

Exploring the smart city agenda using knowledge networks – The emergence of a new global city landscape

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Abstract

In the era of digital transformation, cities increasingly adopt technology-based smart city (SC) agendas. However, implementation depends heavily on locally available scientific knowledge that is simultaneously embedded in global networks. To explore this paradoxical tension, this study provides a nuanced, global-scale analysis of the nexus between academic SC knowledge production and urban economic status. We used Web of Science (WoS) publication metadata (keywords and affiliations) across two distinct periods: 2010–2017 and 2018–2022. First, we employed network analysis (keyword-based thematic networks) to reveal academic SC knowledge segments. Then, we used affiliation data of publications for mapping SC knowledge hubs by scientific output globally. Finally, we derived SC knowledge ranking from collaboration data, adopting the Globalization and World Cities (GaWC) ranking methodology. We used the GaWC economic-related ranking for capturing economic status, based on the international corporate advanced producer services-related firms' data in 2016 and 2020. Our findings confirm that academic SC knowledge is highly interdisciplinary with a strong technological focus. While an increasing number of cities accumulate SC knowledge production, it becomes concentrated within a small subset of hubs. In addition, emerging economies such as China, India, South Korea, and Brazil as newly prominent regional hubs, are strengthening their position in the global knowledge landscape. Comparing SC knowledge ranking with GaWC ranking, focusing on change in time, our analysis reveals four distinct urban trajectories: *dynamic cities of economic and SC knowledge importance*; *SC knowledge accumulators*; *economic weight gainers*; and *potential laggards*. Although European cities dominate the top 100 in the rankings, a dynamic shift appears: European cities are mostly sliding into the economic weight gainer or potential laggard categories, while Asian (especially Chinese) cities dominate the dynamic category. These trajectories signal an emerging global urban paradigm where local SC knowledge increasingly complements traditional economic dimensions, particularly in less prominent cities.

Keywords: smart city, science mapping, knowledge network, global smart city knowledge space, global city network, city rankings

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Introduction

Cities are the primary engines of the global economy, acting as concentrated hubs of population, finance (BALLAND, P.A. *et al.* 2020), and knowledge. Several factors determine the global status of cities; among these, the economic role of the city is traditionally con-

sidered a significant one that influences urban development.

Knowledge has also been increasingly contributing to city status, along with the rising complexity of urban activities. Not only more people live in cities than in rural areas, but there are more devices connected in real-time than people, including smart-

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phones, public LCDs, or sensors deployed on trams, just to mention a few (TOWNSEND, A.M. 2014; UN 2022; BRIGLAUER, W. *et al.* 2024). Based on the connectedness of devices, cities have been increasingly adopting technology-based Smart City (SC) agendas (HAQUE, A.K.M.B. *et al.* 2022; TOH, C.K. 2022; SORRI, K. *et al.* 2024). This SC transformation is manifested in the growing output of SC-related knowledge and in emerging SC activities.

Furthermore, cities are both independent hubs and parts of a globally interconnected network. This network approach to determining cities' global rank is well captured in the concept of Globalization and World Cities (GaWC) network, based on economic and business-related linkages between cities. These change over time and the global city rankings reflect global influence correlated with economic growth (TAYLOR, P.J. 2001, 2004; TAYLOR, P.J. *et al.* 2002; DERUDDER, B. and TAYLOR, P.J. 2005, 2020; LIU, X. *et al.* 2013; BELDERBOS, R. *et al.* 2022).

Based on these considerations, this research aims to evaluate the thematic structure and spatial-temporal evolution of SC academic knowledge, and the relationship with SC activities, ultimately deploying a network approach to contrast these emerging knowledge-based urban structures against traditional economic configurations. To achieve this, the study first delineates the subfields of SC research (the SC knowledge segments), then maps the geographical footprint of its publication output over time. Finally adapts the GaWC framework to construct SC knowledge-based global city rankings based on scientific collaborations between cities. To grab the changes in time, we compare two time periods, which allows us to examine the changing patterns of SC knowledge segments, how SC knowledge hubs appear globally at the city levels, and, compared with GaWC rankings, what the differences are in time and in city development dimensions.

By contrasting this relational network with traditional economic-focused ones, the study seeks to isolate contemporary trends and possible new paths of global urban development. To guide the empirical investigation, the overarching aim is operationalised through the following specific research objectives and corresponding research questions:

RO1: To explore academic SC knowledge segments and the relation with SC activities.

RO2: To identify global SC knowledge hubs by mapping their geographical distribution based on publication output and city involvement.

RO3: To compare SC knowledge-based city rankings against GaWC economic-based rankings to identify emerging global SC knowledge hubs beyond established benchmarks.

The paper is structured as follows. Firstly, we review the literature, conceptualising SC transformations and arguing how this phenomenon is worth scrutinising more in depth as a global city phenomenon. We introduce the GaWC framework and propose to include academic SC knowledge in understanding global city status. At the end of this section, we highlight the importance of academic local and global knowledge in the case of adopting SC activities. Secondly, we describe our data and methods of mapping SC knowledge segments, visualising SC knowledge hubs and how GaWC ranking approach will adapt for SC knowledge ranking. Thirdly, we present the results, beginning with the thematic segmentation of SC knowledge, followed by its geographical and temporal distribution, and comparing the GaWC-derived global city SC knowledge rankings with the original economically focused GaWC ranking. The last section of the paper concludes with a discussion of findings and limitations. Our work advances the understanding of SCs and informs future research, encouraging extended global, local, social, and technological perspectives.

Literature review

Smart city transformations

The smart city (SC) literature highlights multiple interrelated dimensions, including technology, efficiency, citizenship, social organisation, and sustainability in urban development (TRANOS, E. and GERTNER, D. 2012; COCCIA, A. 2014; ALBINO, V. *et al.* 2015; ZUBIZARRETA, I. *et al.* 2016; EREMIA, M. *et al.* 2017; ANDREANI, S. *et al.* 2019; ZHAO, F. *et al.* 2021; MORTAHEB, R. and JANKOWSKI, P. 2023). In this study, we adopt the smart city as an urban system that supports economic and social activity through intelligent governance, technological and non-technological innovation, and efficient resource management, while reducing environmental impacts and improving quality of life for urban stakeholders (VAN DER HOOGEN, A. *et al.* 2019; KESHAVARZI, G. *et al.* 2021; KUENTZ-SIMONET, V. *et al.* 2023).

Cities are evolving, and many are currently engaged in processes of SC transformation (APPIO, F.P. *et al.* 2019; KUMAR, H. *et al.* 2020; DAI, Y. *et al.* 2024). This dynamism, reflected in the production of SC-related knowledge, provides a useful analytical entry point. To understand how SCs evolve in practice, it is necessary to examine the specific activities that constitute them. Accordingly, the literature has developed a range of frameworks that specify which urban functions are involved and how they are coordinated. A widely used framing is provided by APPIO, F.P. *et al.* (2019), who argue that SCs offer quality of life, business and innovation opportunities, and infrastructure and natural environments for citizens to *live-and-play* as well as dynamic spaces to *work-and-learn*. Building on this, we adopt the framework of KUMAR, H. *et al.* (2020), which maps SC solutions, aiming to structure the full spectrum of services capable of rendering a city smart, into four broad domains derived from large-scale crowdsourcing and expert validation:

information and communication technologies (ICT) infrastructure; environment protection and cleanliness; government planning, policy design and execution; smart services.

Integrating these frameworks allows the identification of the key combinations of activities that underpin SC development. For example, if a city authority deploys digital sensors and restricts combustion engine car circulation based on real-time smog data, this constitutes an SC project. Executing it requires the cross-coordinated management of sensor networks, pollution control, transportation, urban zoning, and citizen participation. Consequently, advancing SC transformations requires mobilising complex and diverse sets of related knowledge.

In *Figure 1* the two axes represent the social vs. physical, and live/play vs. work/learn components of the SC framework, as described by APPIO, F.P. *et al.* (2019), and the digital dimension – as offered by MORTAHEB, R. and JANKOWSKI, P. (2023) – is added. The three grey fields frame the aggregated combinations of these components, as in APPIO, F.P. *et al.* (2019). The coloured fields represent the major SC activities, originally described as SC solutions in KUMAR, H. *et al.* (2020), which are mapped onto the space defined by the axis components. Taken together, the figure offers a bird's-eye view of the main activities and activity fields of the SC.

Figure 1 provides an overview of SC activities. The axes distinguish social versus physical dimensions (vertical) and live/play versus work/learn functions (horizontal), following APPIO, F.P. *et al.* (2019). A digital dimension is added based on MORTAHEB, R. and JANKOWSKI, P. (2023). The resulting space defines combinations of urban functions, within which the major SC activity fields from KUMAR, H. *et al.* (2020) are positioned. The figure, thus, provides a bird's-eye view of the main activity domains and their inter-relations in smart city systems.

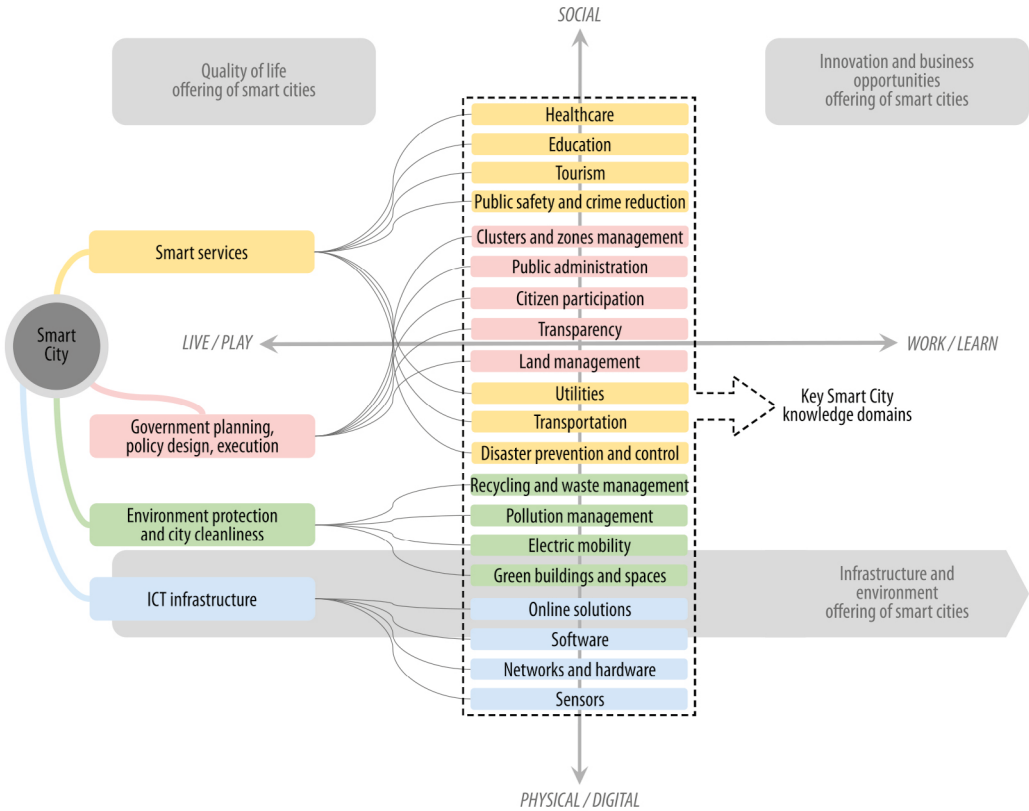


Fig. 1. Overview of SC activities. For detailed explanation see the text. Source: Combined from and simplified based on APPIO, F.P. *et al.* (2019), KUMAR, H. *et al.* (2020), and MORTAHEB, R. and JANKOWSKI, P. (2023).

