional metropolitan services and cities' overall planning and renewal.
This is because of the perceived lack of a systematic comprehension of the existing literature of the field and the fact that, despite the research efforts by scholars, crucial knowledge about Smart Cities remains scattered and fragmented on several fronts, leading to limited contributions also in terms of potential policy indications. More in detail, the perception, confirmed by the analysis, is of a scarcity of studies referring specifically to applications of Blockchain technology to urban activities and phenomena that allow, as a whole, an integrated vision of their impacts on the overall urban system. In particular, studies related to financial applications specifically devoted to Smart Cities from an integrated perspective, like in the field of payment systems, smart contracts, digital currencies, financial real estate and investments, seem to be largely missing. This is to the benefit of both economic operators and governance authorities in charge of the regulatory choices on the subject and for managing the urban contexts.

In light of that, the main objective of this section is to: i) perimeter the reference literature investigating smart cities and, more specifically, Blockchain technology applied to the urban environment; ii) outline the knowledge in the field – with focus on economic and business applications and, in particular, on financial issues – in terms of research topics and results, as well

[3] This section is taken from Biasin, M.; Delle Foglie, A. (2024). Blockchain and Smart Cities for Inclusive and Sustainable Communities: A Bibliometric and Systematic Literature Review. Sustainability, 16, 6669. https://doi.org/10.3390/su16156669, partly readapted and repurposed for consistency with the present report.

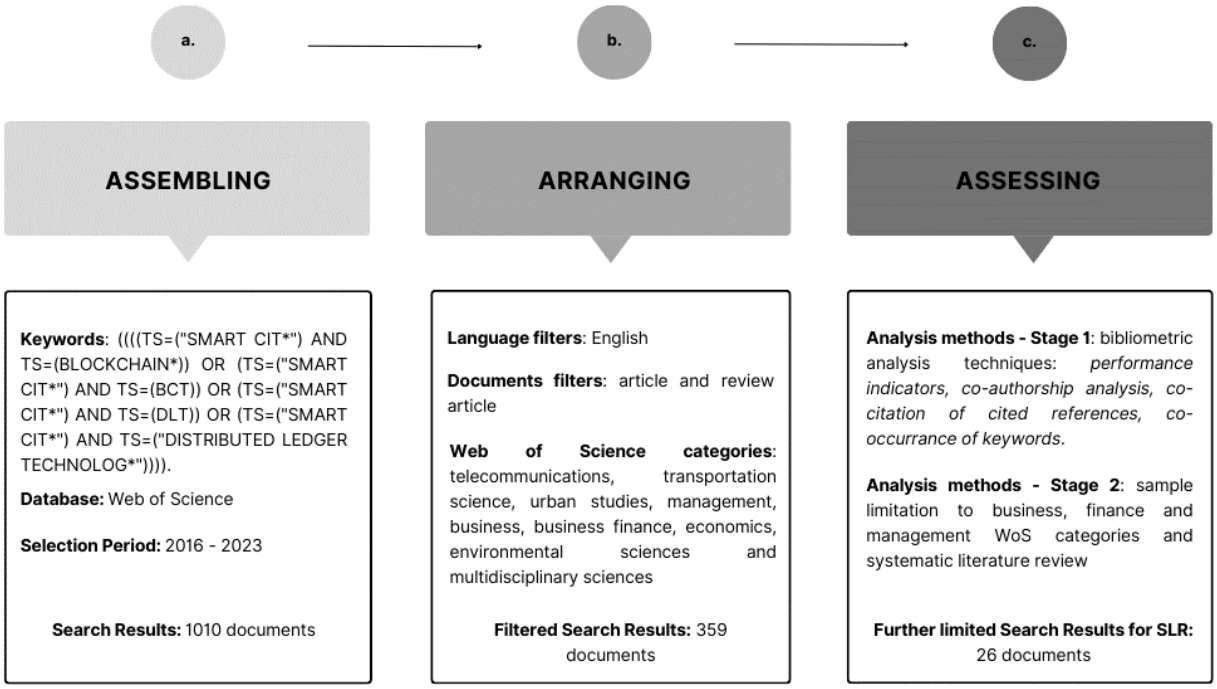
as to map emerging trends and intellectual structures in smart cities research over an extensive period (from 1950 to 2023); iii) highlight the directions for potential future research with a pioneer research agenda in relation to economic and financial systems' developments in Smart Cities. A specific *focus* on urban mobility and development is reported in Section 4.

The original contribution of this section is twofold and lies, on one side, in the mapping and systematization of the existing literature also in terms of covered research topics and results related to Smart Cities and Blockchain, and, on the other side, in proposing further research issues for developing a systematic investigation agenda based on the previous analysis. This is especially true for those research directions, like the financial perspective, not yet sufficiently exploited by the existing studies in terms of blockchain applications to the urban context capable of a global view of their impact on Smart Cities.

3.1. Methodology & Design

According to Paul and Criado (2020) suggestions for literature review works, the research methodology combines qualitative and quantitative methods in researching this topic. Notably, we use bibliometric indicators to provide a more comprehensive understanding of the knowledge in the field and map emerging trends, collaboration patterns, and intellectual structure in smart cities research over time (Donthu et al., 2021). It is possible through the use of statistical and graphical interfaces such as the VOSviewer software (Van Eck and Waltman, 2010) and the Bibliometrix package of R (Aria and Cuccurullo, 2017) (Pattnaik et al., 2020; Hassan et al., 2021; Patel et al., 2022; Delle Foglie and Keshminder, 2022; Sgambati and Gargiulo, 2022). We have also conducted a systematic literature review (SLR), a well-established scientific research method in management and social sciences, to enhance our analysis and specifically focus on the financial systems of smart cities. This involves a transparent and replicable review protocol that can be used to analyze research insights and trends, identify gaps, and propose ways to advance the field (Rao et al., 2022; Lim and Weissmann, 2021; Akello et al., 2022; Kumar et al., 2022; Paul et al., 2021; Hajek et al., 2022; Sharifi et al., 2024).
To organize relevant research on smart cities research and blockchain technology, this review section adopts, alternatively to the common PRISMA (Moher et al., 2009; Moher et al., 2015), the SPAR-4-SLR protocol proposed by Kumar et al. (2022), Paul et al. (2021) and He et al. (2022), consisting of assembling, arranging, and assessing. The methodology is described below and charted in Figure 1.

Figure 1
Research Design using SPAR-4-SLR Protocol.



Assembling: The authors conduct a preliminary review of the most significant literature on smart cities and blockchain technology to start the process. They also brainstorm to find the most accurate combination of keywords representing the knowledge body in this field (Donthu et al., 2021). One of the most comprehensive bibliometric databases of high-quality peer-reviewed journals, Web of Science, was selected as the research engine. It captures missed references and involves most scientific papers in the field. (Paltrinieri et al., 2019; Lim et al., 2021; Lim and Weissmann, 2021; Sharifi et al., 2024). To search the papers, in the assembling activity we have used a combination of keywords ("TS" corresponds to *title, keywords,* and *abstract* in Web of Science Core Collection) and Boolean operators (*"AND/OR"*): *((((TS=("SMART CIT*") AND TS=(BLOCKCHAIN*)) OR (TS=("SMART CIT*") AND TS=(BCT)) OR (TS=("SMART CIT*") AND TS=(DLT)) OR (TS=("SMART CIT*") AND TS=("DISTRIBUTED LEDGER TECHNOLOG*"))))).*
All the articles in the database were considered for the selection and span the period from 1950 (the first year available in the field) to 2023. The research returned 1010 documents from 2016 to 2023.

Arranging: In this stage, we applied WoS cleaning filters to limit the sample selection to articles written in English and include, following Paul et al., 2021, only articles and review articles since proceeding papers and book chapters may need to be peer-reviewed and do not ensure the quality of the final sample from a committed scientific perspective. Then, we refined the research by selecting only papers published in the Web of Science Categories of telecommunications, transportation science, urban studies, management, business, business finance, economics, environmental sciences, and multidisciplinary sciences to exclude more technical contributions related to blockchain technology applications to other scientific fields such as engineering or computer sciences. In this way, we pursue the aim of the research related to the role of blockchain technology in the construction of innovative, inclusive, and sustainable smart cities. After this stage, the final sample lies in 359 articles.

Assessing: To assess the final sample of 359 articles resulting from the arranging stage, this analysis adopts a bibliometric analysis such as *i)* performance analysis in which we describe the sample characteristics, most influential authors, journals, and documents in the field, *ii)* co-authorship analysis, *iii)* co-citation analysis of cited references and *iv)* co-occurrence analysis of the most popular keywords (Sgambati and Gargiulo, 2022).
Furthermore, to enhance the contribution of this study, the final sample (359) has been further limited to business, finance, management, and economics WoS Categories to systematically review and focus on those papers related to the role and the application of blockchain technology in the smart cities financial system. After applying this filter, the sample included in the SLR consists of 26 documents. In the final section, we aim to contribute to the advancement of the field by providing a future research agenda based on the analysis of the articles. This can be useful for researchers looking to identify gaps in the field and work towards addressing those gaps.

3.2. Results of the Bibliometric Analysis

Sample data and performance analysis

Examining the dataset resulting from the *arranging* stage (Table 3), we highlight that even if there are 94 journals involved in the field, *IEEE Access multidisciplinary journal* is the top journal with 1,996 total citations, which also host the most global cited documents (Fuller et al., 2020, etc.) (Table 4, 5). This paper reviews the definition of Digital Twin technology, focusing on the various definitions in manufacturing, healthcare, and smart cities research, providing insights for further research. However, looking at the local citations reported in Table 5, which considers the number of citations received in the sample, Fuller et al. (2020) has only 1 local citation. This work may not have a direct connection to the research stream related to smart cities, despite its high importance in literature.
Looking at most local cited paper, Xie et al. (2019) is the first, with 38 local citations and 298 global citations (the highest LC/TC ratio, 11,27) and published in *IEEE Communications Surveys and Tutorials* (the fourth most influential source), the journal with the highest impact factor (35.6). In this paper, the authors provide a comprehensive survey relating to the applications of blockchain technology in smart cities, providing initial future research challenges and directions. High levels of citations often characterize survey and literature reviews.

Table 3
Sample Details

Description	Results
Sources (Journals)	94
Authors	1278
Documents	359
References	19966
Average years from publication	2.53
Average citations per documents	34.14
Average citations per year per doc	8.021
Documents per Author	0.281
Authors per Document	3.56
Co-Authors per Documents	4.27
Collaboration Index	3.73

Source: Data elaboration from Bibliometrix.

Table 4
Top 10 Influential Sources by Total Citations (TC)

Source	H Index	G Index	M Index	TC	N. of Articles published	PY_start	Impact Factor**
IEEE Access	22	39	3,14	1996	39	2018	3.9
IEEE Internet of Things Journal	21	38	3,50	1490	41	2019	10.6
Sustainable Cities and Society	13	13	1,86	1291	13	2018	11.7
IEEE Communications Surveys and Tutorials	6	6	1,00	1212	6	2019	35.6
Sustainability	14	23	2,00	632	37	2018	3.9
Cities	5	5	0,83	610	5	2019	6.7
IEEE Network	7	8	1,40	335	8	2020	10.294
Computer Communications	5	7	1,00	301	7	2020	6
Financial Innovation	1	1	0,11	279	1	2016	8.4
Transactions on Emerging Telecommunications Technologies	7	10	1,75	260	10	2021	3.6

Source: Data elaboration from Bibliometrix. ** data from the journal website.
PY start indicates the publication year.

Table 5
Top 10 Global Cited Documents

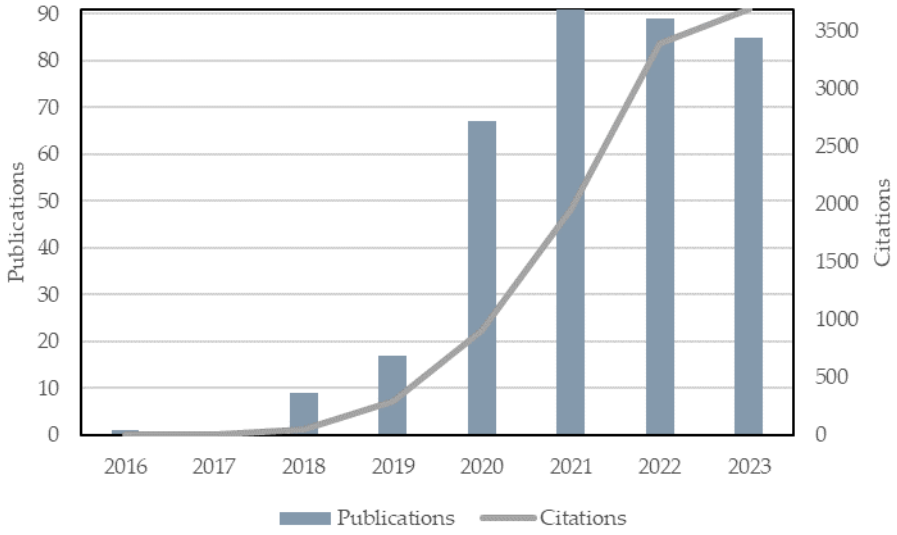
Author(s) (Year)	Title	Journal	Local Citation	Total Citations	TC per Year	LC/TC Ratio (%)	Normalized TC
Fuller et al. (2020)	Digital Twin: Enabling Technologies, Challenges and Open Research	IEEE Access	1	630	126.000	0.16	103.753
Allam and Dhunny (2019)	On big data, artificial intelligence, and smart cities	Cities	11	409	68.167	2.69	36.441
Dagher et al. (2018)	Ancile: Privacy-preserving framework for access control and interoperability of electronic health records using blockchain technology	Sustainable Cities and Society	7	373	53.286	1.88	26.559
Xie et al. (2019)	A Survey of Blockchain Technology Applied to Smart Cities: Research Issues and Challenges	IEEE Communi-cations Surveys & Tutorials	40	355	59.167	11.27	31.630
Nguyen et al. (2021)	Federated Learning for Internet of Things: A Comprehensive Survey	IEEE Communi-cations Surveys & Tutorials	1	346	86.500	0.29	100.907
Stoyanova et al. (2020)	A Survey on the Internet of Things (IoT) Forensics: Challenges, Approaches, and Open Issues	IEEE Communicatio ns Surveys & Tutorials	6	331	66.200	1.81	54.511
Sun et al. (2016)	Blockchain-based sharing services: What blockchain technology can contribute to smart cities	Financial Innovation	30	279	31.000	10.75	10.000

Shen et al. (2019)	Privacy-Preserving Support Vector Machine Training Over Blockchain-Based Encrypted IoT Data in Smart Cities	IEEE Internet of Things Journal	13	240	40.000	5.42	21.384
Banerjee et al. (2018)	A blockchain future for internet of things security: a position paper	Digital Communi-cations and Networks	11	240	34.286	4.58	17.089
Guan et al. (2018)	Privacy-Preserving and Efficient Aggregation Based on Blockchain for Power Grid Communications in Smart Communities	IEEE Communi-cations Magazine	2	232	33.143	0.86	16.519

Source: authors elaboration from Bibliometrix.