As we can see, the SC agenda requires not only interconnected technologies, but also engaged citizens through public initiatives KESHAVARZI, G. *et al.* 2021; McLEAN, D. *et al.* 2021), a focus we term *the socio-technological duality*.

Given the interdisciplinary nature of SC development, it is necessary to understand how related knowledge domains are structured and evolve. Therefore, this study connects SC activities with the structure of academic knowledge as represented in WoS publications (ROI), enabling an analysis of how thematic research patterns align with urban transformation processes.

The global city landscape and the GaWC framework

While SC activities are implemented and appear locally, cities are not isolated islands, dynamics reinforce each other globally as well. Globalization has transformed the urban hierarchy, leading to the connection of not only countries but also cities (SASSEN, S. 1991; DERUDDER, B. *et al.* 2003; TAYLOR, P.J. 2004; DERUDDER, B. and TAYLOR, P.J. 2005; DERUDDER, B. and WITLOX, F. 2010; KRÄTKE, S. 2014; VAN DE VIJVER, E. *et al.* 2014; PERIS, A. *et al.* 2018; ACUTO, M. and LEFFEL, B. 2020; ACUTO, M. and LEFFEL, B. 2020. LEFFEL, B. *et*

al. 2023). The foundational work of SASSEN, S. (1991) introduced the concept of the “global city”, identifying strategic hubs like New York, London, and Tokyo as the primary command centres of the global economy. Within this framework, global cities serve as crucial geographic hubs that concentrate the advanced producer services necessary to manage and control geographically dispersed economic activities. Building on this concept, the Globalization and World Cities (GaWC) rankings are determined using an Interlocking Network Model (INM) that conceptualises the world city network through the locational strategies of advanced producer service firms (TAYLOR, P.J. 2001). Rather than assessing cities based on their internal economic attributes, this relational approach evaluates cities as nodes that are interconnected by the global office networks of transnational firms (as sub-nodes) in sectors like accountancy, advertising, banking, and law (TAYLOR, P.J. *et al.* 2002). This model assumes that the presence of offices of firms in two cities creates links, and a flow of information, capital, and labour (TAYLOR, P.J. 2011).

Through this relational lens, the GaWC framework maps a “world city network” characterized by hierarchical tendencies and complex regional patterns (TAYLOR, P.J. *et al.* 2002; DERUDDER, B. *et al.* 2003). This methodology has proven to be highly effective in yielding notable global city rankings that change over time, capturing the shifting geographies of corporate influence, economic growth, and global commodity chains (DERUDDER, B. *et al.* 2012; LIU, X. *et al.* 2013; DERUDDER, B. and TAYLOR, P.J. 2020; BELDERBOS, R. *et al.* 2022).

The role of academia and the knowledge-based global network

Since SC activities rely on diverse expertise, understanding how SC knowledge is structured is essential. SC knowledge em-

braces specific academic knowledge fields, where expertise, information, and understanding are organised, developed, and shared (ISRAILIDIS, J. *et al.* 2021).

Nevertheless, universities have already started acting as catalysts for locally applicable knowledge. First, academia serves as a bridge for managing knowledge within the city. For instance, universities can assist a city’s public health department by analysing data and research from local hospitals to enhance healthcare services. Second, researchers help filter external knowledge entering the city. Third, universities and research centres generate locally relevant new knowledge. Fourth, researchers evaluate external knowledge to ensure its effective application in the city. They might assess and pilot-test new educational technologies before integrating them into local schools (findings by ARDITO, L. *et al.* [2019] with own explanation and examples).

Crucially, this locally available academic knowledge is embedded in the global scientific knowledge networks. GHANBARI, H. *et al.* (2024) emphasise the important role of academic SC centres in connecting SC theories and actions. Furthermore, the growing adoption of technology, and local, knowledge-driven SC agendas in many urban areas indicates a shift in the global city landscape (WALL, R.S. and STAVROPOULOS, S. 2016; HAQUE, A.K.M.B. *et al.* 2022; TOH, C.K. 2022; BRIGLAUER, W. *et al.* 2024; SORRI, K. *et al.* 2024).

MATTHIESSEN, C.W. *et al.* (2010) inspired by the GaWC network approach, studied academic knowledge collaborations on the city level. Other studies on scientific co-authorship and academic networking also demonstrate that cities like Tokyo, New York, Paris, London, and Beijing operate as major knowledge hubs, reflecting hierarchies remarkably like the economic rankings observed in GaWC studies (MAISONOBE, M. *et al.* 2016a; CAO, Z. *et al.* 2023). Mapping this publication output and city-level involvement offers a robust foundation for iden-

tifying which urban nodes are developing into key administrative centres for smart city discourse globally (RO2).

The global connectivity of local knowledge is essential, as rapid technological advancements could otherwise render SC initiatives obsolete (ARPIO, F.P. *et al.* 2019). Therefore, we argue that the academic knowledge crucial to the emergence and development of SCs is globally connected in ways that the existing literature has not yet fully quantified. By adapting the GaWC framework to researcher collaborations and publication outputs, it becomes possible to map the geographical footprint of SC knowledge. Evaluating this novel, knowledge-based global city network directly against traditional, economic-focused GaWC rankings provides an opportunity to isolate contemporary trends, identify emerging knowledge hubs (RO3).

Data and research methodology

For revealing the SC academic knowledge segments, we use publications' metadata from the WoS database, with a document search based on SC definitions and smart urban phenomena (COCCHIA, A. 2014; ALBINO, V. *et al.* 2015; EREMIA, M. *et al.* 2017). Using the search profile in *Table S1* (in Supplement) and more precisely the terms from the literature in *Table S2* (in Supplement), metadata from over 28,000 journal articles were downloaded. Articles without a publication year and those published in 2023 were omitted. Only English-language articles and proceedings papers were retained. In *Figure 2* the number of articles by year is presented. We see the novelty of the field and the different trends of output over time. Articles published before the 2010–2022 period were excluded. This initial period, presumably the most diverse in terms of conceptual usage, contains only 802 articles. Based on the publication trends between 2010 and 2022 two periods were considered for longitudinal comparison: 2010–2017, when the number of articles

grew rapidly, and 2018–2022, when research output began to consolidate. This division makes it possible to compare SC knowledge segments, examine differences between the emerging and settled periods, and assess the global emergence of geographical hubs, as well as to observe differences when comparing these two periods with GaWC.

Number of publications from WoS over time, based on *Table S1* research profile. We included the articles between 2010–2022 and split the time span into two periods as there was a big difference in the trend of the number of articles. We distinguished an emerging period between 2010–2017, when the number of articles rose dynamically, and a consolidated period between 2018–2022, when the number of publications stagnated at a high level.

The authors and WoS-defined keywords in 25,782 articles were pre-processed through a systematic manual keyword standardization and restructuring (KSR) procedure (BORSI, B. *et al.* 2025). The KSR procedure improves the results of revealing SC segments, as instead of raw keywords, cleaned and systematically standardized ones are used during the thematic mapping process. Pre-processed keywords occurring fewer than 20 times were deleted, as they do not contribute significantly at this scale. Metadata from 22,190 articles, associated with 772 pre-processed keywords, were retained.

To explore academic SC knowledge segments (RO1), we used science mapping techniques, namely co-keyword analysis, which is highly effective for identifying conceptual contents in a field (ZUPIC, I. and ČATER, T. 2015). This method is a thematic-detection technique using network analyses as follows. First, a similarity matrix of the articles (nodes) was created, based on shared pre-processed keywords (edges). The cosine similarity of document vectors was applied as the similarity measure (SALTON, G. and MCGILL, M.J. 1983). Second, the similarity matrix was transformed into a proximity network of papers, with communities (clusters) detected using the Louvain method

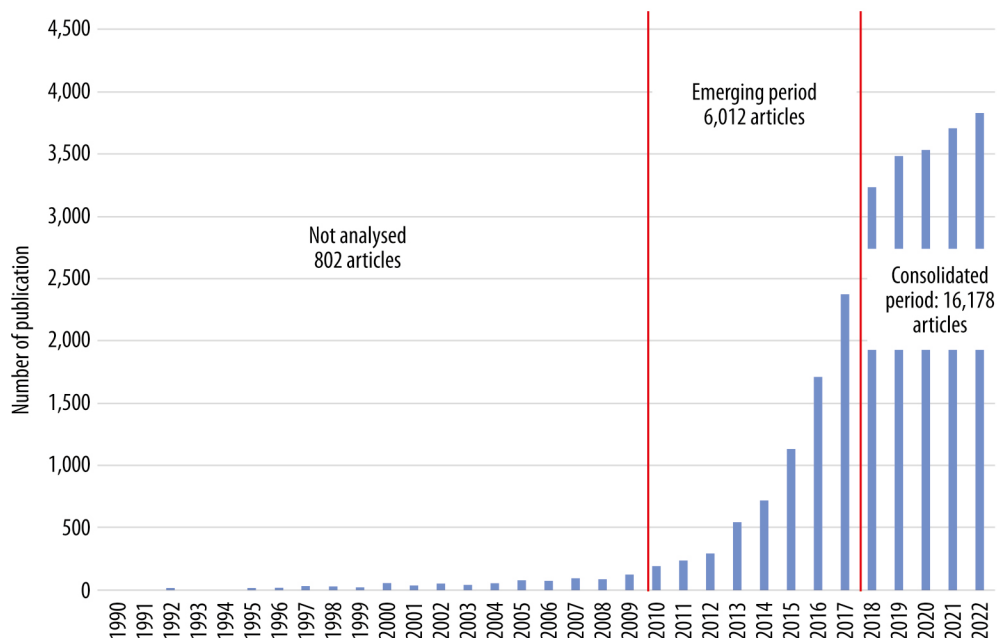


Fig. 2. Number of publications in SC field between 1990–2022. Source: Authors' own elaboration.

(BLONDEL, V.D. *et al.* 2008). The clusters with the Louvain method are non-overlapping, and within a cluster, the density of the co-keywords is high, while between them is low. The resulting two networks for the two periods, with 6,012 and 16,178 articles as nodes, are science maps that contain semantic linkages between the articles (Figure S1 in Supplement).

To identify potential global SC knowledge hubs (RO2), we associated articles with the cities where they were produced, based on authors' affiliations. If an article was a collaboration of multiple authors from the same city, that city was credited with one article. If an article had one author with multiple affiliations, each city was assigned a fraction of the article. The resulting data was projected onto a global map.

Next, for a comparison with GaWC economic-related ranking, we adapted the GaWC methodology for SC knowledge-based city ranking (RO3).

The concrete short methodology of the original Interlocking Network Model (INM) is the following: To quantify these relationships, the model assigns a service value (v) to the office of a specific firm (j) situated in a given city. Service value is a range between 0 and 5, based on the importance of the firm's office, e.g. no presence in a city: 0; headquarters: 5. The elemental connectivity between city a and city b generated by firm j is calculated as the product of their respective service values (TAYLOR, P.J. *et al.* 2002). A city's global connectivity (C_a) is subsequently modelled by aggregating these products across all firms and all other cities within the network:

$$C_a = \sum_{b, b \neq a} \sum_j v_{aj} v_{bj}$$

This measure, the city's proportional connectivity rank, is the proportion of a city's global connectivity score (C_a) shared with

the total connectivity score, which is the global sum of cities' global connectivity scores. The city's proportional connectivity rank value (GaWC rank) reflects its relative degree of integration into the global service economy. We use 2016 and 2020 (latest) ranking data which fit to our research periods.³

The GaWC INM model faces three main criticisms (DERUDDER, B. and PARNREITER, C. 2014). First, although critics argue that the model's undirected network structure ignores corporate hierarchies, this aligns well with our analysis of co-authorship, which is inherently undirected. Second, the model's assumption of a homogeneous space ignores geographical boundaries; however, since global scientific collaboration faces similar spatial constraints (HOEKMAN, J. *et al.* 2010; MAISONOBE, B. *et al.* 2016b; WUESTMAN, M.L. *et al.* 2019; Csomós, G. *et al.* 2020), these shared distortions justify the comparability of the rankings. Third, although critics note the model's narrow focus on advanced producer services, alternative frameworks like the Extended Interlocking Network Model (EINM), which incorporates sectors like media and NGOs, lack uniform global data. This narrower interpretation, however, allows us to make comparisons across the various dimensions that shape urban development. Consequently, the original INM remains the methodologically superior choice for this research.

In the case of a SC knowledge-based global network, sub-nodes are authors, nodes are cities and the networks are based on collaboration links. Our adaptation of the GaWC methodology for SC knowledge ranking for the two periods (2010–2017, 2018–2022) is based on three factors: article quantity, global linkages, and the diversity of aca-

demic SC knowledge (thematic segments) in each city. Specifically, we constructed an adjacency matrix to create a weighted network between cities based on co-authorships across different cities. We got a collaboration network at the city level, where cities are the nodes and the links between them are the co-published papers. The edge weights reflected the strength of collaboration between two cities counted on the number of shared articles. Intra-city collaborations and single-authored works were excluded, as they do not reflect the collaborative nature of global SC knowledge production (HALL, K.L. *et al.* 2018). For example, a link between Manchester and Warsaw would be established if authors from both cities contributed to the same article. We excluded cities that had fewer than two articles in each period or fewer than two connections to other cities, as these do not form the "triadic relationships" that are necessary for establishing lasting and meaningful links. Thus, a total of 673 cities in 2010–2017 and 1,724 cities in 2018–2022 was ranked.

In the SC knowledge-based ranking, the number of collaborated papers in a certain cluster corresponded to the service value in the GaWC ranking. The further counting of ranking follows the same way as in the GaWC ranking.

Finally, we compared the SC city rankings with the GaWC rankings for 2016 and 2020. This comparison allowed us to analyse the longitudinal dynamics of SC knowledge in 241 cities that appear in both the GaWC and the SC knowledge-based rankings. *Figure 3* shows the full research workflow.

In *Figure 3* the fields on the far left (green fields) show the work stages. The next section on the left presents the workflow for extracting SC knowledge themes, the geographical mapping of SC knowledge and the rankings. On the right side, the extraction of the GaWC ranking is shown. Fields with dotted borders represent logical and mathematical operations performed to extract content valuable for the analysis. Orange cells highlight ma-

³ The source of GaWC rank data was <https://www.lboro.ac.uk/microsites/geography/gawc/world2020.html>. (Accessed 11 March 2024.) As the webpage renewed the earlier one is available here: <https://web.archive.org/web/20240608095604/https://www.lboro.ac.uk/microsites/geography/gawc/world2020.html>

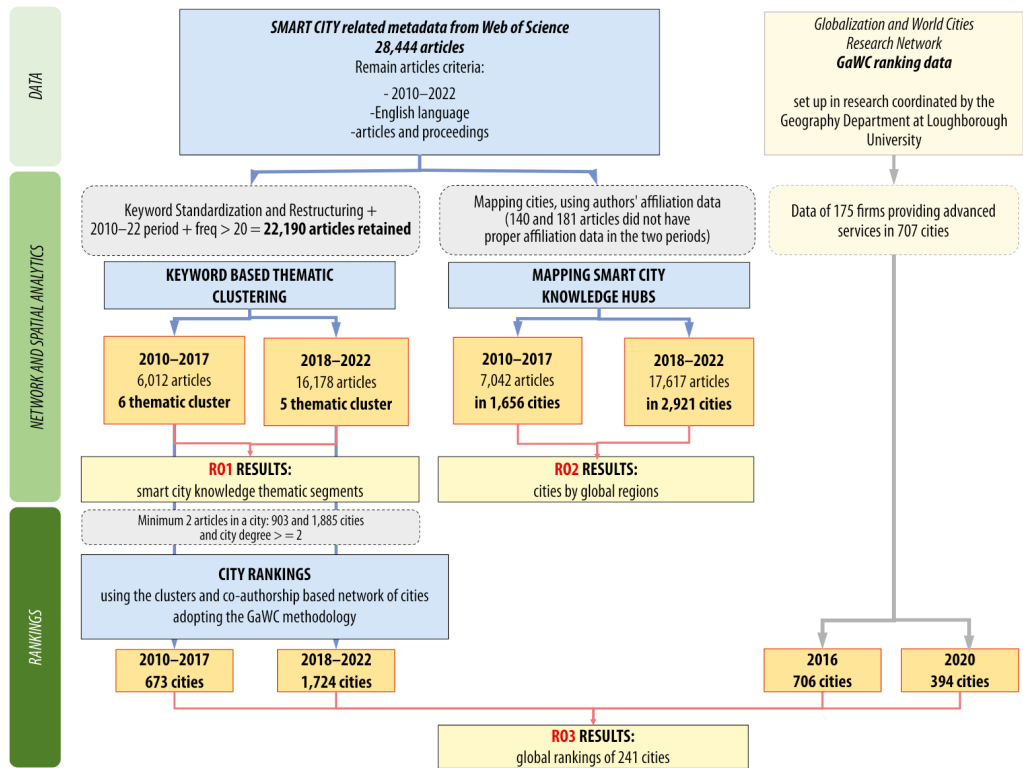


Fig. 3. Research workflow. For detailed explanation see the text. Source: Authors' own elaboration.

for steps directly supporting the research objectives, while yellow cells briefly outline these objectives. A detailed description of the workflow is provided in section “Data and research methodology”.

Results

RO1: The relationship between academic SC knowledge segments and SC activities

The network-based analysis of scientific articles, operationalised through keyword co-occurrence, reveals that SC knowledge segments are dominated by interdisciplinary approaches with a strong technological foundation. The clusters (segments) were named based on the most frequently connected key-

words across the articles (top of the Figure 4, and Figure S1 in Supplement). We studied the content of the clusters by word clouds representing the proportional frequency of keywords across the clusters, available in Figures S2a and S2b (in Supplement). In both periods, the largest cluster of articles – representing approximately one-third of the SC knowledge – focused on sustainable urban development, which encompasses not only technological considerations but also social, governance, and citizenship dimensions. The content of this cluster remained consistent across both periods, suggesting a robust, maturing sub-discipline. This persistence reflects the evolving intersection of sustainability and complex SC concepts, supported by increasingly interconnected technological knowledge bases.

An observable evolution in technological knowledge emerges across the two periods. In the first period, two application areas – transportation and energy systems – became prominent. Due to their shared technological challenges, such as optimization, traffic control, and grid integration, these areas merged into one thematic cluster in the second period. Emerging in the first period were data, sensor networks, and the Internet of Things (IoT), while Machine Learning, a “disruptor” technology relying heavily on Big Data, notably emerged in the second period. Additionally, the general notion of the “digital city” – initially distinct from sustainability – began to merge with sustainable urban development in the second period.

The SC activities (see *Figure 1*) are well-represented by the identified clusters, which visually capture the key themes of SC knowledge. In *Figure 4* we represented the connection between SC activities and the SC academic knowledge. The numbers in the table indicate the number of articles in which a term or word referring to a specific field of study appears among the keywords of SC’s scientific articles. If a term is crossed out, it was not found among the keywords. When only one part of a term is crossed out, the remaining part appeared among the keywords. For each SC activity that appeared notably frequently in a given cluster, we highlighted the number of occurrences (number of articles) in the table using the cluster’s colour. This made it possible to see which SC activities appear in which academic fields of knowledge through scientific publications. Most SC activities are concentrated within the *Sustainable urban development* cluster, with related engineering and technological domains also represented. Technological consolidation and an increasing focus on specific areas are observable between the two periods. This shift is reflected in the network data as a decrease in the number of clusters and an increasing concentration of articles around fewer, more focused topics (JAVED, A.R. *et al.* 2022).

On the left of *Figure 4*, the SC activities (see *Figure 1*) are repeated. At the top, in coloured rectangles, the SC thematic clusters are shown with the number of articles in each cluster. The numbers in the table represent the number of articles whose keywords contain the terms describing the SC activity category. Note: fully and partially strikethrough terms were not found. In case of partially strikethrough, only the remaining parts were found. Numbers highlighted with a coloured background are the highest in their row and/or decisive for the thematic clusters depicted at the top. For an overview of SC activities, see *Figure 1*.

Overall, global scientific SC knowledge predominantly focuses on technology, positioning it at the technological end of the socio-technological duality that shapes the contributions of universities and academia to the SC agenda.

RO2: Mapping global SC knowledge hubs

The number of cities involved in academic SC knowledge production increased rapidly until around 2017. Since then, consolidation has been observed, with approximately 1,600 cities globally contributing annually. While the volume of knowledge production continues to rise in cities in developing regions, cities in more developed regions are showing signs of consolidation (*Figure 5*).

Despite the growing number of cities, SC research is becoming increasingly concentrated in a smaller subset of cities. Occasionally, significant shifts at a more detailed level accompany this concentration. For example, cities such as Casablanca, Bucharest, Budapest, São Paulo, Rio de Janeiro, Montreal, Ottawa, Sydney, and Melbourne – previously less prominent in this domain – have emerged as regionally notable producers (*Figure S3a* and *S3b* in Supplement). Emerging economies are strengthening their positions in the SC knowledge landscape, with cities in China, India, South Korea, and Brazil making notable contributions (*Table S3* in Supplement).