Furthermore, in Table 4, we also identified the top 10 influential journal in the research stream ranking them by the total number of citations (TC) received. Table 5 reports the top 10 global cited documents in the database, always ranking by the TC received.
Finally, looking at the bibliometric performance of the sample, we have noted that the contribution and the interest of academics are characterized by a growing increase in the last years, starting from 2016. Starting in 2019, the number of publications has boomed by about 300% over the previous period, probably relating to the increase in interest in digitalization and the use of Blockchain during and after the COVID-19 pandemic (Figure 2).

Figure 2
Times cited and published over time



Source: WoS citation report

Co-citation analysis[4]

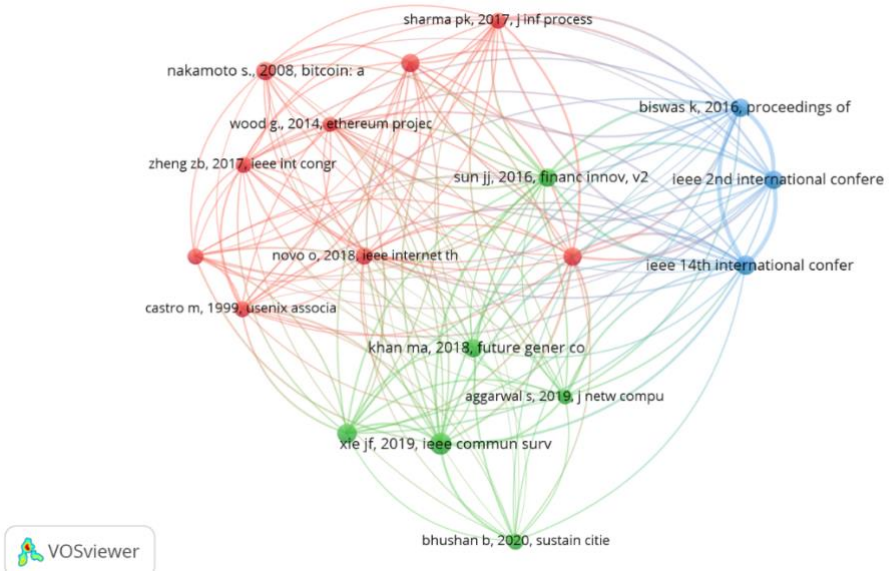
The co-citation analysis (referred to in Table 6 and visually depicted in Figure 3) overcomes the mere counting of citations and is instrumental in identifying the most relevant aspect of the field. This bibliometric method allows for identifying the articles that cite each other on the same concept or topic. This method provides valuable insights into the commonalities and research streams or clusters in the literature, thereby aiding in the identification of emerging trends and areas of interest (Panetta et al., 2023; Paltrinieri et al., 2019; Patel et al., 2022; Hajel et al., 2022). The most cited references in the sample are ordered by considering the number of citations received.

Table 6
Co-Citation Network and Local Cited References (Top 10 list)

Author/s (Year)	Citations	Total Link Strength	Cluster
Xie et al. (2019)	40	122	Green
Nakamoto (2008)	33	82	Green/Red
Biswas et al. (2016)	30	150	Blue
Sun et al. (2016)	30	114	Green
Khan and Salah (2018)	28	46	Green
Sharma and Park (2018)	28	105	Red
Christidis and Devetsikiotis (2016)	27	83	Red
Novo et al. (2018)	26	68	Red
Zheng et al. (2017)	23	77	Red
Bushan et al. (2020)	22	46	Red

Source: authors elaboration from Bibliometrix.

Figure 3
Chart of co-citation analysis of cited references using VOSviewer software



[4] We conducted also a co-authorship analysis (also known as social network analysis) of a strictly academic nature and not reported here. Interested parties can refer to "Biasin, M.; Delle Foglie, A. (2024). A. Blockchain and Smart Cities for Inclusive and Sustainable Communities: A Bibliometric and Systematic Literature Review. Sustainability, 16, 6669. https://doi.org/10.3390/su16156669" from which relevant parts of this report are taken.

The VOSviewer software identifies three different clusters headed again by Xie et al. (2019) in the *green* cluster, and Nakamoto (2008) the paper that made Blockchain technology famous for introducing the Bitcoin payment system. This paper is always the most cited when discussing blockchain, cryptocurrency, or digital payments. The third most cited paper with 30 citations is Biswas et al. (2016), in the *blue* cluster, followed by by Sun et al. (2016) and Khan and Salah (2018) which led the *green* cluster. Sharma and Park (2018) led the *red* cluster, including all the other most cited papers in Table 6.
All these papers discuss the proposal of a framework architecture for Blockchain applications in future smart cities. In these papers, the authors discussed the advent of Internet of Things (IoT) applications and the importance of blockchain in solving security problems, proposing a new framework for their combined adoption.

Co-occurrence analysis

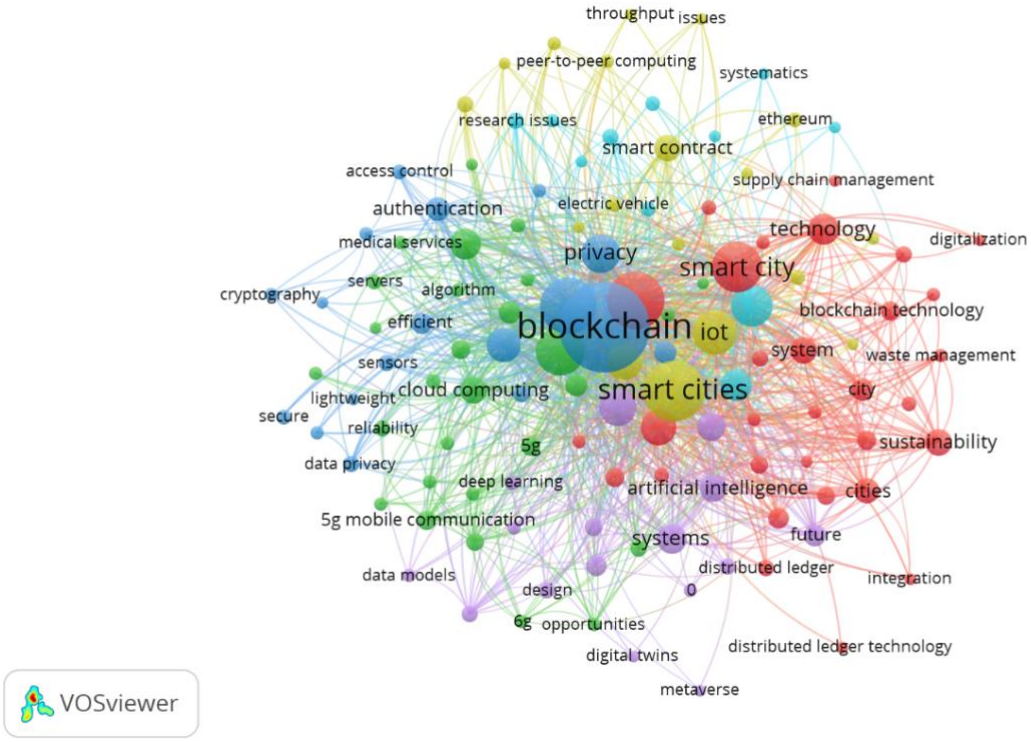
In this section, we present a co-occurrence analysis of the keywords available in the sample, also called cartographic analysis. Cartographic analysis aims to map the keywords that identify different research streams by grouping them into clusters that represent content areas. The relatedness of these areas is evaluated by considering the total link strength and the number of occurrences of the keywords in the sample (Khan et al., 2022; Migliavacca et al., 2023; Bahoo et al., 2020; Sgambati and Gargiulo, 2022). Table 7 and Figure 4 present the results obtained using the VOSviewer software. In the *green* are the keywords representing the topic of this literature review, which are also the most used by the authors, such as *Blockchain* and *Smart City/ies.* The *blue* cluster, instead, contains keywords that recall another research stream related to the previous one related to IoT, big data, cybersecurity, or distributed ledger. The term IoT is also presented in the complete form of the Internet of Things in the *red* cluster, which also contains keywords related to another research stream that treated other Blockchain applications such as cloud computing, 5G, wireless networks, or the Internet of Vehicles. It is possible to note how these keywords also identify the most relevant articles discussed in the previous bibliometric analysis.

Table 7
Keyword occurrence and cluster details (Top 10 list)

Keywords	Occurrences	Total Link Strenght	Cluster
Blockchain	267	1574	Blue
Smart Cities	124	844	Blue
Security	103	823	Blue
Internet	108	798	Red
Internet of Things	80	611	Green
IoT	66	490	Yellow
Smart City	86	487	Red
Challenges	56	451	Light Blue
Privacy	49	393	Blue
Management	46	392	Purple

Source: authors elaboration from VoSviewer.

Figure 4
Cartographic analysis through VoSviewer software



3.3. Systematic Analysis: WoS Business, Finance, Economics and Management

This paragraph focuses on the current status of blockchain applications in developing economic and financial ecosystems for Smart Cities, summarized in Table 8 below. For doing that, we have limited the WoS database to the *Business, Finance, Economics, and Management* categories to achieve this, yielding 26 documents published between 2016 and 2023. According to Paul et al. (2021), the process of conducting a SLR is the best option to achieve our objective since it helps to develop a comprehensive understanding of existing literature (state of the art) and provides new avenues for future research (stimulating agenda). The term "state-of-the-art" refers to the mapping and up-to-date literature summary. In contrast, "stimulating agenda" refers to the potential directions for future research to enrich the literature and enhance our understanding.

Table 8
Summary of the systematic analysis

Topic	Paper Aims	Main Findings	Reference
Blockchain, governance, and infrastructure	Systematic review + meta-analysis on the application of blockchain technology and smart contract in decentralized governance systems	• Blockchain-based smart governance systems involve public engagement by deploying data-computing capabilities, distributed ledger technologies, visual analytics, and smart connected devices. • By utilizing data visualization tools, spatial data mining, and machine learning techniques, blockchain-based smart contracts and decentralized	Balcerzak et al. (2022)

		applications can enhance trust in computationally networked urbanism. • Smart cities leverage the Internet of Things (IoT) to deploy decision support tools, computer vision techniques, and visual data mining. This enables scalable networked interoperability across urban environments and efficient data resource management. • Urban sensing technologies integrate geospatial big data analytics, IoT sensors, and smart city software systems, enhancing the overall functionality of urban environments.	
	Create a new searchable 3D city model to help managers improve their decision-making.	The digitization of data and integration of new technologies into various management processes have made it possible to interconnect city systems. While numerous 3D city models are available, none identified in this research can be queried for multiple sectors.	Lafioune and St-Jacques (2019)
	Examine the current implementation of strategic smart city agendas and the methods used to measure and present their performance. It proposes a new approach involving blockchain technology to create a more inclusive and collaborative platform known as the People's Smart City Dashboard (PSCD).	The People's Smart City Dashboard (PSCD) uses blockchain technology to empower and collaboratively reimagine smart city agendas and performance measurement, achieving citizen-centric governance.	Marsal-Llacuna (2020)
	Propose the Digital Twin City model, a systematic review of advanced technologies applied in DTC, research directions, and a new framework	Digital twin cities (DTC) offer great potential in transforming urban governance paradigms towards smart cities by combining digital twins, IoT, blockchain, and AI technologies.	Deng et al. (2021)
Definitions and key components	Review of definitions and components of current smart cities	• There is no consensus about a standard definition of smart city, components, and applications since the diverse nature of the field • Provide a brief presentation of smart city key components such as smart buildings, smart transportation, smart healthcare, and smart energy. The emergence of specific technologies such as blockchain, 5G internet, virtual and augmented reality, and quantum computing can contribute to the development of smart cities.	Bohloul (2020)
Blockchain implementation	Review and study the use of performance indicators	According to the Delphi method, the experts proposed eight additional performance	Ivanisevic et al. (2023)