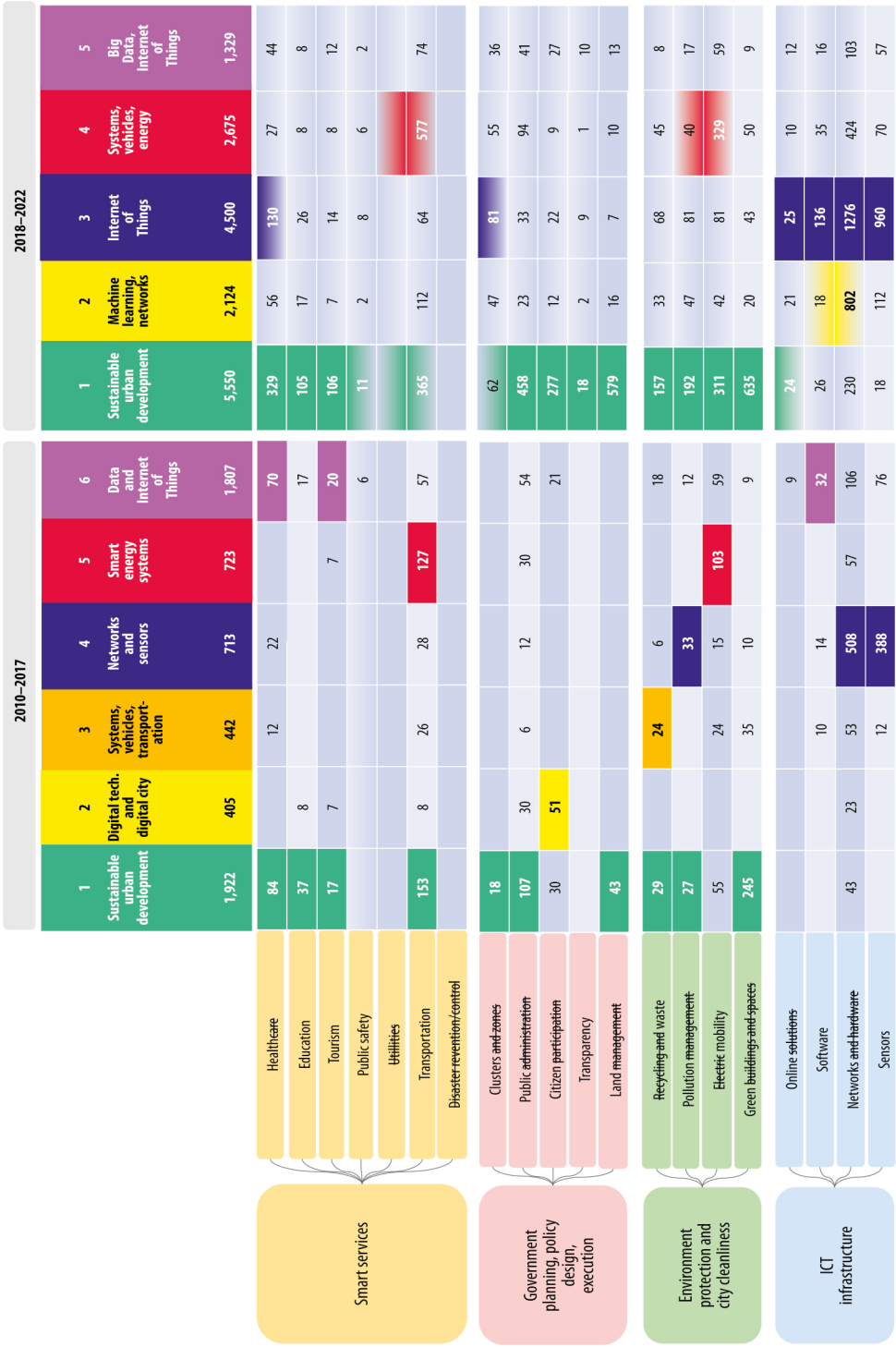


Fig. 4. Number of articles by thematic clusters with their keywords matching the SC activity categories. For detailed explanation see the text. Source: Authors' own elaboration.

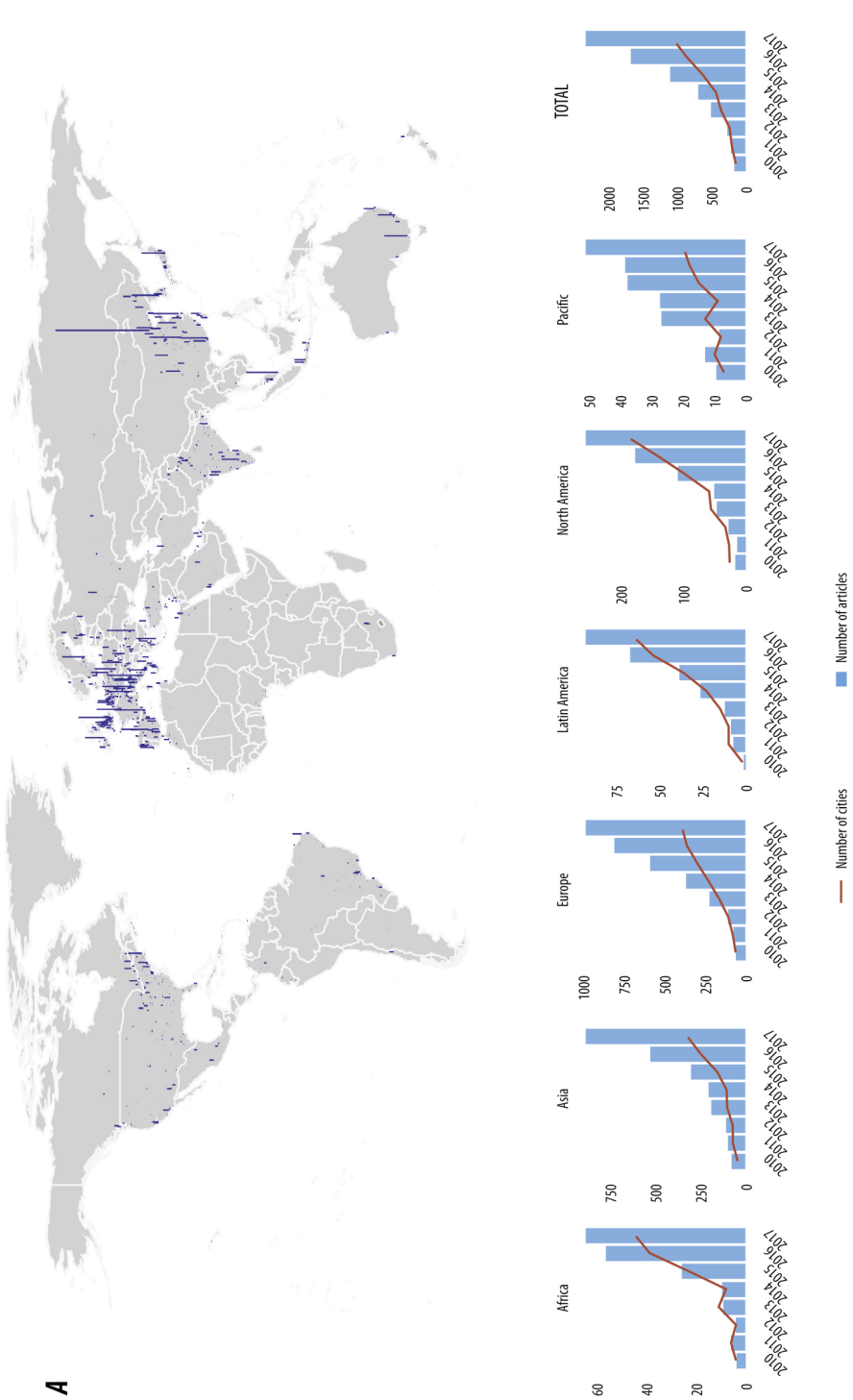


Fig. 5. Number of SC articles and SC knowledge producing cities in the two periods: 2010–2017 (A), and 2018–2022 (B). For detailed explanation see the text.
Source: Authors' own elaboration.



Fig. 5. Continued.

The bars on the maps represent the total number of articles produced at each city location, across two periods. Fractional counts were applied; for instance, if an article involved three cities, each city was assigned a count of 0.33. Below the map, the number of articles (bars) and cities involved in academic SC knowledge production (lines) are shown by major regions, with a summary provided in the Total chart. Note: The y-axes of the smaller graphs are scale-independent and not directly comparable.

As we will demonstrate through the network-based data used for the results, high publication output from a city is rarely achieved without substantial inter-city collaborations. Major article-producing cities are typically connected to many others, serving as hubs for scientific knowledge.

RO3: Comparing SC knowledge-based city ranking with GaWC ranking

Although we assumed that the two types of rankings represent different dimensions of urban development, the correlation between them suggests a weak-to-moderate relationship (0.506–0.620) (Table S4 in Supplement). This weak-to-moderate correlation justifies our initial selection of these two dimensions, as it demonstrates that traditional corporate economic weight does not automatically guarantee a central position in global SC knowledge production. However, high correlation is observed between the two periods within SC knowledge ranking (0.812) and GaWC ranking (0.933), pointing to deep structural path-dependencies within each respective network.

In analysing the rankings, first, we compared the top 50 cities separately in all four rankings, focusing on the changes between the two periods. Sixteen cities are consistently ranked among the top 50 in all four rankings. However, they differ in their significance and dynamic characteristics. Beijing leads in SC knowledge production through

cross-city collaboration and is the sixth most important global city. London, despite losing some of its SC knowledge edge, remains top-ranked in economic significance. Sydney, still in the top 10 global cities, excels in SC knowledge collaborations and significance. Among smaller cities, Prague is an important economic hub and local regional centre, but more populous cities have surpassed it in SC knowledge (Table 1).

Table 1 summarises the top 50 cities in the four city rankings used in the article, involving 241 cities which are equally found in all four rankings. (For methodological details of the rankings see section “Data and research methodology”.) Table 1 includes rank changes for cities appearing in both the SC rankings (left) and the GaWC rankings (right), indicated by arrows. In the middle, the 16 cities consistently featured in all four rankings are listed in descending order of their combined position.