and performance indicators	to evaluate blockchain implementation projects in smart cities using the Delphi method.	indicators: user base growth over time, environmental sustainability, risk density, policy revision based on the implementation of new data, ease of access, data integrity, resiliency, and number of transactions executed.	
Smart City development financing	Identify modern investment processes in developing smart technologies for the world's smart cities amidst large-scale digitization.	Investment in the development of smart cities involves using advanced technologies and innovations to improve the lives of residents, optimize resources, and increase the efficiency of the urban economy. This investment can take various forms, including direct investment, venture capital, corporate investment, corporate partnerships, state and local funds, crowdfunding, bonds and municipal bonds, fintech, blockchain, and more.	Kalenyuk et al. (2023)
Robotic services	Describe different methods of organizing robotic services for smart cities using secure, encrypted decentralized technologies and market mechanisms.	• In the article, Ethereum and ROS were proposed as interaction mechanisms in a smart city. These market mechanisms ensure the effectiveness and practicality of the agents. The study demonstrates that the services of a smart city are more efficiently and effectively managed when implemented based on the robot economy.	Kapitonov et al. (2019)
Blockchain applications in the Smart City development	Show how blockchain networks will disrupt the urban context, similarly to what is happening in the fintech and insurtech industries, among other emerging applications.	Blockchain networks will disrupt urban networks, similar to other network fevers like Cybernetics, Ekistics, and IoT, and serve as the following enabling network for cities.	Marsal-Llacuna (2018)
	Investigate the applicability of blockchain in the governance process in autopoietic smart cities.	• Blockchain has the potential to enable self-regulation and self-sufficiency in the governance systems of smart cities. • Integrating blockchain technology with IoT devices such as cars, houses, and public places is hindered by people's lack of familiarity with blockchain. • The main challenges hindering the implementation of blockchain technology in government services are the management of smart contract variables related to the origin, transportation, and consumption of resources, as well as health and financial services. Another significant factor is the need for higher-speed broadband connections to enable seamless blockchain integration. • Lack of awareness and education from the public sector contrasts with the private sector's greater investment in blockchain technology and information.	Migliorini et al. (2021)

	Security of IoT devices, resilience to cyber-attacks, flexibility, and rapidity of system development.	DLT-based attestation system provides decentralized security for IoT devices, ensuring connectivity and correct functioning in Smart Cities.	Moro and Duke (2020)
	Propose a framework to identify the features of smart cities from the angle of the sharing economy.	Blockchain-based sharing services can contribute to smart cities by enhancing the sharing economy's human, technology, and organizational factors.	Sun et al. (2016)
Transport and logistic systems	Review Smart City transport and logistic systems.	• The research outlines the dominant trends and specifics of the smart mobility services development in real-time for businesses and individuals, as well as intelligent transportation systems and highly autonomous vehicles in smart cities worldwide. • The rise of the Internet of Things is driving a shift towards a multimodal environment. • The study highlights the need to develop urban logistics as a tool to expand opportunities for managing flow processes sustainably in an urban area.	Savin et al. (2021)
Big Data	Systematic review of big data in Smart City	• The bibliometric analysis indicates a significant increase in research publications in recent years, with China leading research efforts on smart cities in developing countries. • The network analytics and article classification identified six domains within the smart cities' literature. • A conceptual framework has been proposed to implement Industry 4.0 technologies in smart cities successfully.	Tiwari et al. (2019)
Blockchain and sustainability of Electric Vehicle performance	Test the readiness of Electric Vehicles (EV) in UAE, the role of EV as mediator to sustainability, and the role of Blockchain as a moderator	• The study revealed a positive correlation between EV readiness in the UAE and quality of service, power quality, and infrastructure. • The adoption of blockchain technology in the UAE is still in its early stages, as its role in enhancing the relationship between power quality, infrastructure, and sustainability is not yet significant. • The adoption of blockchain technology has the potential to save energy.	Sundakarani et al. (2023)
Off-Topic	Liu et al. (2022); Liu et al. (2023); Fathi et al. (2023); Chung et al. (2023); Parmentola et al. (2021); Prabucki (2020); Ren et al. (2023); Saric et al. (2022); Zhang et al. (2022); Zhang (2022); Jnr et al. (2023)		

The SLR process classifies the documents into nine main themes: i) Blockchain, governance and infrastructure, ii) Definitions and key components, iii) Blockchain implementation and performance indicators, iv) Smart City development financing, v) Robotic services, vi) Blockchain applications in the Smart City development, vii) Transport and logistic systems, vii) Big Data, ix) Blockchain and sustainability of Electric Vehicle performance. Papers that cover more technical topics, such as Wi-

Fi sensors, 5G, or data transmission, are classified as off-topic since they are unsuitable for the research aim. The results of the analyses are summarized in Table 8, which highlights each paper's aims and main findings.

A brief discussion of the documents highlights that the first category includes a systematic literature review on decentralized governance systems, which first highlights the impact of blockchain technology in smart city governance. Blockchain-based smart governance systems utilize data computing, DLT, visual analytics, and smart devices to engage the public. These technologies have multiple applications and can increase trust in computationally networked urbanism. Blockchain technology enables seamless data-sharing and reduces transaction costs, while smart contracts democratize governance structures. The decentralized nature of blockchain optimizes smart city self-governance (Balcerzak et al., 2022). For this purpose, Marsal-Llacuna (2020) proposed using community-led technologies such as blockchain to solve the problem of smart cities, which fail to be citizen-centric due to the top-down approach. The author proposes using a People's Smart City Dashboard (PSCD). This community-led initiative aims to provide an alternative to the current top-down approach to smart city development. The project uses Blockchain technology, which is designed to be community-led. This means citizens will significantly implement smart city agendas and collaborate with society. Furthermore, Bohloul (2020) provides a comprehensive review of challenges, trends, and opportunities in the topic of smart cities, also giving an overview of the main definition of a smart city, which does not result in a no consensus about the exact definition of it. The author affirms that certain technologies like Blockchain, 5G internet, virtual/augmented reality, and quantum computing can contribute to the advancement of smart cities. These technologies have created numerous opportunities for research and entrepreneurial endeavours. Although the current state of smart cities is promising, it remains a rapidly evolving field, with new trends expected to shape its future. Similarly, Marsal-Llacuna (2018). Migliorini et al. (2021) and Sun et al. (2016) highlighted the role of Blockchain technology in disrupting urban networks and essential for the smart cities' governance, infrastructure (Savin, 2021; Sundakarani et al., 2023), and financial services development above all through the use of smart contracts and IoT. Another interesting point of view is provided by Tiwari et al. (2019), which provides a conceptual framework of the smart city for the adoption of Industry 4.0, also highlighting challenges and trends in technologies like big data, cloud computing, edge computing, and IoT. These advanced technologies are crucial for successfully implementing and monitoring a smart city.

4. *Focus* on (1) Blockchain and Transportation/Mobility & (2) Blockchain and Urban Development/Planning

In view of the results of the preceding bibliometric analysis and in light of the particular relevance of (1) mobility as well as of (2) urban planning & development projects for the city residents because of their public externalities, the literature review work has been extended to focus on the research stream dedicated to these two relevant services.

In particular, looking at the same bibliometric databases of high-quality peer-reviewed journals, Web of Science (WoS), the keywords "*SMART CITY/IES*" and "*BLOCKCHAIN*", previously used, have been combined, alternatively, with "*TRANSPORT**", "*URBAN PLANNING*", "*URBAN DEVELOPMENT*"

and "*MOBILITY*"; this both separately and jointly[5]. The sample has then been limited to the WoS-categories related to the main subject areas of the report, such as Telecommunications, Green Sustainable Science Technology, Computer Science Interdisciplinary Applications, Transportation Science Technology, Environmental Sciences, Environmental Studies, Construction Building Technology, Computer Science Artificial Intelligence, Urban Studies, Business, Management, Multidisciplinary Sciences, Business Finance, Regional Urban Planning, Social Sciences Interdisciplinary.

The final sample consists of 146 documents published between 2019 and 2024 (Table 9).

To gain a comprehensive understanding of the knowledge in the field and map emerging trends, collaboration patterns, and intellectual structure in smart city research over time, we employed bibliometric indicators similar to the ones of the preceding comprehensive analysis[6].

Sample data and performance analysis

The dataset resulting from the bibliometric research shows that IEEE Communications Surveys and Tutorials is the most cited journal, with 1,144 total citations and an impact factor of 35.6 (Table 10). In this regard, the first three global cited documents in the sample (Table 11), respectively Xie et al. (2019), Nguyen et al. (2021), and Stoyanova et al. (2020), are published in this journal and partly overlapping with previous results. The same is true for the third and fourth most global cited documents published in Sustainable Cities and Societies.

In Xie et al. (2019), the paper with the highest citations, the authors provide a comprehensive survey relating to the applications of Blockchain technology in smart cities, providing future research challenges and directions. Moreover, this work dedicates a specific section to smart transportation, analyzing decentralized smart transportation architecture, vehicle communication management, and electric vehicle charging management. The authors finally reveal that Blockchain can enhance decentralized smart transportation systems by enabling trust management in vehicular networks through Road Side Units (RSUs) acting as Blockchain nodes. This maintains a public ledger of trust values and incentivizes data sharing. Additionally, Blockchain and smart contracts facilitate decentralized electricity trading between electric vehicles and charging stations, ensuring transparency and optimal decision-making for EV charging.

Nguyen et al. (2021) focus on the integration of federated learning (FL) in smart transportation systems, emphasizing its potential to enhance intelligent transportation systems (ITS) by enabling decentralized data learning directly at the network edge. This approach involves multiple participants, such as vehicles, collaborating to train AI models without extensive data transmission, thereby addressing privacy concerns. FL is applied in vehicular traffic planning and resource management, improving traffic predictions and efficient vehicle control. FL offers superior outcomes compared to traditional centralized machine learning methods by utilizing the vast data and computational power of numerous vehicles.

[5] The asterisk is used to consider the root of the word and all possible variants, *e.g.* transports, transportation, etc.
The sample has been restricted only to articles and review articles written in English. The choice of document type ensures the quality of papers that are peer-reviewed.

[6] These indicators, along with the VOSviewer software (Van Eck and Waltman, 2010) and the Bibliometrix package of R (Aria and Cuccurullo, 2017), serve as our statistical and graphical interfaces, ensuring a rigorous and systematic analysis of the data.

Looking then at the top-third most cited, Stoyanova et al. (2020) discuss smart transportation in the context of Smart Cities, emphasizing the role of Autonomous Automated Vehicles (AAVs) equipped with sensors for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. These smart vehicles, including cars and buses, provide essential information for efficient and safe city traffic management. Companies like Tesla, BMW, Mercedes, and Daimler have already introduced self-driving features, while tech giants like Google and Uber are testing autonomous driving prototypes. According to them, by 2035, it is expected that there will be nearly 11.8 million connected vehicles with automated driving assistance, inspiring the future of smart transportation.

Table 9
Sample Details

Description	Results
Timespan	2019:2024
Sources (Journals)	58
Documents	146
Average years from publication	2,13
Average citations per document	38,35
Average citations per year per doc	9,716
Documents per Author	0,264
Authors per Document	3,78
Co-Authors per Documents	4,27
Collaboration Index	3,92

Source: Data elaboration from Bibliometrix.

Table 10. Top 5 Influential Sources by Total Citations (TC)

Source	H Index	G Index	M Index	TC	Nos. of Articles published	PY_start	Impact Factor**
Ieee Communications Surveys and Tutorials	5	5	0.833	1144	5	2019	35.6
Sustainable Cities and Society	7	7	1.400	765	7	2020	11.7
Ieee Internet of Things Journal	9	12	1.800	451	12	2020	10.6
Journal of Network and Computer Applications	3	3	0.600	316	3	2020	7.7
Automation in Construction	1	1	0.167	288	1	2019	9.6

Source: Data elaboration from Bibliometrix. ** data from the journal website. *PY start* indicates the publication year.

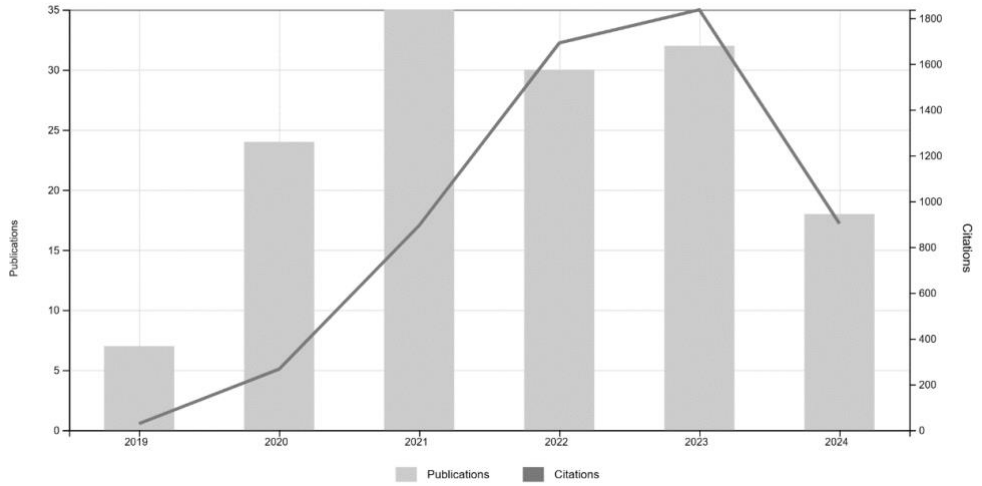
Table 11
Top 5 Global Cited Documents

Author (s) (Year)	Title	Journal	Local Citation	Total Citations	TC per Year	LC/TC Ratio (%)	Normalized TC
Xie et al. (2019)	A Survey of Blockchain Technology Applied to	IEEE Communication	18	354	59.00	5.08	24.012

	Smart Cities: Research Issues and Challenges	s Surveys and Tutorials					
Nguyen et al. (2021)	Federated Learning for Internet of Things: A Comprehensive Survey	IEEE Communications Surveys and Tutorials	3	339	84.75	0.88	70.442
Stoyanova et al. (2020)	A Survey on the Internet of Things (IoT) Forensics: Challenges, Approaches, and Open Issues	IEEE Communications Surveys and Tutorials	3	331	66.20	0.91	35.959
Li et al. (2019)	Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases	*IEEE Transactions on Emerging Topics in Computing*	1	288	48.00	0.35	19.535
Ahad et al. (2020)	Enabling technologies and sustainable smart cities	Sustainable Cities and Society	6	223	44.60	2.69	24.226

Source: Authors elaboration from Bibliometrix

Figure 5
Times cited and published over time



Source: WoS citation report

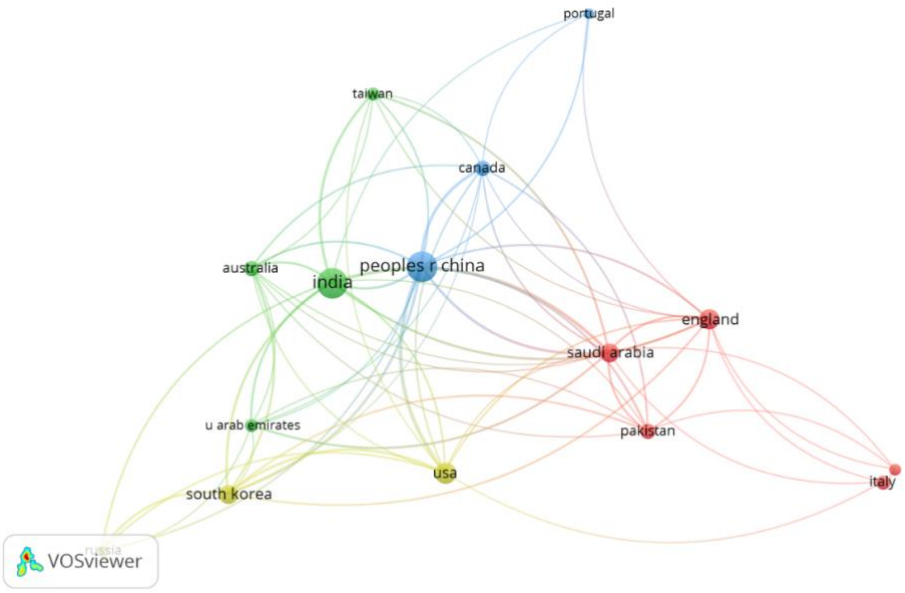
Co-autorship analysis

The review work continues with co-authorship analysis by country[7] (Figure 6) that is considered functional to the subsequent identification and analysis of international case studies in the field of mobility and urban development.

[7] We conducted also a co-authorship analysis by authors not reported here. Interested parties can contact the authors of the present section (Biasin, M.; Delle Foglie, A.) for furhter details and data.

Considering the country of the authors involved in the sample, China results as the country with the highest total link strength. Authors from this country act as a link between all the other countries, including India.

Figure 6
Chart of the co-authorship analysis by country using VOSviewer software

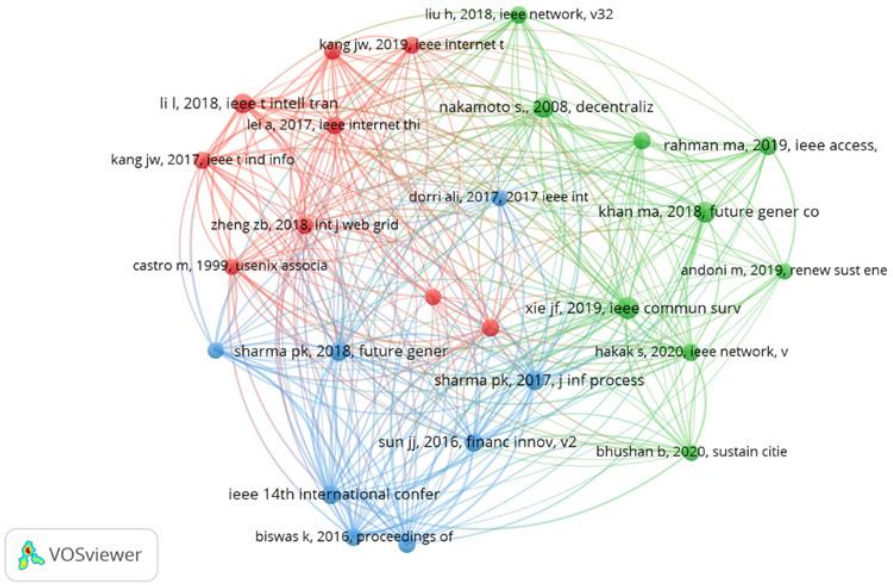


Co-citation & Co-occurance analysis

The co-citation analysis of articles, based on their cited references, is depicted in Figure 7; the related co-occurrence analysis of the keywords available in the sample is reported in cartographic mode in Figure 8.

The first one overcomes the mere counting of citations and is instrumental in identifying the most relevant aspect of the field by focusing on the most cited references in the sample ordered by considering the number of citations received. The results highlight the presence of Nakamoto (2008) (the green cluster). This paper made Blockchain famous for introducing Bitcoin and the concept of decentralized payment systems, which is always cited when talking about Blockchain. The second most cited paper with 38 citations is Xie et al. (2019), previously discussed, which led to the red cluster with Sun et al. (2016) and Sharma and Park (2018). All these papers discuss the proposal of a framework architecture for Blockchain applications in future smart cities. Finally, Khan and Salah (2018) and Novo et al. (2018) guide the third blue cluster. In these papers, the authors discussed the advent of Internet of Things (IoT) applications and the importance of Blockchain in solving security problems, proposing a new framework for their combined adoption.

Figure 7
Chart of co-citation analysis of cited references using VOSviewer software



Furthermore, looking at the co-occurrence analysis, also chartered in Table 12, the blue cluster includes the keyword representing the topic of this report, which is also the most used by the authors, such as Blockchain. This cluster also includes the internet and security. The second keyword guiding this research, such as smart city/ies, is in the green/blue cluster, depending on the form used.

Instead, the red and yellow cluster contains keywords that recall another research stream related to the previous one, such as the Internet of Things (IoT). The term IoT is also presented in the complete form of the Internet of Things in the yellow cluster, which also contains keywords related to another research stream that treated other blockchain applications such as vehicles, models, networks, etc. Please note how these keywords also identify the most relevant articles previously reported.

Figure 8
Cartographic analysis through VoSviewer software

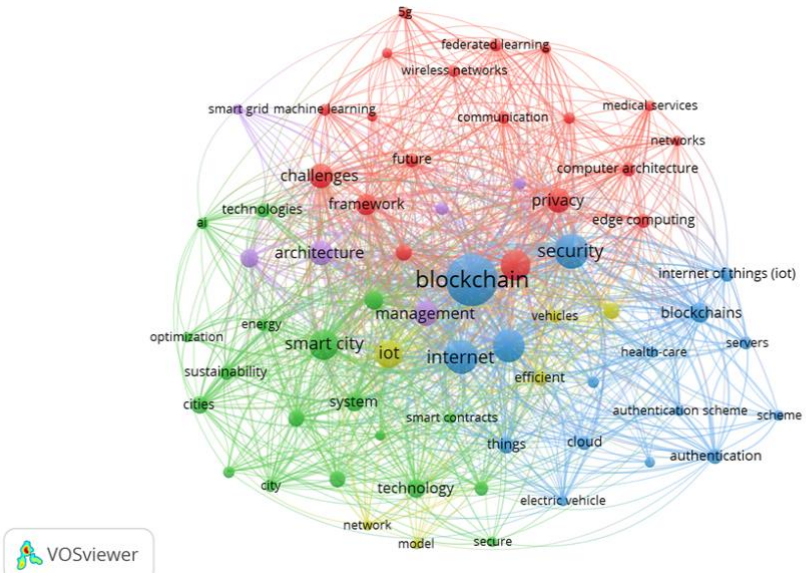


Table 12
Keyword occurrence and cluster details (Top 10 list)

Keyword	Occurrences	Total Link Strength	Cluster
Blockchain	112	654	Blue
Security	50	374	Blue
Internet	47	362	Blue
Smart Cities	45	309	Green
Smart City	39	229	Blue
Internet Of Things	38	301	Red
IoT	32	259	Yellow
Architecture	25	163	Purple
Challenges	25	196	Red

5. Summary considerations[8]

The bibliometric and systematic analysis results give several insights into the research landscape of blockchain applications in Smart Cities.

The co-authorship and co-citation networks underscore the collaborative nature of this research domain, fostering interdisciplinarity and cross-group research efforts within this area. This structure provides a solid platform for Blockchain and Smart City research, which is inherently dynamic and fast-paced.
Systematic analysis shows that blockchain is instrumental in the decentralized governance system for transparency, security, and increasing public engagement in urban management. In overall

[8] Also part of this section, readapted, is taken from Biasin, M.; Delle Foglie, A. (2024) (see above).

terms, the studies largely focus on the concept of Smart Cities and the potential impact of Blockchain considering: (1) the merge of information systems and urban infrastructure like *e.g.* transportation/mobility; connections; electricity and waste management; safety & healthcare; (2) the progressive extension to the areas of planning, development, civil/administrative services and sustainability issues; (3) citizens' participation and cooperation in the urban governance in terms both of actions and processes, moving from a largely technological focusses perspective to a social, economic and political approach.

This is evidenced by studies, such as Balcerzak et al. (2022), which adduce how Blockchain democratizes governance structures with smart contracts and decentralized applications to have a more inclusive model of urban governance. Although there has yet to be a single agreed definition of what constitutes a Smart City, which reflects the field's diversity and multi-disciplinarity, common components identified include *e.g.* smart buildings, transportation, healthcare, and energy systems. Most of the emerging technologies are related to 5G, IoT, and AI; thus, being already recognized as critical enablers of Smart City advancement would point out a trend towards their integration for holistic urban development. The Delphi method reveals a number of more performance indicators relevant to evaluating Blockchain projects in Smart Cities. These include environmental sustainability, data integrity, and increasing the user base, among others, which consequently give a holistic framework for assessing blockchain impact and effectiveness within urban contexts.

These findings are within the larger research trends that put Blockchain at the core of efficiency and security in Smart City infrastructures worldwide. Other authors of research papers, such as Marsal-Llacuna, 2020, and Deng et al., 2021, underline Blockchain's disruptive role in urban governance, relating its integration to digital twins and IoT technologies. It contributes to the novel identification of specific performance indicators regarding Blockchain implementation in Smart Cities, which needs to be explored more in previous literature. This provides more granularity in understanding how Blockchain can be effectively used and measured within urban environments.

The research uncovers several implications for future studies. The absence of a unified concept of Smart Cities presents a research opportunity: developing an agreed core set of components and applications could enhance the comparability and coherence of this area of research. Moreover, the integration of emerging technologies like quantum computing and augmented reality into the contexts of Smart Cities is certain to open up further interesting lines of inquiry. The systematic application of bibliometric and co-authorship analyses strengthens the methodology for understanding the research landscape. Future research could consider similar approaches to map the evolution of other emerging technologies and their applications across different domains, inspiring further exploration and discovery.

There is significant potential for improving urban governance and infrastructure through the integration of Blockchain. More research is needed to standardize definitions, develop comprehensive performance metrics, and explore synergies between Blockchain and other emerging technologies. This ongoing exploration and discovery should excite and engage researchers in the field.

Furthermore, the application of Blockchain technology specifically referred to *transportation, urban planning,* and *mobility* in Smart Cities demonstrate enormous potential to create more efficient, secure, and sustainable urban settings. A broad set of literature reviewed shows that Blockchain,

through its decentralized and transparent ledger system, could serve as the solution to various critical challenges currently affecting urban development and transportation systems. Papers used in the bibliometrics review range from:

- Decentralized Smart Transportation: Blockchain can enrich smart transportation systems, which can make trust management in vehicular networks, and the supporting mechanisms of decentralized electricity trading between electric vehicles and charging stations, feasible, followed by much greater transparency and optimized decisions;

- Federated Learning in Smart Transportation: This can be achieved through the infusion of federated learning with Blockchain in intelligent transportation systems for better traffic prediction and vehicle control, in a decentralized data learning process that not only helps protect the privacy concerns of individuals but also saves a lot on data transmission;

- Autonomous Automated Vehicles (AAV): Blockchain ensures safe V2V+V2I communication of AAVs, thereby leading to effective and safe traffic management in the smart city;

- Urban Planning and Development: Blockchain, therefore, plays a very major role in urban planning by ensuring integrity in the data, enhancing transparency of public records, and facilitating secure transactions of the real estate and construction industries;

- Collaboration and Research Trends: In essence, such bibliometric data demonstrates that there is major collaboration on this subject among researchers, primarily from China, which is leading the way in the field of Blockchain applications for Smart Cities.