Then we compared the changes in ranking places between the two rankings. This type of comparison allows us to determine which dimension of urban development (economic or academic) is more significant for each city. Based on this, we observed four categories: *dynamic cities of economic and SC knowledge importance*, when the rank change was positive in both rankings; *SC knowledge accumulators*, when SC knowledge rank changed positively but GaWC rank negatively; *economic weight gainers*, when GaWC rank changed positively but SC knowledge rank negatively; *potential laggards*, when the rank change was negative in both rankings. Figure 6 illustrates these dynamics focusing on the top of the rankings. 54 cities rank in the top 100 across all four rankings, with European cities dominating this combined list. Looking deeper, we can see notable differences. In the *dynamic cities of economic and SC knowledge importance* group many Chinese cities are significantly strengthening their positions as both global economic hubs and centres for SC knowledge, joined by a few cities from other emerging economies and even less from the de-

Table 1. Top 50 cities in the SC knowledge, and Global World City (GWC) rankings

Rank	SC knowledge ranking		Rank change		Rank change	GWC ranking		Rank
	2010–2017	2018–2022				2020	2016	
1	Beijing	Beijing	0	Cities in the top 50 on all rankings	0	London	London	1
2	London	Hong Kong	↑ 1		0	New York	New York	2
3	Hong Kong	Seoul	↑ 7		↑ 1	Hong Kong	Singapore	3
4	Rome	Shanghai	↑ 2		↓ -1	Singapore	Hong Kong	4
5	Wuhan	Sydney	↑ 16		↑ 4	Shanghai	Paris	5
6	Shanghai	Nanjing	↑ 14		0	Beijing	Beijing	6
7	Barcelona	Wuhan	↓ -2		↑ 1	Dubai	Tokyo	7
8	Milan	London	↓ -6		↓ -3	Paris	Dubai	8
9	Melbourne	Guangzhou	↑ 25		↓ -2	Tokyo	Shanghai	9
10	Seoul	Melbourne	↓ -1		0	Sydney	Sydney	10
11	Madrid	Riyadh	–	Hong Kong	↑ 17	Los Angeles	Sao Paulo	11
12	Bucharest	Shenzhen	↑ 21		↑ 9	Toronto	Milan	12
13	Singapore	Xi'an	↑ 10		↑ 2	Mumbai	Chicago	13
14	Paris	Singapore	↓ -1		↑ 12	Amsterdam	Mexico City	14
15	Turin	Madrid	↓ -4		↓ -3	Milan	Mumbai	15
16	Stockholm	Islamabad	–		↑ 1	Frankfurt	Moscow	16
17	Tokyo	Barcelona	↓ -10		↓ -3	Mexico City	Frankfurt	17
18	Athens	Chengdu	↑ 12		↓ -7	Sao Paulo	Madrid	18
19	Berlin	Hangzhou	↑ 21		↓ -6	Chicago	Warsaw	19
20	Nanjing	Bucharest	↓ -8		↑ 4	Kuala Lumpur	Johannesburg	20
21	Sydney	Rome	↓ -17	Lisbon	↓ -3	Madrid	Toronto	21
22	Dublin	Tokyo	↓ -5		↓ -6	Moscow	Seoul	22
23	Xi'an	Jeddah	–		↑ 2	Jakarta	Istanbul	23
24	Bologna	Montreal	–		↑ 3	Brussels	Kuala Lumpur	24
25	Vienna	Paris	↓ -11		↓ -6	Warsaw	Jakarta	25
26	Naples	Lisbon	↑ 1		↓ -4	Seoul	Amsterdam	26
27	Lisbon	Changsha	–		↓ -7	Johannesburg	Brussels	27
28	Prague	Brisbane	↑ 3		↑ 5	Zurich	Los Angeles	28
29	Bangalore	Chennai	–		↑ 1	Melbourne	Dublin	29
30	Chengdu	Bangalore	↓ -1		↓ -7	Istanbul	Melbourne	30
31	Brisbane	Athens	↓ -13	Prague	↑ 5	Stockholm	Washington	31
32	Amsterdam	Istanbul	–		↑ 2	Vienna	New Delhi	32
33	Shenzhen	Chongqing	–		↑ 4	Guangzhou	Zurich	33
34	Guangzhou	Berlin	↓ -15		↓ -5	Dublin	Vienna	34
35	Tianjin	Turin	↓ -20		0	Buenos Aires	Buenos Aires	35
36	Jinan	New Delhi	–		↑ 4	Luxembourg	Stockholm	36
37	Zurich	Milan	↓ -29		–	Montreal	Guangzhou	37
38	Ottawa	Budapest	–		↑ 11	Munich	Bogota	38
39	Birmingham	Doha	–		↓ -7	New Delhi	Miami	39
40	Hangzhou	Taichung	–		↑ 2	Santiago	Luxembourg	40
41	New York	Moscow	–		↑ 5	Boston	Riyadh	41
42	Cardiff	St. Petersburg	↑ 5		–	Shenzhen	Santiago	42
43	Bristol	Qingdao	–		↓ -2	Riyadh	Barcelona	43
44	Toronto	Warsaw	–		0	Lisbon	Lisbon	44
45	Manchester	Valencia	–		0	Prague	Prague	45
46	Harbin	Ottawa	↓ -8		–	Bangalore	Boston	46
47	St. Petersburg	Prague	↓ -19		↓ -16	Washington	Copenhagen	47
48	Pune	Stockholm	↓ -32		↓ -10	Bogota	Athens	48
49	Kolkata	Bologna	↓ -25		↓ -10	Miami	Munich	49
50	Florence	Naples	↓ -24		–	Rome	Atlanta	50

Sources: SC knowledge rankings computed by the authors. The source of Global World City rankings: <https://www.lboro.ac.uk/microsites/geography/gawc/world2020.html>. (Accessed 11 March 2024). As the webpage renewed the earlier one available here: <https://web.archive.org/web/20240608095604/https://www.lboro.ac.uk/microsites/geography/gawc/world2020t.html>.

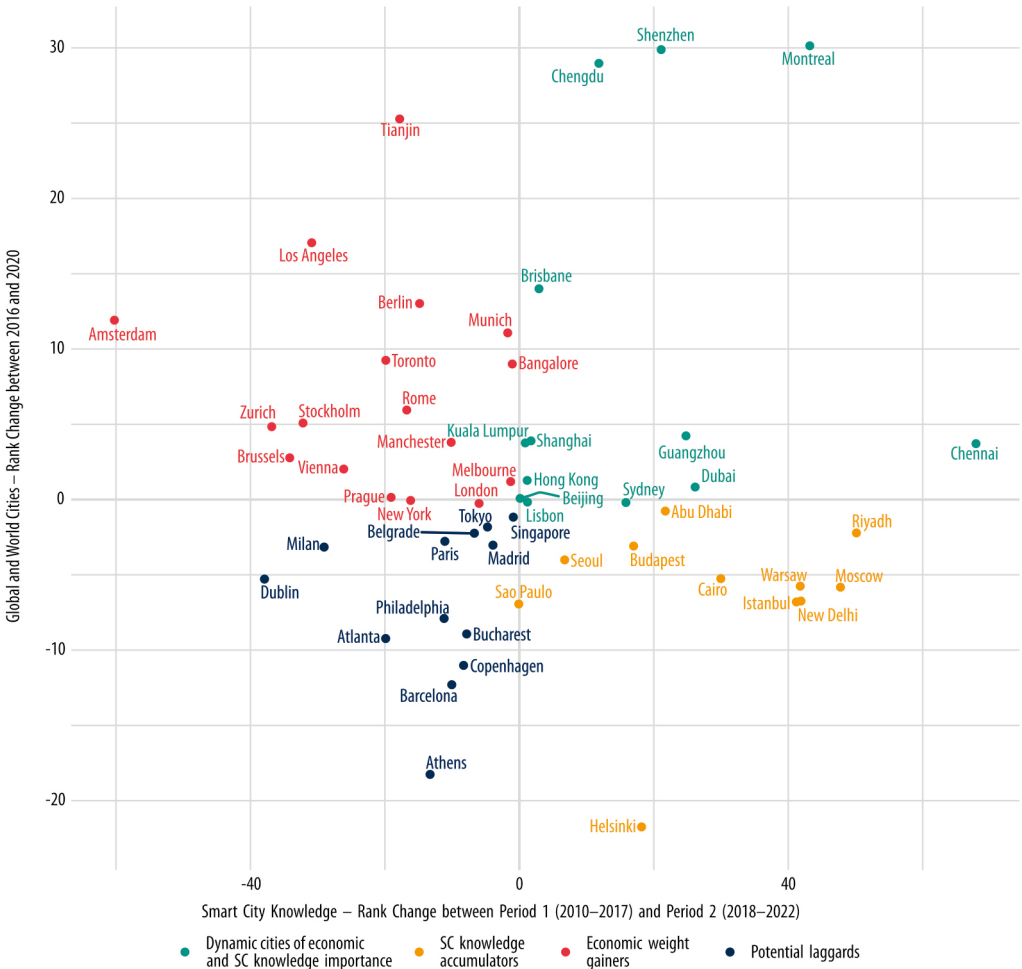


Fig. 6. Changes in the ranking of cities positioned in the top-100 in both networks and in both periods. For detailed explanation see the text. *Source:* Authors' own elaboration.

veloped nations. Montreal, for example, has made notable advancements in both areas. Europe is represented in this group only by one of the top 100 cities, Lisbon.

Conversely, in the *potential laggards* group, many European cities, such as Paris, Barcelona, Dublin, and Athens are indicated, showing a decline in both economic and SC knowledge importance.

In the *economic weight gainer* group, several European cities – such as Amsterdam, Berlin, Zurich, Rome, and Manchester – have

improved their economic positions but have seen a decline in their significance as SC knowledge hubs.

In the *SC knowledge accumulator* group cities like Budapest, Warsaw, and especially Helsinki appear to have experienced a decline in their global importance while improving their role in SC knowledge.

Figure 6 depicts the intersection of the top 100 cities from the four rankings. (For methodological details of the rankings see: Data and research methodology.) Cities are

positioned along two axes, indicating rank changes in the SC knowledge rankings (x-axis) and GaWC rankings (y-axis). Colours correspond to the four quadrants defined by these axes.

Finally, we applied the same approach globally to the 241 cities that appear in every ranking for both periods. From a more global perspective, we determined which cities and macro-regions are dominating each group. In the *dynamic cities of economic and SC knowledge importance* group, mostly cities of Asia, particularly China, have appeared, highlighting an increasing SC knowledge connectedness alongside economic connectedness. However, this group also has a regional character, including cities from other macro-regions, such as Australia, the Middle East, Europe, and the Gulf Coast region of Florida. Cities in the *SC knowledge accumulators* group are representing mostly India, the Middle East, Latin America, and Central and Eastern Europe.

In contrast, in the *economic weight gainer* group, in two developed macro-regions – Europe and North America – a notable number of cities have moved down the SC knowledge rankings, while a significant fraction of these cities has managed to enhance their global economic connectedness and influence (Figure 7). Most cities of the *potential laggards* group