In conclusion, the application of Blockchain technology in transportation, urban planning, and mobility in Smart Cities is at a very nascent stage but bears excellent potential. Now, further interdisciplinary research and collaboration, coupled with enabling policy frameworks, would be critical in harnessing the full potential of Blockchain towards smarter and more sustainable urban environments.

Box 1: Legal Issues related to the use of Blockchain data

The use of the Blockchain raises important legal issues, *inter alia* with regard to consent, publicity, unchangeability, accessibility and availability (public or private) of the data. Although these topics are outside the scope of this investigation, the present box reports some considerations on the subject that are deemed useful for a better understanding of the overall issue.

Legal considerations on data in the Blockchain environment.

By Manuel Feliu Rey

It is important to underline the difficulty of exercising the data subject's rights, in particular the rights of access, rectification, preservation, erasure and objection to the use of personal data in Blockchain technology.
Blockchain implies a secure digital identity by using advanced and secure encryption systems that guarantee anonymity and confidentiality, together with the GDPR's legal requirement of anonymization and data minimization (data controllers must ensure that data are adequate, relevant and limited to what is necessary in relation to the purposes for which the data are processed).

> *European Declaration on Digital Rights and Principles for the Digital Decade,* COM (2022) 28 final (Jan. 1, 2022) "Everyone should have access to all key public services online across the Union. Nobody is to be asked to provide data more often than necessary when accessing and using digital public services".

On the other hand, blockchain also implies the immutability of information and storage in blocks. This immutability implies a clear obstacle to the exercise of the rights of rectification of the information stored in the blocks, as well as for the action of cancellation, and even for the portability of personal data. These legal actions are a fundamental pillar of the GDPR: the guarantee of the exercise of data subjects' rights.

> *Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation)*
> (39) "The personal data should be adequate, relevant and limited to what is necessary for the purposes for which they are processed. This requires, in particular, ensuring that the period for which the personal data are stored is limited to a strict minimum. Personal data should be processed only if the purpose of the processing could not reasonably be fulfilled by other means. In order to ensure that the personal data are not kept longer than necessary, time limits should be established by the controller for erasure or for a periodic review. Every reasonable step should be taken to ensure that personal data which are inaccurate are rectified or deleted".
> (59) Modalities should be provided for facilitating the exercise of the data subject's rights under this Regulation, including mechanisms to request and, if applicable, obtain, free of charge, in particular, access to and rectification or erasure of personal data and the exercise of the right to object.

Ensuring the right to information, access and data retention does not pose particular difficulties in the context of Blockchain technology, as data controllers can inform and/or respond to data subjects' requests for access to their personal data or requests for data retention.
However, the French Data Protection Authority (CNIL) in its report Blockchain and the GDPR: Solutions for a responsible use of the blockchain in the context of personal data (2018) recognized the technical impossibility for data controllers to be able to respond to requests from data subjects requesting the erasure of their personal data entered on the blockchain ('The immutability of actions carried out on blockchains have, in particular, allowed for the development of solutions that

meet the requirement for traceability of consent and operations carried out on data' https://www.cnil.fr/en/blockchain-and-gdpr-solutions-responsible-use-blockchain-context-personal-data).

"The CNIL observes that it is technically impossible to grant the request for erasure made by a data subject when data is registered on a Blockchain. However, when the data recorded on the Blockchain is a commitment, a hash generated by a keyed-hash function or a ciphertext obtained through "state of the art" algorithms and keys, the data controller can make the data practically inaccessible, and therefore move closer to the effects of data erasure."

"It is technically impossible to grant the request for rectification or for erasure made by a data subject when cleartext or hashed data is recorded on a Blockchain. It is therefore strongly recommended not to register personal data in cleartext on a Blockchain, and to use one of the cryptographic solutions mentioned above".

As regards the right of rectification, the impossibility to modify the data in a block must cause the data controller to enter the updated data in a new block. It requires, similarly to other rights, a careful consideration in advance regarding the right to restriction (introduced by Article 18 of the GDPR) and to human intervention in the context of entirely automated decision-making (Article 22 Paragraph 3 GRDP).

> It appears that an exclusively automated decision arising from a smart contract is necessary for its performance, given that it enables the fulfilment of the very essence of the contract (i.e., the reason for which the parties concluded the contract). With respect to the suitable measures to safeguard the data subject's rights and freedoms and legitimate interests, the data subject should be able to obtain human intervention, to express his or her point of view and to contest the decision after the smart contract has been performed. The data controller should therefore provide the possibility of human intervention allowing the data subject to contest the decision even if the contract has already been performed, and regardless of what is registered on the Blockchain.

In other words, it is precisely the immutability and integrity of the Blockchain itself that prevents data from being rectified or deleted once it has been entered into the Blockchain system. And this in itself represents a serious drawback that could affect the most essential rights of the individual: the right to be forgotten (art. 17 GDPR).

> It is worth remembering that the aforementioned right to be forgotten was actually born two years before the GDPR. We refer to the CJEU of 13 May 2014, Google Spain, S.L. case, Google Inc. versus Agencia Española de Protección de Datos (AEPD) and Mario Costeja González (Case C-131/12)[9] ,

[9] On 5 March 2010, Mr. Costeja González, a Spanish national resident in Spain, lodged a complaint with the AEPD against La Vanguardia Ediciones, S.L., which publishes a widely distributed newspaper, specifically in Catalonia ('La Vanguardia'), and against Google Spain and Google Inc. This complaint was based on the fact that, when an internet user entered the name of Mr. Costeja González in the Google search engine ('Google Search'), he obtained as a result links to two pages of the newspaper La Vanguardia, dated 19 January 1998 and 9 March 1998 respectively, which contained an

by declaring that, in application of Directive 95/46/EU of the European Parliament and of the Council of 24 October 1995, on the protection of individuals with regard to the processing of personal data and on the free movement of such data (OJ 1995 L 281, 23/11/1995), any person may request the operator of the search engine to delete his personal data where they are 'inaccurate, inadequate or irrelevant or have become irrelevant'[10].

In other words, to date, the chaos known to the CJEU (2014 and 2019) in relation to the right to be forgotten has been in relation to results relating to personal data displayed by search engines, where the responsibility of a search engine operator is to remove links to personal information from search results in specific circumstances, effectively introducing the right to be forgotten. There was not and could not be any reference to Blockchain, nor is there any reference to Blockchain in the GDPR.

In short, the current legal regulation of the right to be forgotten in the GDPR is largely coincidental to the judgment of 13 May 2014 of the CJEU, which boosted the consideration of the right to be forgotten as a fully-fledged European Union right.

This may be important when considering the possible limits of the right to be forgotten, since, let us remember that 'it is not an absolute right', as provided for in Article 17.3 GDPR.

We could legitimately ask ourselves whether the fact that a user adopts Blockchain technology entails a waiver of the right to be forgotten? Or also, whether a change of technological parameters should entail a change of regulation. The question is even more controversial and complex if we consider that the expression Blockchain is a generic term to designate a technological tool, but the reality is that there is a large typology of Blockchain networks, each with its own configuration, requirements and guarantees[11]. Finally, we believe that it is a relevant interpretative element that during the processing of the GDPR, Blockchain had hardly any presence in the market, as shown in the attached graphs.

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advertisement for a property auction in connection with a distraint for social security debts, mentioning the name of Mr Costeja González.

By this complaint, he requested, firstly, that La Vanguardia be required to remove or amend the publication so that his personal data would not appear, or to use the tools provided by search engines to protect those data. On the other hand, he requested that Google Spain or Google Inc. be required to remove or hide his personal data so that they would no longer appear in their search results and would no longer be linked to La Vanguardia's links. In this context, the plaintiff claimed that the embargo to which he had been subjected at the time had been fully settled and resolved years ago and was no longer relevant.

[10] The CJEU's 2019 judgment (Google LLC v Commission nationale de l'informatique et des libertés (CNIL) clarified the geographical scope of its previous ruling, in the new context of Regulation (EU) 2016/679 (the General Data Protection Regulation), which modernised and unified data protection regulation across the European Union (EU) and repealed Directive 95/46/EC. (Case 507/17). This judgment was handed down while the GDPR was in force. The CJEU 2019 recalls, citing the GDPR, that 'The right to the protection of personal data is not an absolute right but must be considered in relation to its function in society and be balanced with other fundamental rights, in accordance with the principle of proportionality

[11] The public blockchain network is a unique identifier that allows you to access the wallet, but does not reveal your identity (anonymisation). However, despite this anonymisation, data can be aggregated and cross-referenced with other sources of information to identify an individual. Private blockchains are known only to the people invited to participate in them, so the nodes are known, although transactions can be anonymous (pseudonymisation, art 4.5 GDPR).

The CNIL suggested some technical solutions such as storing data in the Blockchain in encrypted form and storing outside the blockchain (in a private environment) all additional information not necessary to validate the transaction. Even so, the proposed solution is neither effective, nor a guarantee, nor consistent with Blockchain technology.

Similarly, in relation to the right to rectification of personal data, the same CNIL recommends that the controller enter the updated data in a new block, as a subsequent operation may cancel the first operation, even if the first one still appears in the chain. This solution extends to the right of erasure and the erasure of inaccurate data. The question then is how this solution can affect the automatism of the blockchain and smart contracts.

In line with the above, the recent resolution of the AEPD (March 2024) is of interest, ordering as a precautionary measure that Worldcoin (cryptocurrency) may continue to process personal data in Spain in application of Article 66.1 of the GDPR. The AEPD demands the cessation of the collection and processing of special categories of personal data and the blocking of data already collected, having received several complaints denouncing insufficient information, the collection of data from minors or that the withdrawal of consent is not allowed.

One of the possible solutions for the protection of personal data in Blockchain could be the use of unique hashes for personal data, whereby the hash would be stored in the Blockchain network itself while the personal data would be stored in an external file managed by the relevant data controller. When personal data are to be deleted, in accordance with the principles of lawfulness of processing, limitation of the retention period, right to be forgotten or erasure, the data controller will delete the data from the external database, while the corresponding hash will remain in the Blockchain network.
By deleting the data corresponding to the hash, the hash becomes a random number with no direct association with personal data, so that the information stored in the Blockchain becomes irrelevant.
It can be logically concluded that the Blockchain environment in the Smart City entails great benefits, but at the same time great risks.
We may be heading towards a new legal framework for personal data and blockchain. It would sound good.

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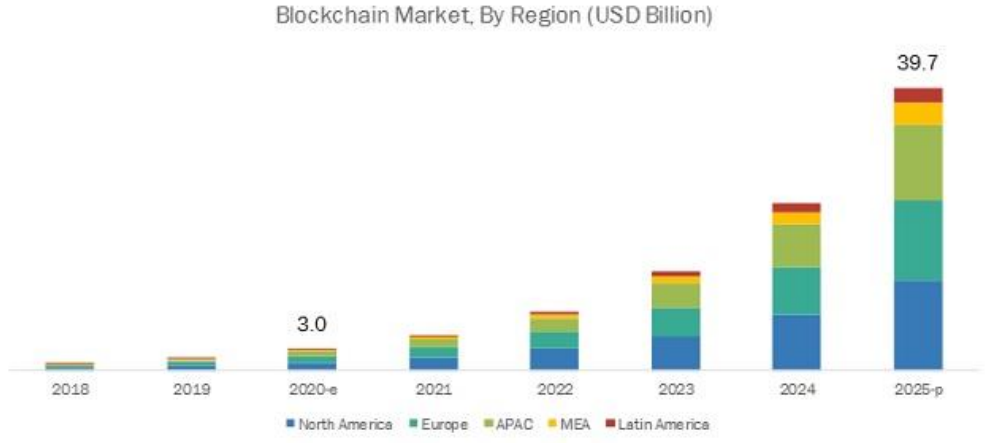
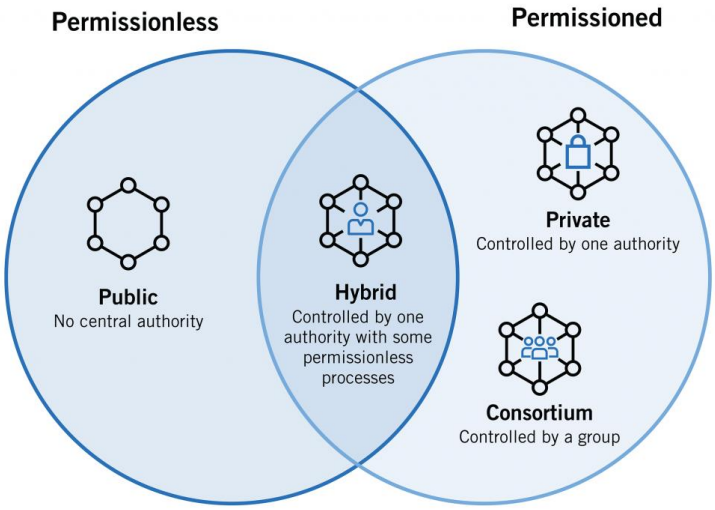
Appendix



e: estimated; p: projected

Source: Secondary Literature, Expert Interviews, and MarketsandMarkets Analysis



6. Conclusions and Policy Indications

Overall, based on the above reviews, despite the potential of Blockchain – as a distributed ledger technology – of conveying secure and trusted information across sites and market participants (and so potentially capable of reducing transaction costs), knowledge on BCT applied to Smart Cities appears altogether surprisingly limited.