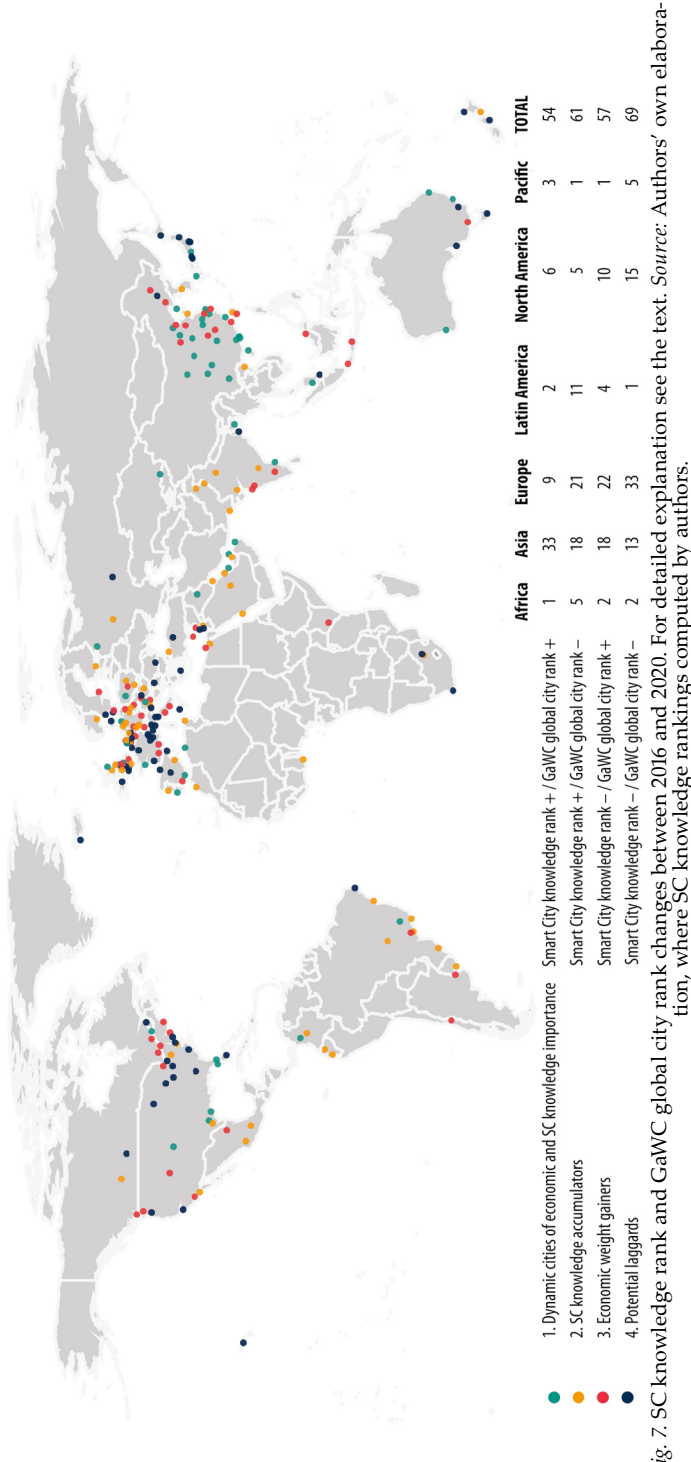


Fig. 7. SC knowledge rank and GaWC global city rank changes between 2016 and 2020. For detailed explanation see the text. Source: Authors' own elaboration, where SC knowledge rankings computed by authors.

are found in Europe, with a significant number in Asia and North America. The map shows 241 cities which are equally found in all four rankings. Below the map, the table summarises the number of cities in each category by major regions.⁴

Discussion

In our exploration of academic SC knowledge segments and their relationship with SC activities (RO1) we synthesized data from academic publications and we found that SC knowledge segments are dominated by interdisciplinary approaches with a strong technological foundation. The uncovered SC knowledge segments also represent the SC activities that shape SC transformations, directly reinforcing the findings of KUMAR, H. *et al.* (2020). The predominance of technology-oriented segments suggests that academic SC knowledge remains driven by the search for technical solutions to urban challenges. While governance, participation, and sustainability are visible components of the intellectual structure, they appear largely embedded within broader technologically-focused research agendas. This high technological density aligns with the framework of BIBRI, S.E. and KROGSTIE, J. (2017), where advanced ICT serves as the foundational engine for modern urbanism.

At a more granular level, we found that the intellectual structure of SC knowledge is divided between distinct technological-engineering domains – such as Big Data, smart energy systems, or machine learning – and sustainable urban development knowledge, which incorporates social and civil govern-

ance dimensions along with environmental sustainability. This finding matches the SC activity conceptualizations by experts; our findings also align with studies that focus on SC development (MORA, L. *et al.* 2019a) and on the practices cities adopt to foster the SC agenda (MORA, L. *et al.* 2019b).

However, the insight on the global divide of SC knowledge is accompanied by significant local variations. It remains uncertain whether emerging city hubs in developing countries, like European cities, and to lesser extent cities in Australia and Latin America, will embrace social and environmental sustainability in the same way. Regions like East Asia heavily prioritize technological infrastructure (CHEN, X. 2019; KONG, L. *et al.* 2020; JAVED, A.R. *et al.* 2022), and emerging urban environments in the Middle East, India, and Africa similarly employ context-driven technological frameworks. Nevertheless, these are increasingly adapted to local affordability and socio-economic planning (PARK, J. and Yoo, S. 2023). Whether or not developing city hubs will achieve a true convergence of sustainability and technological infrastructure is not self-evident. Emerging cities may not mimic Western trajectories; instead, they are likely to exhibit a hybrid model where technology serves as the primary mechanism to deliver basic needs.

By mapping global SC knowledge hubs and the geographical distribution of publication output (RO2), we showed that a growing number of cities contribute to and accumulate SC knowledge. Nevertheless, the majority of output comes from just a few cities, so concentration is evident in this sector as well, similar to what FLORIDA, R. *et al.* (2017) observed in other creative and intellectual sectors.

In the comparison of SC knowledge-based city ranking with GaWC ranking (RO3), a weak-to-moderate relationship was found. This correlation suggests that economic centrality and SC knowledge centrality represent related but distinct dimensions of global urban importance. Knowledge-intensive

⁴ The source of GaWC rankings: <https://www.lboro.ac.uk/microsites/geography/gawc/world2020.html> 3. (Accessed 11 March 2024). As the webpage renewed the earlier one available here: <https://web.archive.org/web/20240608095604/https://www.lboro.ac.uk/microsites/geography/gawc/world2020.html>

business service research also emphasizes the GaWC approach, which includes a knowledge dimension rather than just an economic one, as it uses advanced producer services data (MULLER, E. and ZENKER, A. 2001).

Cities topping these rankings show some European dominance; however, almost all Chinese cities are significant as both global economic hubs and centres for SC knowledge.

The temporal changes provided insights into four city categories: dynamic cities of economic and SC knowledge importance; SC knowledge accumulators; economic weight gainers; and potential laggards. Regional variance is notable among these groups, and from representing specialisation avenues across SC knowledge and economic hub dynamics. From a global perspective, the four identified city categories reveal that trajectories of urban development are becoming heterogeneous. Rather than following a single pathway towards global prominence, cities appear to specialise in different combinations of economic integration and SC knowledge accumulation. From this divergence, we can deduce a structural decoupling in the global urban hierarchy: while Asian hubs are using knowledge accumulation as a dynamic vanguard for growth, several legacy European hubs are experiencing a relative decline in SC related academic discourse despite maintaining corporate economic weight. The rise of several cities in the SC knowledge ranking without corresponding gains in the economic ranking suggests that scientific collaboration networks may act as an early indicator of emerging urban importance. Whether such knowledge advantages eventually translate into broader economic influence remains an open question. Conversely, cities that maintain strong economic positions while showing comparatively weaker performance in SC knowledge networks may face challenges in sustaining long-term competitiveness within increasingly knowledge-intensive urban environments.

Taken together, the results imply that global city status is becoming increasingly multidimensional. Economic connectivity remains a defining feature of urban prominence and SC knowledge networks reveal additional forms of centrality that are not fully captured by existing global city frameworks.

We have to acknowledge several limitations too.

First, the study relies on a single database of academic publications for SC knowledge. Although WoS provides extensive coverage and is widely used in similar studies, it does not capture all forms of SC-related knowledge production, such as local journal publications, policy reports, industrial research etc. We believe, however, that the scale of our study and the international coverage of the database provide a robust basis for the analysis and conclusions.

Second, the study conceptualizes SC knowledge through scientific publications and collaboration networks, reflecting the dynamics of codified academic knowledge rather than the practical implementations of SC agendas. Cities may differ substantially in their capacity to translate scientific knowledge into urban transformation.

Third, city-level knowledge hubs were identified through author affiliations. While this approach is common in spatial scientometrics, with the increasing prevalence of multi-institutional and internationally distributed research teams, geographical attribution of knowledge production might seem an oversimplification.

Fourth, the SC knowledge rankings and GaWC rankings capture fundamentally different forms of urban connectivity and the observed differences may arise both from genuine divergence between economic and knowledge dimensions and from differences in the underlying network structures. Future research should further investigate the relationship between these dimensions and the mechanisms through which they interact.

Finally, the analysis covers two broad time periods and therefore captures rather medium-term shifts. More detailed longitudinal analyses may reveal new patterns in the emergence, persistence, or decline of SC knowledge hubs.

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REFERENCES

- ACUTO, M. and LEFFEL, B. 2020. Understanding the global ecosystem of city networks. *Urban Studies* 58. (9): 1758–1774. <https://doi.org/10.1177/0042098020929261>
- ALBINO, V., BERARDI, U. and DANGELICO, R.M. 2015. Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of Urban Technology* 22. (1): 3–21. <https://doi.org/10.1080/10630732.2014.942092>
- ANDREANI, S., KALCHSCHMIDT, M., PINTO, R. and SAYEGH, A. 2019. Reframing technologically enhanced urban scenarios: A design research model towards human centered smart cities. *Technological Forecasting and Social Change* 142. 15–25. <https://doi.org/10.1016/j.techfore.2018.09.028>
- APPIO, F.P., LIMA, M. and PAROUTIS, S. 2019. Understanding smart cities: Innovation ecosystems, technological advancements, and societal challenges. *Technological Forecasting and Social Change* 142. 1–14. <https://doi.org/10.1016/j.techfore.2018.12.018>
- ARDITO, L., FERRARIS, A., MESSINI PETRUZZELLI, A., BRESCIANI, S. and DEL GIUDICE, M. 2019. The role of universities in the knowledge management of smart city projects. *Technological Forecasting and Social Change* 142. 312–321. <https://doi.org/10.1016/j.techfore.2018.07.030>
- BALLAND, P.-A., JARA-FIGUEROA, C., PETRALIA, S.G., STEIJN, M.P.A., RIGBY, D.L. and HIDALGO, C.A. 2020. Complex economic activities concentrate in large cities. *Nature Human Behaviour* 4. (3): 248–254. <https://doi.org/10.1038/s41562-019-0803-3>
- BELDERBOS, R., BENOIT, F. and DERUDDER, B. 2022. World city innovation and service networks and economic growth. *Papers in Regional Science* 101. (4): 979–999. <https://doi.org/10.1111/pirs.12687>
- BIBRI, S.E. and KROGSTIE, J. 2017. Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustainable Cities and Society* 31. 183–212. <https://doi.org/10.1016/j.scs.2017.02.016>
- BLONDEL, V.D., GUILLAUME, J.-L., LAMBIOTTE, R. and LEFEBVRE, E. 2008. Fast unfolding of communities in large networks. *Journal of Statistical Mechanics: Theory and Experiment* 10. 0008. <https://doi.org/10.1088/1742-5468/2008/10/P10008>
- BORSI, B., SOÓS, S. and VIDA, Zs. 2025. Keyword standardization and restructuring: The impact on analysing network-based science maps in innovation management research. *Scientometrics* 130. (2): 593–617. <https://doi.org/10.1007/s11192-025-05232-2>
- BRIGLAUER, W., KRÄMER, J. and PALAN, N. 2024. Socioeconomic benefits of high-speed broadband availability and service adoption: A survey. *Telecommunications Policy* 48. (7): 102808. <https://doi.org/10.1016/j.telpol.2024.102808>
- CAO, Z., DERUDDER, B., DAI, L. and PENG, Z. 2023. An analysis of the evolution of Chinese cities in global scientific collaboration networks. *Advances in Economic Geography* 67. (1): 5–19. <https://doi.org/10.1515/zfw-2021-0039>
- CHEN, X. 2019. The development trend and practical innovation of smart cities under the integration of new technologies. *Frontiers of Engineering Management* 6. (4): 485–502. <https://doi.org/10.1007/s42524-019-0057-9>
- COCCHIA, A. 2014. Smart and digital city: A systematic literature review. In *Smart City: How to Create Public and Economic Value with High Technology in Urban Space*. Eds.: DAMERI, R.P. and ROSENTHAL-SABROUX, C., Cham, Springer International Publishing, 13–43. https://doi.org/10.1007/978-3-319-06160-3_2
- CSOMÓS, G., VIDA, Z.V. and LENGVEL, B. 2020. Exploring the changing geographical pattern of international scientific collaborations through the prism of cities. *PLoS ONE* 15. (11): e0242468. <https://doi.org/10.1371/journal.pone.0242468>
- DAI, Y., HASANEFENDIC, S. and BOSSINK, B. 2024. A systematic literature review of the smart city transformation process: The role and interaction of stakeholders and technology. *Sustainable Cities and Society* 101. 105112. <https://doi.org/10.1016/j.scs.2023.105112>
- DERUDDER, B., TAYLOR, P.J., WITLOX, F. and CATALANO, G. 2003. Hierarchical tendencies and regional patterns in the world city network: A global urban analysis of 234 cities. *Regional Studies* 37. (9): 875–886. <https://doi.org/10.1080/0034340032000143887>
- DERUDDER, B. and WITLOX, F. 2010. World cities and global commodity chains: An introduction. *Global Networks* 10. (1): 1–11. <https://doi.org/10.1111/j.1471-0374.2010.00271.x>
- DERUDDER, B., HOYLER, M., TAYLOR, P.J. and WITLOX, F. (eds.). 2012. *International Handbook of Globalization and World Cities*. Cheltenham, Edward Elgar Publishing. <https://doi.org/10.4337/9781781001011>
- DERUDDER, B. and TAYLOR, P.J. 2005. The cliquishness of world cities. *Global Networks* 5. (1): 71–91. <https://doi.org/10.1111/j.1471-0374.2005.00108.x>