Even if academic attention has grown significantly over the last years in parallel to the spread of the same technology, systematic research is actually quite restricted in substantial terms, especially with reference to economic and business applications. Focusing on pure financial BCT-uses in urban environments, investigations are almost absent.

Moreover, what seems to be missing, are investigations regarding BCT applications specifically targeted to the urban context from an aggregate economic perspective. The current literature does not seem to depict a comprehensive framework for the implementation of BCT to Smart Cities. The studies seem:

- to widely adopt a scattered and fragmented approach of smaller, transversal application areas, largely driven by technical analysis;
- missing a measuring capability of the performance gains of Blockchain technology compared to conventional information systems and traditional models.

Based on that evidence, there appears to be great potential for further studies in order to develop (economic and financial) applications specifically intended for Smart Cities that might commonly be used for shared micro- and macro-constructs also in the logic of related policy and governance interventions considering the public externalities of most urban services.

In that perspective, potential research directions both in the business and financial area as well as in the mobility and urban development sector are reported at the end of the present Section. The

future research suggestions have been assessed also on the basis of the "Smart City" cases documented at internationally stage in Annex 2.
The same research agenda could be capable of effectively support, in a coordinated manner, the governance agenda for Smart Cities referred to below.

In terms of **policy indications**, in the opinion of the author of this report, it is possible to distinguish two levels of action represented respectively by (1) the political governance of cities and (2) the governance and management of (public) urban services:

(1) With reference to the political stage of interventions by the metropolitan authorities in charge for the urban government, it is desirable to adopt a comprehensive perspective of the potential Blockchain applications to the aggregate urban services and processes capable of enhancing their types and quality. This could best be achieved *via*:

(i) a preliminary, interdisciplinary study aimed at mapping all processes and identifying, for each urban service and combination of them, provided by both the public and private sectors, potential Blockchain applications. This preliminary analysis could also profit from the below proposed research areas.
Moreover, for superordinate service areas the study stage could be conducted jointly with the governing bodies of various metropolitan areas in a logic of shared cooperation;

(ii) the definition, on the basis of the findings of the same analysis, of an action plan aimed at identifying the lines and related programs of intervention to be implemented in the production and management of the urban services involved;

(iii) the implementation of a territorial steering committee – with the participation of public and private service providers – in order to coordinate the initiatives [resulting from *ii)*], monitor their implementation and undertake any corrective action.

(2) With respect to the governance and management level of urban services, it is of key relevance to ensure – within the regulatory constraints (see in that respect *inter alia* the considerations reported in the Box above "*Legal considerations on data in the Blockchain environment*") – adequate accessibility and sharing of data in the production and delivery processes of the various activities. This in order to ensure potential scope economies and to avoid unnecessary and costly duplication of data with related inefficiencies.

This is especially relevant for those metropolitan service and processes like *e.g.* transportation, urban planning, waste management and, to some extent, healthcare, of strictly local nature that are usually provided by the public hand, either directly or through subsidiaries rather than public tenders.

For all services within the public orbit or with public externalities, it would be appropriate to ensure adequate publicity and sharing of the data. The same attitude of data sharing should best be pursued also by private service providers on a participatory basis in improving the quality of the services delivered capable of effectively achieving Smart Cities.

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Potential future research directions of Blockchain applications to Smart Cities (Economics, Business, Finance & Mobility/Transportation, Urban Planning and Development)[12]

Research Area	Further Research Issues
Integration with Other Emerging Technologies	• Future studies should dwell more on how the synergy of Blockchain integration with other emerging technologies, such as IoT, AI, and big data analytics, can bring more comprehensiveness to smart city functionalities
Scalability and Efficiency	• Improving blockchain systems with scalability and energy use efficiency will remain among the basic points of research. Consensus algorithm and layer-two solutions are among the possible pathways to more sustainable applications of Blockchain
Policy and Governance	• A model for regulation and a governance model should be designed, taking into account the decentralized nature of Blockchain. This will include developing standards of data privacy, security, and interoperability across different blockchain platforms
Case Studies and Real-world Implementations	• There is a need for more case studies and pilot projects that would test theoretical models in the real world to assess practical benefits and feasibility that Blockchain can deliver in an urban setting
Socio-economic Impacts	• Researching the socio-economic impact of Blockchain technology on urban populations, in terms of inclusivity and accessibility as well, will be important to develop policies that allow for equally distribution of benefits
Payment services in smart city transactions	• How can blockchain systems be scaled to handle increasing transactions in smart cities without compromising performance? • What strategies can be developed to enhance interoperability between different blockchain platforms and traditional payment systems in the context of Smart Cities? • What regulations and standards are necessary for Blockchain adoption in Smart City payment services, and how can they be effectively implemented? • What is the most suitable governance model for managing decentralized payment systems in smart cities, and how can it balance decentralization with the need for regulatory vigilance? • What factors influence the adoption of Blockchain-based payment systems in Smart Cities, and how can user experience be improved to encourage widespread acceptance? • How can Blockchain networks be made more energy-efficient to ensure sustainability, especially in smart cities where environmental concerns are crucial?
CBDC and application for the Cities of the Future	• How can Central Bank Digital Currencies (CBDCs) be integrated seamlessly into Smart Cities' existing and future infrastructure, including transportation systems, utility networks, and public services? • What are the challenges in ensuring CBDC interoperability with digital currencies from other regions, and how can they facilitate cross-border transactions within Smart Cities? • What strategies can ensure CBDCs promote financial inclusion and accessibility across diverse socioeconomic groups in Smart Ccities? • How can the efficiency and transparency of public services, such as tax payments, licensing, and social welfare distributions, be enhanced in Smart Cities using CBDCs and smart contracts? • How can CBDC platforms be designed to be resilient to cyber threats and attacks, ensuring the security and continuity of digital currency transactions in Smart Cities?
Blockchain for the smart city real estate market	• How can Blockchain technology be utilized to create secure and immutable records of title and ownership (*i.e.* asset market) and leases (*i.e.* space market) for real estate properties, thereby reducing fraud and enhancing transparency in Smart Cities?

[12] Relevant parts of the table are taken from Biasin, M.; Delle Foglie, A. (2024).

	• How might the implementation of Blockchain technology enable the creation and preservation of immutable records of real estate assets in terms of single property characteristics in terms of historical ESG & technical-data, cash-flows, yields, appraisal values, transaction prices, etc.? • How can Blockchain be used to tokenize real estate assets, allowing for fractional ownership and enabling a broader range of investors to participate in Smart City real estate markets? • How can Blockchain protect sensitive information in real estate transactions while ensuring transparency for relevant parties? • How might the implementation of Blockchain technology enable the creation and preservation of immutable records of property development processes, such as planning, construction, and regulatory approvals, within the context of Smart Cities? • How can Blockchain technology improve transparency in the real estate supply chain? It can track the origin and authenticity of construction materials while ensuring compliance with sustainability standards. • How can Blockchain technology play a role in determining a property's value in real time while considering factors such as market demand, neighborhood development, and economic indicators in Smart Cities? • How can smart contracts be employed to automate and enforce rental agreements, ensuring efficient property management and tenant-landlord relationships in smart cities?
Smart contract and urban services	• Can smart contracts enable automated parking reservation and payment systems, ensuring transparency and efficiency? • Is it possible for smart contracts to streamline the waste collection and disposal processes, leading to cost savings in labor and enhancing overall efficiency and supporting sustainability? • Optimizing waste collection routes and minimizing waste overflow can be achieved by integrating smart contracts with smart waste bins and sensors. How can this integration be achieved? • Is there a way to utilize smart contracts for managing prescriptions and delivering medication in an automated manner that can help reduce errors and improve patient adherence? • How can smart contracts optimize energy distribution and reduce reliance on traditional grids for decentralized renewable energy source management? • In what ways can smart contracts be utilized to enhance energy efficiency in buildings and households, thereby leading to decreased energy expenses and encouraging sustainability?
Blockchain and data storage, security, and privacy	• As Smart Cities generate more and more data, it becomes increasingly important to have storage solutions that can handle the volume and complexity of this data. To achieve this, research is needed to develop decentralized data storage systems that use Blockchain technology. These systems must ensure data integrity, security, and immutability while efficiently handling large datasets. • Smart cities produce vast amounts of data that can be used for various purposes. However, conducting research and developing reliable and secure data marketplaces that allow data sharing and monetization while ensuring data privacy, ownership rights, and fair compensation for data providers is essential. • Increasing vulnerability of Smart City infrastructure to cyberattacks and data breaches calls for research on Blockchain technology-based cybersecurity solutions that improve data security, network resilience, and incident response capabilities in Smart Cities.
Smart city governance and integration with other systems	• Blockchain technology can be utilized to develop secure and transparent e-voting systems that protect voters' privacy and prevent electoral fraud. Researching to create robust e-voting protocols that incorporate Blockchain technology to ensure fair and verifiable elections in smart cities is essential. • Blockchain technology can automate governance procedures by utilizing smart contracts and self-executing agreements that enforce rules and regulations without intermediaries. There is a need for further research to investigate the potential applications of smart contracts for enhancing service delivery, managing resources more efficiently, and effective contract management in Smart City governance.

- Blockchain technology can potentially improve supply chain transparency and traceability by creating a tamper-proof record of product movement and origin. Further research is necessary to investigate how blockchain can enhance food safety, prevent the circulation of counterfeit goods, and ensure ethical sourcing in supply chains for Smart Cities.
- For Blockchain to be fully utilized in Smart City governance, it must integrate seamlessly with existing systems and technologies. This requires research to develop standards and protocols that enable the integration of Blockchain solutions with legacy systems, e-government platforms, and other smart city infrastructure.

Annexes:

Annex 1: References of Blockchain studies related to Smart Cities (including bibliometric *focus* on mobility/transport and urban planning & development)

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Annex 2: Examples of Smart Cities Projects

A collection of 11 case studies on Smart Cities applying Blockchain to mobility/transport and urban development

I. DUBAI

1) General overview

1.1) Dubai as a smart city

a) Smart Dubai Office (2015): the Smart Dubai Office was established with the aim of making Dubai a citizen-centric smart city;
b) Smart Dubai Strategy: was launched in 2021 (to be completed by 2028); it promotes 100 smart initiatives and 1.000 smart services, with the aim to enhance government services and improve their accessibility. More particularly, this strategy provides for digitization and automation in the fields of energy, transport (including driverless vehicles) and public infrastructure (also promoting the construction of buildings using only 3D printers).

1.2) Blockchain within the smart city

UAE Blockchain Strategy was launched by the UAE Government in April 2018 with the purpose of making Dubai the first city in the world to use blockchain technology in all the city's services.
The Blockchain strategy is based on: a) Government Efficiency: empowering all the government services through Blockchain technology; b) Industry Creation: promoting startups and businesses by creating a Blockchain-based industry ecosystem; c) Local and International Thought Leadership: spreading Dubai's Blockchain vision thus making the City the hub for Blockchain intellectual capital and skill development.
Thanks to the Blockchain strategy, the city aims to speed up connectivity and improve productivity across all sectors. Moreover, this technology will save time, effort and resources. In particular, the UAE government expects to save: AED 11 billion in transactions and documents processed routinely; 398 million printed documents annually; 77 million work hours annually.

2) Blockchain in the field of transport

The RTA (Roads and Transport Authority) designed "The Strategic Plan 2024-2030" to support the development of roads and transit systems, with a view to ensure that 80 percent of daily services are accessible within a 20-minute journey by walking or cycling.
In this context, in 2018 RTA launched the "Vehicle history blockchain project" aimed at creating a vehicle lifecycle management system using the blockchain technology. This platform tracks ownership, sale and accident history to create smart and more efficient systems for supply chains.
Thanks to the blockchain-based system, trust and transparency in vehicle transactions will be allowed, lowering cost of services and avoiding disputes.

3) Blockchain for urban development

- In 2023, Dubai Customs has launched its own blockchain platform to improve clearance procedures by providing a more comfortable and easy way for shipping operations across Dubai. Benefits: ability to enhance transparency in supply chains. It increases trust and efficiency in trade operations through secure data sharing on a tamper-proof network, which helps reduce the storage of vast amounts of paper. This integration not only promotes transparency in the supply chain but also enhances goods authentication and anti-counterfeiting measures, ensures data security and privacy, and lays the groundwork for reduced fees for goods passing through the free zones.
- In 2021 RTA also announced the start of a project titled "Dubai in Motion" that aims to facilitate effective decision-making on transport and community planning. This project will be based on the latest technology such as big data, artificial intelligence, IoT, and also blockchain.
  The project builds on a set of specialized data (regarding hotels, communities, buses, and taxis) to draft various scenarios dedicated to drawing improvements to public transport, accessibility, and mobility. The project provides decision makers with statistics-based data about the transport sector and people's movement in Dubai. It also provides indices about areas that welcome tourists, calculates mobility time and periods, and analyzes the transport movement. Data will be used for developing digital models of public transport to support urban planning for the main transportation elements in Dubai and improve the transport sector and urban development.

II. SINGAPORE

1) General overview

1.1) Singapore as a smart city

a) The "Smart Nation" Strategy was launched by Singapore Government in 2018, to deliver digital solutions and make Singapore a unique smart city. This Plan aims to improve city and municipal services through technology, enhancing civic engagement, and enabling efficient and effective planning and administration.
b) "The Digital Government Blueprint" was created by the Government of Singapore in 2018, basing on three key pillars (digital economy, digital government and digital society), with the aim of "harness digital technologies to transform how it serves the public."