- DERUDDER, B. and PARNREITER, C. 2014. Introduction: The interlocking network model for studying urban networks: Outline, potential, critiques, and ways forward. *Tijdschrift voor Economische en Sociale Geografie* 105. (4): 373–386. <https://doi.org/10.1111/tesg.12108>
- DERUDDER, B. and TAYLOR, P.J. 2020. Three globalizations shaping the twenty-first century: Understanding the new world geography through its cities. *Annals of the American Association of Geographers* 110. (6): 1831–1854. <https://doi.org/10.1080/24694452.2020.1727308>
- DUYGAN, M., FISCHER, M., PARLI, R. and INGOLD, K. 2022. Where do Smart Cities grow? The spatial and socio-economic configuration of smart city development. *Sustainable Cities and Society* 77. 103578. <https://doi.org/10.1016/j.scs.2021.103578>
- EREMIA, M., TOMA, L. and SANDULEAC, M. 2017. The smart city concept in the 21st century. *Procedia Engineering* 181. 12–19. <https://doi.org/10.1016/j.proeng.2017.02.357>
- FLORIDA, R., ADLER, P. and MELLANDER, C. 2017. The city as innovation machine. *Regional Studies* 51. (1): 86–96. <https://doi.org/10.1080/00343404.2016.1255324>
- GHANBARI, H., SOE, R.-M., TOISKALLIO, K. and MORA, L. 2024. How do academic smart city centres operate in complex environments? A business model perspective. *Cities* 152. 105211. <https://doi.org/10.1016/j.cities.2024.105211>
- HALL, K.L., VOGEL, A.L., HUANG, G.C., SERRANO, K.J., RICE, E.L., TSAKRALIDES, S.P. and FIORE, S.M. 2018. The science of team science: A review of the empirical evidence and research gaps on collaboration in science. *American Psychologist* 73. (4): 532–548. <https://doi.org/10.1037/amp0000319>
- HAAQUE, A.K.M.B., BHUSHAN, B. and DHIMAN, G. 2022. Conceptualizing smart city applications: Requirements, architecture, security issues, and emerging trends. *Expert Systems* 39. (5): e12753. <https://doi.org/10.1111/exsy.12753>
- HOEKMAN, J., FRENKEN, K. and TIJSEN, R.J.W. 2010. Research collaboration at a distance: Changing spatial patterns of scientific collaboration within Europe. *Research Policy* 39. (5): 662–673. <https://doi.org/10.1016/j.respol.2010.01.012>
- HU, Y. 2005. Efficient, high-quality force-directed graph drawing. *The Mathematic Journal* 10. (1): 37–71.
- ISRAILIDIS, J., ODUSANYA, K. and MAZHAR, M.U. 2021. Exploring knowledge management perspectives in smart city research: A review and future research agenda. *International Journal of Information Management* 56. 101989. <https://doi.org/10.1016/j.ijinfomgt.2019.07.015>
- JAVED, A.R., SHAHZAD, F., REHMAN, S.U., ZIKRIA, Y.B., RAZZAK, I., JALIL, Z. and XU, G. 2022. Future smart cities: requirements, emerging technologies, applications, challenges, and future aspects. *Cities* 129. 103794. <https://doi.org/10.1016/j.cities.2022.103794>
- KESHAVARZI, G., YILDIRIM, Y. and AREFI, M. 2021. Does scale matter? An overview of the “smart cities” literature. *Sustainable Cities and Society* 74. 103151. <https://doi.org/10.1016/j.scs.2021.103151>
- KONG, L., LIU, Z. and WU, J. 2020. A systematic review of big data-based urban sustainability research: State-of-the-science and future directions. *Journal of Cleaner Production* 273. 123142. <https://doi.org/10.1016/j.jclepro.2020.123142>
- KRÄTKE, S. 2014. How manufacturing industries connect cities across the world: Extending research on ‘multiple globalizations’. *Global Networks* 14. (2): 121–147. <https://doi.org/10.1111/glob.12036>
- KUENTZ-SIMONET, V., RAMBONILAZA, T. and LYSER, S. 2023. Assessing the multidimensional structuring of quality of life. Evidence from a French city. *Cities* 140. 104427. <https://doi.org/10.1016/j.cities.2023.104427>
- KUMAR, H., SINGH, M.K., GUPTA, M.P. and MADAAN, J. 2020. Moving towards smart cities: Solutions that lead to the Smart City transformation framework. *Technological Forecasting and Social Change* 153. 119281. <https://doi.org/10.1016/j.techfore.2018.04.024>
- LEFFEL, B., MARAHRENS, H. and ALDERSON, A.S. 2023. Divergence of the world city system from national economies. *Global Networks* 23. (2): 459–477. <https://doi.org/10.1111/glob.12405>
- LIU, X., DERUDDER, B., CSOMÓS, G. and TAYLOR, P. 2013. Featured graphic. Mapping shifting hierarchical and regional tendencies in an urban network through alluvial diagrams. *Environment and Planning A, Economy and Space* 45. (5): 1005–1007. <https://doi.org/10.1068/a45488>
- MAISONOBE, M., ECKERT, D., GROSSETTI, M., JÉGOU, L. and MILARD, B. 2016a. The world network of scientific collaborations between cities: Domestic or international dynamics? *Journal of Informetrics* 10. (4): 1025–1036. <https://doi.org/10.1016/j.joi.2016.06.002>
- MAISONOBE, M., GROSSETTI, M., MILARD, B., ECKERT, D. and JÉGOU, L. 2016b. The global evolution of scientific collaboration networks between cities (1999–2014). *Revue française de sociologie* 57. (3): 417–441. (Translated by Hamilton, P.) <https://doi.org/10.3917/rfs.573.0417>
- MATTHIESSEN, C.W., SCHWARZ, A.W. and FIND, S. 2010. World cities of scientific knowledge: Systems, networks and potential dynamics. An analysis based on bibliometric indicators. *Urban Studies* 47. (9): 1879–1897. <https://doi.org/10.1177/0042098010372683>
- MCLEAN, D., RACHAL, M. and ZUKOWSKI, D. 2021. Smart city evolution: How cities have stepped back from a ‘tech arms race’ <https://www.smartcitiesdive.com/news/smart-city-evolution-how-cities-have-stepped-back-from-a-tech-arms-race/609732/>

- MORA, L., DEAKIN, M. and REID, A. 2019a. Combining co-citation clustering and text-based analysis to reveal the main development paths of smart cities. *Technological Forecasting and Social Change* 142. 56–69. <https://doi.org/10.1016/j.techfore.2018.07.019>
- MORA, L., DEAKIN, M. and REID, A. 2019b. Strategic principles for smart city development: A multiple case study analysis of European best practices. *Technological Forecasting and Social Change* 142. 70–97. <https://doi.org/10.1016/j.techfore.2018.07.035>
- MORTAHEB, R. and JANKOWSKI, P. 2023. Smart city re-imagined: City planning and GeoAI in the age of big data. *Journal of Urban Management* 12. (1): 4–15. <https://doi.org/10.1016/j.jum.2022.08.001>
- MULLER, E. and ZENKER, A. 2001. Business services as actors of knowledge transformation: the role of KIBS in regional and national innovation systems. *Research Policy* 30. (9): 1501–1516. [https://doi.org/10.1016/S0048-7333\(01\)00164-0](https://doi.org/10.1016/S0048-7333(01)00164-0)
- PARK, J. and YOO, S. 2023. Evolution of the smart city: Three extensions to governance, sustainability, and decent urbanisation from an ICT-based urban solution. *International Journal of Urban Sciences* 27. Supplement 1. 10–28. <https://doi.org/10.1080/12265934.2022.2110143>
- PERIS, A., MEIJERS, E. and VAN HAM, M. 2018. The evolution of the systems of cities literature since 1995: Schools of thought and their interaction. *Networks and Spatial Economics* 18. (3): 533–554. <https://doi.org/10.1007/s11067-018-9410-5>
- SALTON, G. and MCGILL, M.J. 1983. *Introduction to Modern Information Retrieval*. New York, McGraw-Hill Book Co.
- SASSEN, S. 1991. *The Global City: New York, London, Tokyo*. Princeton, N.J., Princeton University Press.
- SORRI, K., KYRÖNKOSKI, K. and SEPPÄNEN, M. 2024. Smart cities, smarter values: Unpacking the ecosystem of urban innovation. *Technology in Society* 77. 102499. <https://doi.org/10.1016/j.techsoc.2024.102499>
- TAYLOR, P.J., CATALANO, G. and WALKER, D.R.F. 2002. Measurement of the world city network. *Urban Studies* 39. (13): 2367–2376. <https://doi.org/10.1080/00420980220080011>
- TAYLOR, P.J. 2001. Specification of the world city network. *Geographical Analysis* 33. (2): 181–194. <https://doi.org/10.1111/j.1538-4632.2001.tb00443.x>
- TAYLOR, P.J. 2004. Regionality in the world city network. *International Social Science Journal* 56. (181): 361–372. <https://doi.org/10.1111/j.0020-8701.2004.00499.x>
- TAYLOR, P.J. 2011. The interlocking network model. In *International Handbook of Globalization and World Cities*. Eds.: DERUDDER, B., HOYLER, M., TAYLOR, P.J. and WITLOX, F.. Cheltenham, Edward Elgar Publishing, 45–54.
- TOH, C.K. 2022. Smart city indexes, criteria, indicators and rankings: An in-depth investigation and analysis. *IET Smart Cities* 4. (3): 211–228. <https://doi.org/10.1049/smc2.12036>
- TOWNSEND, A.M. 2014. *Smart Cities – Big Data, Civic Hackers, and the Quest for a New Utopia*. New York–London, W.W. Norton & Company.
- TRANOS, E. and GERTNER, D. 2012. Smart networked cities? *Innovation: The European Journal of Social Science Research* 25. (2): 175–190. <https://doi.org/10.1080/13511610.2012.660327>
- UN 2022. *World Population Prospects 2022: Summary of Results*. UN Department of Economic and Social Affairs, Popular Division, DESA/POP/2022/TR/NO. 3. New York, United Nations.
- VAN DE VIJVER, E., DERUDDER, B., BASSENS, D. and WITLOX, F. 2014. Filling some black holes: Modelling the connection between urbanization, infrastructure, and global service intensity. *The Professional Geographer* 66. (1): 82–90. <https://doi.org/10.1080/0030124.2013.781488>
- VAN DER HOOGEN, A., SCHOLTZ, B. and CALITZ, A.P. 2019. A smart city stakeholder classification model. In *2019 Conference on Information Communications Technology and Society (ICTAS)*, Durban, South Africa, 6–8 March 2019. <https://doi.org/10.1109/ICTAS.2019.8703633>
- WALL, R.S. and STAVROPOULOS, S. 2016. Smart cities within world city networks. *Applied Economics Letters* 23. (12): 875–879. <https://doi.org/10.1080/13504851.2015.1117038>
- WUESTMAN, M.L., HOEKMAN, J. and FRENKEN, K. 2019. The geography of scientific citations. *Research Policy* 48. (7): 1771–1780. <https://doi.org/10.1016/j.respol.2019.04.004>
- YAN, X., JEUB, L.G.S., FLAMMINI, A., RADICCHI, F. and FORTUNATO, S. 2018. Weight thresholding on complex networks. *Physical Review E* 98. (4): 042304. <https://doi.org/10.1103/PhysRevE.98.042304>
- ZHAO, F., FASHOLA, O.I., OLAREWAJU, T.I. and ONWUMERE, I. 2021. Smart city research: A holistic and state-of-the-art literature review. *Cities* 119. 103406. <https://doi.org/10.1016/j.cities.2021.103406>
- ZUBIZARRETA, I., SERAVALLI, A. and ARRIZABALAGA, S. 2016. Smart city concept: What it is and what it should be. *Journal of Urban Planning and Development* 142. (1): 04015005. [https://doi.org/10.1061/\(ASCE\)UP.1943-5444.0000282](https://doi.org/10.1061/(ASCE)UP.1943-5444.0000282)
- ZUPIC, I. and ČATER, T. 2015. Bibliometric methods in management and organization. *Organizational Research Methods* 18. (3): 429–472. <https://doi.org/10.1177/1094428114562629>
- Other source:
World Cities 2020 – GaWC (<https://gawc.lboro.ac.uk/gawc-worlds/the-world-according-to-gawc/world-cities-2020/>)
As the webpage renewed the earlier one available here: <https://web.archive.org>