1.2) Blockchain within the smart city

a) The "Singapore's Blockchain Landscape" was released by IMDA (Infocomm media development Authority) in 2019, in order to build a blockchain ecosystem in Singapore. This Map includes local blockchain companies and initiatives leading the development of blockchain technology in a variety of industries. Among these initiatives, in 2020, there was the launch of Singapore Blockchain Innovation Programme (SBIP), a nationwide technical collaboration supported by the Singapore Government through the National Research Foundation. SBIP conducts research into the next-generation blockchain systems and facilitates the adoption of blockchain for real-world applications.

Nowadays, Blockchain is mostly adopted within the Financial Technology ("FinTech") industry and Web 3.0 Gaming industry. Some key applications of Blockchain or DLT solutions in Singapore include: Cross-Border Payments; Trade Finance; Clearing and Settlement; and proof for Provenance. Generally, cryptocurrencies are increasingly being used and accepted as payments for goods and services offered on online platforms

Smart Nation has the mission to drive transformation in the following sectors: a) Health: Singapore digital transformation by using Blockchain is projecting to deliver healthcare services efficiently; b) Education: the use of Blockchain in the educational sector will enhance the relationships between students, teachers and parents, as well as capabilities of the physical infrastructure are augmented to create a holistic and conducive environment for effective learning; c) Finance: Singapore will continue to be a leading regional and global financial hub, powered by financial institutions that readily adopt fintech solutions for better customer service, greater efficiencies in trade finance, strengthened supervision and reduced compliance cost; d) Transport: roads and transport system will be optimised, making traffic smoother, public transport more comfortable and reliable, and the air cleaner with less need for private cars.

2) Blockchain in the field of transport

Within the Strategic National Projects, the Smart Urban Mobility project has been developed.

- Blockchain-based Used Car Database. Singapore's online car marketplace "sgCarMart", together with "Ocean Protocol" has developed the first "Know-Your-Vehicle data marketplace", which will provide customers comprehensive, secure and traceable information of a used car.
  According to Land Transport Authority 2018 figures, nearly 9,000 cars changed ownerships per month in Singapore. Since Singaporeans generally opt for a used car instead of buying a new one, there is the need to provide customers with adequate reliable data about a used vehicle. The "Ocean Protocol" uses blockchain technology to connect data providers and consumers, allowing data to be shared while guaranteeing traceability, transparency, and trust for all stakeholders involved. It also uses smart contracts and tokens to enable safe and secure sharing of data, guaranteeing control and auditability while protecting privacy. Buyers can confirm details such as engine and chassis number, safety rating, past accident records, number of owners the car had, etc. before purchasing a used car.
  Ocean Protocol will provide an ecosystem for data and related services. The platform can be used to share and monetize data using tokens.
- Smart port challenge system was launched by Singapore maritime and port authority in 2017 to improve the efficiency of maritime logistics of delivery goods. The Singapore Shipping Association is working with the International Chamber of Commerce (ICC) and Singapore tech startup Perlin to build the International E-Registry of Ships (IERS) system, which they hope will improve the currently laborious ship registration and renewal process.
  A Blockchain-based ship registration preparation system for international adoption is being developed, with the purpose of reducing time, costs and the incidence of error and fraud in the ship-registration process.

3) Blockchain for urban development

Singapore is implementing the use of blockchain across the urban services.

OpenCerts was created in 2018 thanks to the collaboration between the National Future Skills Program, State Technology Agency, and the Ngie An Polytechnic Institute, Ministry of Education.

This is an open-source platform based on blockchain technology for issuing non-forgery digital academic certificates.
Citizens will receive digital certificates which will each have a unique cryptographic proof embedded within for secure verification. They will no longer need to obtain certified true copies of their education and training certificates for job and academic admission applications. Individuals can instead provide potential employers with digital certificates issued by these institutions. These digital certificates can be easily verified by employers directly through the OpenCerts platform (opencerts.io), which will check the certificate data against its code on the blockchain for validity and to detect any signs of tampering. This automatic verification will simplify and reduce administrative processes and physical paperwork for employers. Moreover, certificate holders can select the parts they want to show or hide. It also allows custom viewing of the document. The issuing entity can customize the form of the certificate and include multiple views for it. To prevent the leakage of any private information, academic records of the certificate and personal data are not published via technology.

III. ANTWERP

1) General overview

1.1) Antwerp as a smart city

City Council in 2017 adopted a vision document addressing the "Smart city policy" where five priorities have been set: governance, smart mobility, smart energy and materials, smart security and smart citizens.
In order to achieve this goal, in 2018 the city of Antwerp entered into an agreement with IMEC aiming to install an ecosystem for digital and innovative entrepreneurship in which several sectors, such as city departments, private businesses and organisations could experience smart technologies in real-life urban contexts. The key partners of the smart city policy were city departments ("Strategy and Coordination" and "Innovation and Business"), IMEC and Digipolis (public body that provides IT-support for the city's entire administration). These two agreements allowed an integrated strategy for Smart City projects in and with the city of Antwerp.
Antwerp's smart city strategy focuses on three main pillars: a) Industry 4.0: in Antwerp there is the 2nd most important chemical cluster in the world, many industries around the port and industrial IoT, that are fundamental for the smart city vision; b) Smart logistics: the Port of Antwerp is the major focus of the strategy, with the hinterland distribution centres; c) Citizen-focused smart city initiatives: prioritizing all things that improve citizen's lives - such as tackling air quality and mobility, and in order to that the city is working on a model shift in transportation modes through investing in Intelligent Transport Systems and encouraging, for example, more railway usage.

2) Blockchain in the field of transport

The port of Antwerp is the second largest port in Europe, and the 5th largest worldwide. It has a key role in the city's economy and it has also the status of global diamond trade hub.
In the Summer of 2017, the port of Antwerp announced a pilot project for a more efficient and secure container handling leveraging blockchain technology. As an example of how a blockchain smart port project can solves a clear challenge, the project "aims to move beyond its first scope of

secure container release towards other smart port applications, is this case whereby in the seaport of Antwerp a blockchain initiative is part of a broader smart port project in an even broader smart city initiative that consists of five pillars aiming to make the Belgian city of Antwerp a European IoT leader".
The actors of the projects are the city, its port, a blockchain start-up (T-Mining) and the NxtPort data utility platform. Data necessary to release a container in a database were collected and digital rights have been created in the blockchain. The blockchain allows that the right can be transferred between parties and ensures that only the parties involved have access to the recorded and non-modifiable information; it also grants that only the owner of the corresponding right can collect the container on the terminal. Blockchain thus avoids the risk of forgery of the paper-based systems for releasing containers.

3) Blockchain for urban development

In 2018, the City of Antwerp started the "Circular South project" within the New South district of the city in order to develop a circular and sustainable urban environment also by using Blockchain. The aim is to encourage more efficient use of energy, water, waste and materials by the citizens of the New South district of Antwerp through an innovative community-driven approach.
This project is based on the "behavioural nudging": circular behaviours (regarding consumption behaviour of energy, water, waste and materials) will be automatically rewarded by an online token, the Circular token – Circules, through a blockchain-based reward and exchange system. A part of the most engaged Circular South participants will form a local energy community co-owning of an innovative collective energy system. In addition, a Circular South Community Centre – CIRCUIT will be set up to host a number of initiatives related to sharing, repairing and reusing activities.

IV. BUSAN

1) General overview

1.1) National initiatives in the field of "smart cities" and blockchain (South Korea)

a) In 2018, the Act on the Promotion of Smart City Development and Industry (also known as the Smart City Act) creates an open-ended definition of a smart city as consisting of interconnected services and facilities that improve competitiveness and quality of life. This plan gives significant power to individual cities and projects to determine key components and themes, effectively making smart city initiatives a fluid platform for the delivery of diverse connected services. The Ministry of Land, Infrastructure and Transportation (MOLIT) is the government body responsible for coordinating smart city policy along with the Ministry of Science and ICT (MSIT), the Ministry of the Interior and Safety (MOIS), the Ministry of Environment and the Ministry of Trade, Industry and Energy (MOTIE). A key role is also played by the Smart Cities Special Committee within the Presidential Commission on the Fourth Industrial Revolution (PCFIR).
b) In 2020, the Government of South Korea announced plans for a multi-trillion won 'new deal' stimulus package including the 'green new deal' and the 'digital new deal'.
c) In April 2020, the central Bank of Korea launched pilot program on central bank digital currency (CBDC) to explore the issuance of its digital currency by 2021.

d) Since 2018, KISA (Korea Internet Security Agency) has implemented a blockchain pilot project with the Ministry of Science and Technology to create public services and spread the use of blockchain solutions. Also, in 2018 MSIT (Ministry of Science and ICT) announced the Blockchain Technology Development Strategy to provide an enabling environment and over 230 billion KRW investment into blockchain initiatives by 2022. In June 2020, at the 16th general meeting of the Presidential Committee on the Fourth Industrial Revolution (PCFIR)10, the Ministry of Science and ICT (MSIT) announced the updated inter-ministerial Blockchain Technology Diffusion Strategy for

   There are three categories of national smart city projects in Korea: pilot projects, R&D validation projects, and urban regeneration projects. National pilot projects are large-scale projects, effectively serving as real-life laboratories for the development and applicability of a model for smart cities.

1.2) Blockchain within the smart city of Busan

Busan was part of the National Pilot project on Smart cities. Busan was selected as the nation's Blockchain Regulation-free Zone. This project was developed in 2021 by the Ministry of Science and ICT.

This project includes: a) mobile transportation card issuance and unmanned convenience store access service: Mobile transportation card issuance and unmanned convenience store access service reduce plastic card issuance costs, and through blockchain distributed identification (DID), customized transportation discounts can be received for teenagers, families with multiple children, and senior citizens. In addition, by using the unmanned convenience store mobile pass, it is possible to conveniently use the unmanned convenience store with one mobile phone authentication; b) apartment integrated management platform; c) smart cold chain platform dedicated to biopharmaceuticals (vaccine); d) movie investment management tool and P2P streaming service.

2) Blockchain in the field of transport

a) Blockchain-based Mobile Identification Service for urban transport services.
   With 'B Pass' app, Busan citizens can use the mobile identification and electronic wallet service which is a blockchain service based on Metadium's decentralized ID (DID) technology.
   The blockchain-based mobile transportation card is developed by Coinplug and operated in cooperation with Cash Bee Card (LOCA Mobility). This service will ensure users that their personal information is protected with blockchain and the risk of loss or theft is significantly reduced by not having to carry a plastic card. The B PASS-based transportation card will work in subway rides, buses and taxis. Advantages: The platform does not store personal information and enables decentralized identifiers (DIDs) controlled by the user to be used for contactless access to facilities. The app will allow Busan citizens to use various public services such as the Busan Citizen Card, City Hall access pass, or the 'multi-child family love' card, which provides benefits to households with three or more children. Payment integration is also planned for use in the city hall cafeteria and other stores. Starting from 2019, also a comprehensive mobile wallet service through the 'B PASS' app was implemented.
b) In august 2019, there was the launch of "Chainportal", an integrated, block-chain based platform aimed to improve the operation of port logistics, with a particular reference to the services of: Integrated Information Share (IIS), the Transshipment Shuttle System (TSS), and Vehicle Booking System (VBS).

IIS allows the secure sharing of vessel details, berth statuses, truck locations and terminal congestions and potential bottlenecks. In this way, it ensures the reduction of time and costs of transshipment of cargo. Moreover, users can have info about check ins, empty containers, berth allocations.

TSS is the world's first Transshipment Shuttle System. It links terminal and forwarder information in advance, automatically grouping orders and allocating containers so as to minimize inefficiencies and disruption to services.VBS (the first in Korea of this kind) allows for the optimized allocation of available transport for cargo, in advance.

3) Blockchain for urban development

In 2023 the City of Busan has allocated a budget of 100 billion Korean won (equivalent to $75 million) for developing a public Ethereum-Compatible Blockchain Mainnet. This initiative aims at incorporating blockchain into all the municipal services: from government services to logistics, healthcare, and finance. The goal is creating a unified platform at the city level, ultimately transforming Busan into a full-fledged blockchain city.

V. SEJONG

1) General overview

The Sejong Special Autonomous City was selected in early 2018 from a total of 39 candidate for a pilot project of smart city.

2) Blockchain in the field of transport

Sejong Self-Governing City established a blockchain-based platform for identification of autonomous vehicles in 2020. This project aims to verify the digital identities of self-driving cars and their systems. It addresses the problem of security of connected mobility, which entails information sharing between autonomous vehicles and other smart city infrastructure.

The project includes a consortium of tech companies such as LG CNS, Unmanned Solution, RoaonSecure and Raon WhiteHat. This solution will be integrated with other smart city solutions, such as on-road facilities, tolls, and traffic lights. Additionally, Sejong's smart city platform will support grid-based energy control, AI-based disaster control, and smart farming linked together with a 5G network.

VI. BUCHEON

1) General overview

Smart city initiative was initiated in 2018 by the Ministry of Land, Infrastructure and Transport under the Smart City Challenge project. It encompasses the use of blockchain also for urban planning, particularly for addressing the parking problems in the area.

2) Blockchain in the field of transport

The “Shared Parking and Mobility Platform” was implemented with the support of the Ministry of Land, Infrastructure and Transport since the second half of 2021.
The project secured 280 shared parking spaces, increasing the supply and demand ratio to 109% from the previous 37%. Additionally, illegal parking saw a decline of 41%. The service is available through a mobile application called CityPass and is implemented by blockchain technology.
These parking spaces were secured from local residents reserved parking spots and companies, including Technopark. The town also set up a company to operate this shared parking service, called ‘Sangsalmi People’.

VII. BARCELONA

1) General overview

In September 2016, the “Barcelona Digital City” Plan was launched, with the aim of realizing a digital transformation process within the public services, following new guidelines based on citizen guidance, and the use of open standards and open software, in accordance with an ethical data strategy that focuses on privacy, transparency and digital rights.
In 2019, the Government of Catalonia has developed the Blockchain Strategy of Catalonia, in which several cases of use have been prioritised, including “Mobility and public transport” relating to Mobility as a Service (MaaS).

2) Blockchain in the field of transport

In 2021 Portic Barcelona, the port community system of the Barcelona Port Community, has integrated its data into TradeLens, the blockchain-enabled digital logistics platform jointly developed by A.P. Moller-Maersk (Maersk) and IBM. The aim is to exchange information in real time and improve transparency on the global logistics chain. This exchange of information improves digitalization, transparency and security in operations, making it possible to make more accurate forecasts and thus offer a better service to customers.

3) Blockchain for urban development

Decidim [https://decidim.org] is a digital infrastructure for participatory democracy based on open-source software (Ruby on Rails), which facilitates the creation of citizen participation within the municipal-related questions. This platform gives citizens a voice in deciding their own future regarding the urban development. It is a digital space for the participatory process to debate and gather proposals, but also to monitor and track the participation activities that take place face-to-face throughout the city. Moreover, through this platform that the participation bodies (permanent citizen participation councils) are monitored. These are the regular meetings and channels for dialogue between citizens and the City Council to debate and gather opinions and proposals in order to influence municipal policies.
By 2023 the voting process has been implemented through blockchain, in order to grant transparency and security.

VIII. MOSCOW

1) General overview

The local government's "Smart City" project has set out a number of objectives to help Moscow transform into a digital economy by 2030.

2) Blockchain for urban development

In 2014 the Moscow City Hall launched "Active citizen", a platform allowing citizens to influence city management decisions and its urban transformation. In 2017, Moscow City Hall announced that this platform would be supported by a blockchain, in order to make voting data immutable and freely searchable, as well as for granting each citizen the possibility to verify the integrity of the voting data. The blockchain used within Active Citizen is an adaptation of the Ethereum blockchain.
Through blockchain every vote in Active Citizen will become a smart contract which is publicly viewable and transparent. Once the vote is placed, it will be listed in a ledger consisting of all votes taken place across a peer-to-peer network. It will guarantee that the data will not be lost or altered by someone after the vote was casted so there is no chance for fraud or third-party interference.
Among the Active Citizen polls there were decisions concerning: construction and further expansion of bike lanes, expansion of pedestrian zones, free Wi-Fi available in metro and parks, dance courses and music bands playing in the parks, decision for the name for the new high-tech subway train, as well as logo and name for Zaryadye park. One of the largest polls was held for "My Street" Moscow redevelopment project. Over 0.5 mln. citizens have decided on specific urban and landscape design to be created, trees to be planted, new public transport routes to be launched, the list of the streets to be renovated first and materials to be used.

IX. SHENZHEN

1) General overview

Plan for Smart Shenzhen was released and in 2018 the city started the "New-Type Smart City Construction Comprehensive Plan" for the smart city development. In February 2019, the Central Committee of the Communist Party of China and the State Council named Shenzhen the leading city in building a regionally integrated smart city cluster in the Pearl River Delta region.
The Smart City Plan's goal is the improvement of public service provision and city governance capacity basing on the establishment of a comprehensive data management system.
On November 17, 2020, Shenzhen won the Global Enabling Technologies Award at the Smart City Expo World Congress held by United Nations Human Settlements Programme (UN-Habitat) and the World Economic Forum.

2) Blockchain in the field of transport

a) Shenzhen is the first city in China to build a transportation online system. This initiative aims to build a traffic information sharing platform for the traffic bureau, planning bureau and the competent departments of the public security traffic police bureau, to build an Intelligent Transportation Systems, traffic planning management, decision support system, and intelligent

transportation management system respectively. Moreover, Shenzhen Transport Commission has built a platform (“Traffic information exchange platform”) and five major systems (traffic integrated monitoring system, traffic integrated control system, traffic operation command system, public travel information service system, and traffic management system), and has accumulated some experience in big data collection and integration, application and new technology storage.

Shenzhen successively launched the Shenzhen's comprehensive transportation big data platform: it integrates cross-industry and cross-department transportation big-data resources. It promotes the comprehensive and in-depth application of big data in transportation planning, construction, and operation management by following the requirements of "multiple integrations, real-time simulation, and decision support". It also supports Shenzhen's urban transportation planning and construction decision-making with big data technology services to increase efficiency and improve comprehensive transportation services, and the quality of the refined transportation environment.

b) In 2018, a blockchain e-invoice platform, developed by Tencent and Shenzhen's tax bureau, was launched, making Shenzhen the first Chinese city to apply the technology. This progress in international standardization will speed up the application of blockchain technology in the worldwide tax and transport sector.

   Meanwhile, the “Easy E-invoice” (开票易) feature was recently added to Shenzhen’s platform in order to further optimize paperless application and issuance of invoices on the Internet. Anyone interested can scan the following QR code for detailed instructions. At present, over 25,000 companies nationwide are using the platform. Since its launch, the system has handled over 60 billion yuan (US$9.16 billion) in transactions. More than 47 million blockchain e-invoices have been issued, with the average daily number of invoices exceeding 120,000.

   The service is available at Shenzhen's metro stations as well as some of the city's taxis and airport shuttle buses. The service will replace the standard paper invoices for the Shenzhen Metro, which are estimated to cost about 400,000 yuan each year (about 59,577 U.S. dollars).

   Passengers can submit applications for invoices on the blockchain platform after paying a fee. The platform will automatically generate electronic invoices after the transaction is completed, according to Shenzhen's tax bureau.

c) In 2021 the Blockchain cargo release platform was launched. The platform was jointly developed by the city’s transport bureau, Yantian International Container Terminals (YICT), COSCO Shipping Lines Co. Ltd., and the Global Shipping Business Network, to boost the innovation and development of blockchain technology.

   The “all-weather+one-stop” service allows customers to complete the operation process on the blockchain through the shipping firm and the port side at the same time, resulting in “paperless” import delivery and “zero delay” operations. The platform will enhance operation efficiency and efficiently reduce personnel contact.

3) Blockchain for urban development

According to the Smart City Future Development White Paper, released by Huawei and Accenture (the White Paper), the development of Smart Cities must be gradual.

The smart city development follows three phases:

- Smart City 1.0: simple scenarios and foundation consolidation;
- Smart City 2.0: data is converged and the platform is built;
- Smart City 3.0, which features co-construction and sharing, as well as self-evolution.

According to the White Paper, once the last phase is completed, the smart city will have reached a level of intelligence where it can evolve by itself.
Shenzhen is in the second phase of intelligence, as the experts said; the city is making progress in many ways: resource governance, public services, and industry development. It is also implementing projects, that involve the use of smart technology in several fields such as transport; education; healthcare; maritime sectors and for the community as a whole.
A public participation platform has been created for urban governance, based on blockchain technology, with the principal aim to gain the transparency of policy making and public participation through smart technologies. Starting from the potential of blockchain technology applied to the urban governance, the platform elaborates design concept, technical architecture, smart contract design, and the selection and optimization of the consensus mechanism of the platform, through a comprehensive analysis of policy, technical challenges and regulatory adaptability.
Smart contracts play a functional role in enabling policy voting and feedback collections, also strategies for protecting user data privacy and security are discussed in order to improve, on one hand, the transparency and efficiency of urban governance, and on the other, to provide smart solutions to make the urban governance model more open and democratic by promoting the active public participation.
Public chains, such as Bitcoin and Ether, are used for financial applications and in urban governance they can be used to build trustworthy public service record systems, as public resource allocation and social assistance, in order to enhance public trust.
Private chains, instead, are superior to public chains in terms of efficiency and processing speed, so they are suitable for different scenarios: data protection, security, internal file sharing and personal data management.

X. HYDERABAD

1) General overview (INDIA)

The National Smart Cities Mission was launched in 2015 by Prime Minister Narendra Modi. The Union Ministry of Urban Development are responsible for the implementation of the mission.
A total of 100 cities were selected for developing a smart city architecture.
The aim of the mission is to enhance citizen's quality of life and advance the urban areas, solving the issues created in India by urbanization (such as pollution, inadequate infrastructure, poor public services).
The Smart City Mission plans to address these challenges by: urban planning, improving resource management, improving public services. This mission is a calculated reaction to develop resilient, sustainable urban environments that can also harness digital innovations to enhance public administration and enhance the welfare of citizens. The cities are selected through a fixed process and sectorial and financial convergence must be kept in mind. Ensuring efficiency and accessibility for all inhabitants by modernizing and upgrading essential services including waste management, sanitation, and water delivery, building public areas, leisure spaces, and infrastructure that meets the many requirements of the populace in order to promote social and cultural inclusion.
The National Strategy on Blockchain was launched in 2021, with the goal of facilitating trusted service delivery to citizens and businesses and also make India a global leader in terms of research and development and harnessing the benefits of this technology.

1.1) Hyderabad as a smart city:

a) It is the leading smart city in India. Hyderabad Smart Cities Mission started in 2015 . Key initiatives under this mission include the development of smart transportation systems, enhanced public utilities, sustainable urban planning, and the integration of digital solutions to streamline governance and public services.
b) The Government of Telangana has conceptualized India's first Blockchain District which will be a physical area within Hyderabad and will aim to create the world's best blockchain technology ecosystem. The Blockchain District will house all major blockchain technology companies, will have a huge incubator and a world-class facility for promoting research, innovation and industry collaboration. This one of its kind initiatives will aim to put all blockchain companies based out of Hyderabad at a strategically advantageous position globally.
   Existing Blockchain initiatives include: E-Voting system; Gunny Bag Tracking; Seed Traceability; Transport Management.

2) Blockchain in the field of transport

The Transport Department of the Telangana government has deployed blockchain technology Transportation Management. This blockchain-based system aims to enhance efficiency and transparency in managing transportation services. It is based on an a) Intuitive Dashboard Implementing a user-friendly vehicle lifecycle management data dashboard which allows the department to manage and monitor its transportation services and data effectively; b) Blockchain Integration: A private blockchain network is utilized to ensure secure and decentralized storage of transportation data. This enables the department to have full control over the network while maintaining data integrity and privacy; c) Smart Contract Implementation; d) APIs & SDKs: Application Programming Interfaces (APIs) and Software Development Kits (SDKs) are integrated to enable seamless integration of data from various sources into the blockchain network. This ensures a comprehensive and accurate record of transportation information; e) Blockchain Explorer: The implementation of a blockchain explorer allows authorized personnel to analyze and explore the data stored in the blockchain. This provides valuable insights and facilitates data-driven decision-making within the department.

3) Blockchain for urban development

In addition to the innovations mentioned above, smart contracts, blockchain integration, the APIs and the SDKs, a pilot blockchain platform, called Secured Logistics Document Exchange (SLDE) was developed in 2022 by Hyderabad-based ISV startup Cargo Exchange using Oracle Cloud Infrastructure and Oracle Blockchain Cloud Service. This platform gives the participants in India's import/export/domestic supply chains centralized access to a comprehensive electronic audit trail of trade documents, in order to avoid the loss or manipulation of documents. In fact, currently more than 80% of such documents are exchanged manually in India, manufacturers, banks, shippers, government authorities, and end customers have had little visibility into their flow. As a result, documents can get misplaced or manipulated.

XI. AMSTERDAM

1) General overview

Amsterdam as a smart city: Following a holistic strategy to become smarter launched in 2009, the Dutch capital city has become one of the leading smart cities in Europe and, in 2016, was named the European Capital of Innovation by the European Commission.
The city adopted a bottom-up methodology based on startups, social inclusion and smart growth, that covers all the main fields of action for a municipality: smart economy, smart environment, smart government, smart living, smart mobility and smart people.
There are several projects aimed at kitting out Amsterdam's citizens with the tools they need – both figurative and literal – in order to take on a more active role in the development of smart solutions for their city. Amsterdam Smart Citizens Lab and Smart Kids Lab (part of the European Union's Making Sense project) are two examples which seek to engage people in scientific discussion in order to monitor the environment and contributing to the city's future by equipping its children to become a central resource.

2) Blockchain for urban development

Amsterdam's City Data project is a (mostly) open database that includes topographical and address data, land value and ownership information, healthcare data, traffic data and more, born as a result of an inventory of the local records of more than thirty individual city departments.
The Blockchain technology is a tool that the city of Amsterdam decided to use in several ways: a solution to allow young people to verify their age in the city; a useful solution to give people control over their personal data; a proof for situations where individuals need to prove their age without revealing other personal information (for example to gain access to a club or to buy alcohol).
The Claim Verification 18+ is a prototype application, based on the technologies of DECODE (Decentralised Citizens Owned Data Ecosystem project), that allow people to prove that they are over 18 years old, without revealing name, date of birth or any other information.
The city has developed an app called Stadspas (city pass) to facilitate access to city services as part of the "Open City" program. It is possible to use blockchain with zero-knowledge proof and attributes-based credentials to prove claims with limited exposure of personal data.

Sitography

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