Supplement

Table S1. SC research search profile

Search profile	Hits in Web of Science
TS = ("intelligent city" OR "knowledge city" OR "ubiquitous city" OR "sustainable city" OR "digital city" OR "smart city" OR "future city" OR "eco city" OR "eco-city" OR "compact city" OR "liveable city" OR "digital city" OR "innovative city" OR "green city"), OR TS = ("intelligent cities" OR "knowledge cities" OR "ubiquitous cities" OR "sustainable cities" OR "digital cities" OR "smart cities" OR "future cities" OR "eco cities" OR "eco-cities" OR "compact cities" OR "liveable cities" OR "digital cities" OR "innovative cities" OR "green cities"), OR TS = (urban OR city OR cities) AND ("smart econom*" OR "smart people" OR "smart govern*" OR "smart mobility" OR "smart environment*" OR "smart living"), AND DT = ("Article" OR "Proceedings paper") and English (Languages)	28,444

Note: Our search profile based on SC definitions and smart urban phenomena (COCCHIA, A. 2014; ALBINO, V. *et al.* 2015; EREMIA, M. *et al.* 2017). Publications’ metadata were downloaded from the Web of Science (WoS) database on 18 May 2023. *Source:* Authors’ own elaboration.

Table S2. Search string construction and supporting literature for each term

COCCHIA, A. 2014	knowledge city knowledge cities; ubiquitous city ubiquitous cities
ALBINO, V. <i>et al.</i> 2015	urban + smart econom*; urban + smart people; urban + smart govern*; urban + smart mobility; urban + smart environment*; urban + smart living; city + smart econom*; city + smart people; city + smart govern*; city + smart mobility; city + smart environment*; city + smart living; cities + smart econom*; cities + smart people; cities + smart govern*; cities + smart mobility; cities + smart environment*; cities + smart living;
DUYGAN, M. <i>et al.</i> 2022	future city future cities; eco city eco-cities; smart city smart cities; intelligent city intelligent cities; sustainable city sustainable cities; compact city compact cities; liveable city liveable cities; digital city digital cities; innovative city innovative cities; green city green cities

Note: In the table and in the search strings, the asterisk (*) is used as a truncation (wildcard) operator to capture all word variants and derivatives complementing core smart city terms (e.g. ‘govern*’ captures ‘governance’, ‘government’, or ‘governing’; ‘environment*’ captures ‘environmental’ and ‘environment(s)’; and ‘econ*’ captures ‘economy’, ‘economies’, ‘economics’, etc.). *Source:* Authors’ own elaboration.

Table S3. The top ten countries by production of SC knowledge

2010–2017				2018–2022			
Country	Number of		Articles, %	Country	Number of		Articles, %
	cities	articles			cities	articles	
China	108	1037	14.5	China	203	2803	15.9
Italy	84	698	9.9	USA	428	1538	8.7
USA	253	581	8.2	India	260	1250	7.1
Spain	63	420	6.0	Italy	97	1025	5.8
India	123	406	5.8	United Kingdom	80	726	4.1
United Kingdom	57	359	5.0	Spain	85	703	4.0
Germany	81	237	3.4	Australia	35	524	3.0
Australia	26	196	2.8	Germany	130	494	2.8
France	69	183	2.6	South Korea	43	479	2.7
Japan	48	161	2.3	Brazil	135	467	2.6

Note: The table shows the total number of articles by cities within their respective countries (for details see: Data and research methodology) across two periods. It includes only the top 10 producer countries. Fractional counts were applied; for instance, if an article involved three cities, each city was assigned a count of 0.33. Articles published from 2010 to 2017 are summarized on the left, while those published from 2018 to 2022 are summarized on the right. The percent of articles is computed as share of the total number of articles. *Source:* Authors’ own elaboration.

Table S4. Spearman’s rank correlation coefficient between the four rankings

Rankings	Period	City rankings based on SC knowledge		Global and world cities ranking	
		2010–2017	2018–2022	2016	2020
City rankings based on SC knowledge	2010–2017	1.000	0.812	0.506	0.521
	2018–2022	–	1.000	0.579	0.620
Global and world cities ranking	2016	–	–	1.000	0.933
	2020	–	–	–	1.000

Note: The table summarizes the Spearman ranking correlations between the four city rankings used in the article, involving 241 cities (for details of deriving the rankings see: Data and research methodology). *Source:* Authors’ own elaboration.

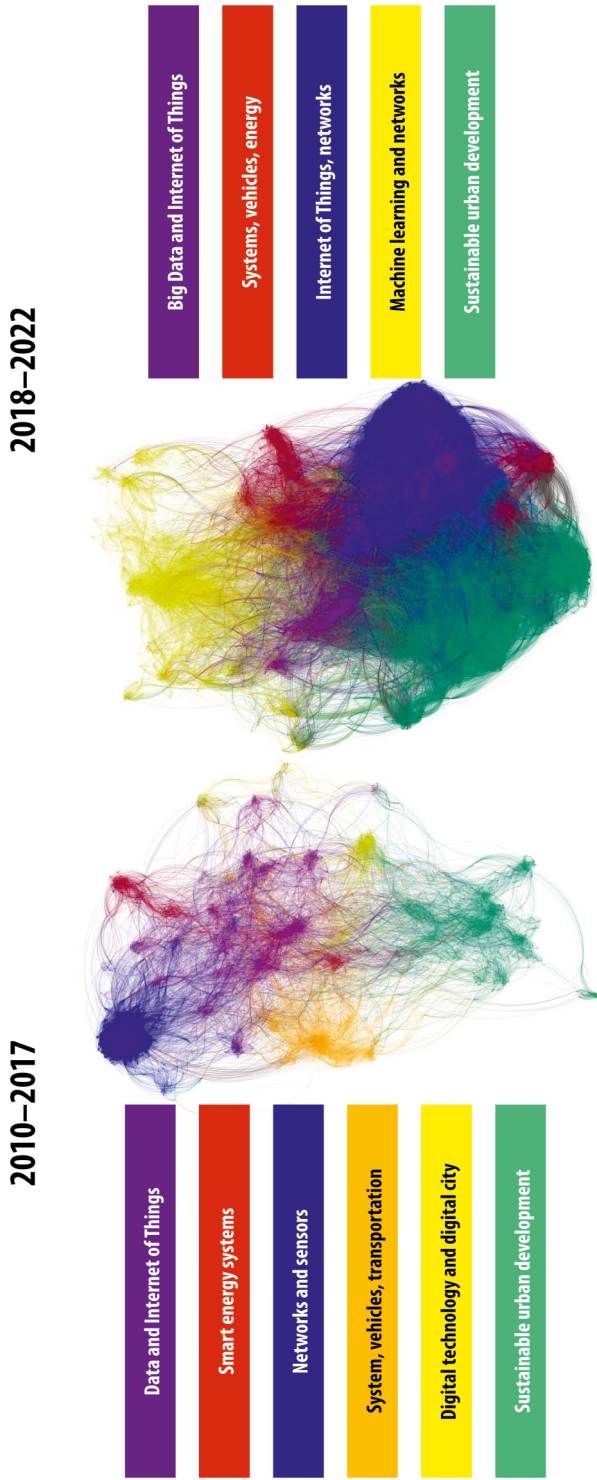


Fig. S1. Thematic clusters in the SC knowledge space. Note: The figure contains articles as nodes connected by shared keywords as edges, organized by the thematic clusters that emerged in the science mapping during two periods (for details see: Data and research methodology). The network of articles published from 2010 to 2017 is visualized on the left, while those published from 2018 to 2022 are shown on the right. The colours represent articles in different thematic clusters: nodes of the same colour belong to the same thematic cluster. For the cluster names and themes, see Figure 4 at the top. Similar colours were applied to clusters with comparable contents in the two periods. The detailed content, represented by word clouds, is depicted in Figures S2a and S2b. The following identical steps were sequentially performed in Gephi to facilitate visualization: Yifan-Hu network optimization was used (Hu, Y. 2005); edges below 0.4 edge weight were deleted, because low edge weights represent low cognitive similarity based on the shared keywords and there is no loss of influential content or influence on the community structure (YAN, X. *et al.* 2018); setting the minimum degree to 5 to further support visual clarity. Source: Authors' own elaboration.

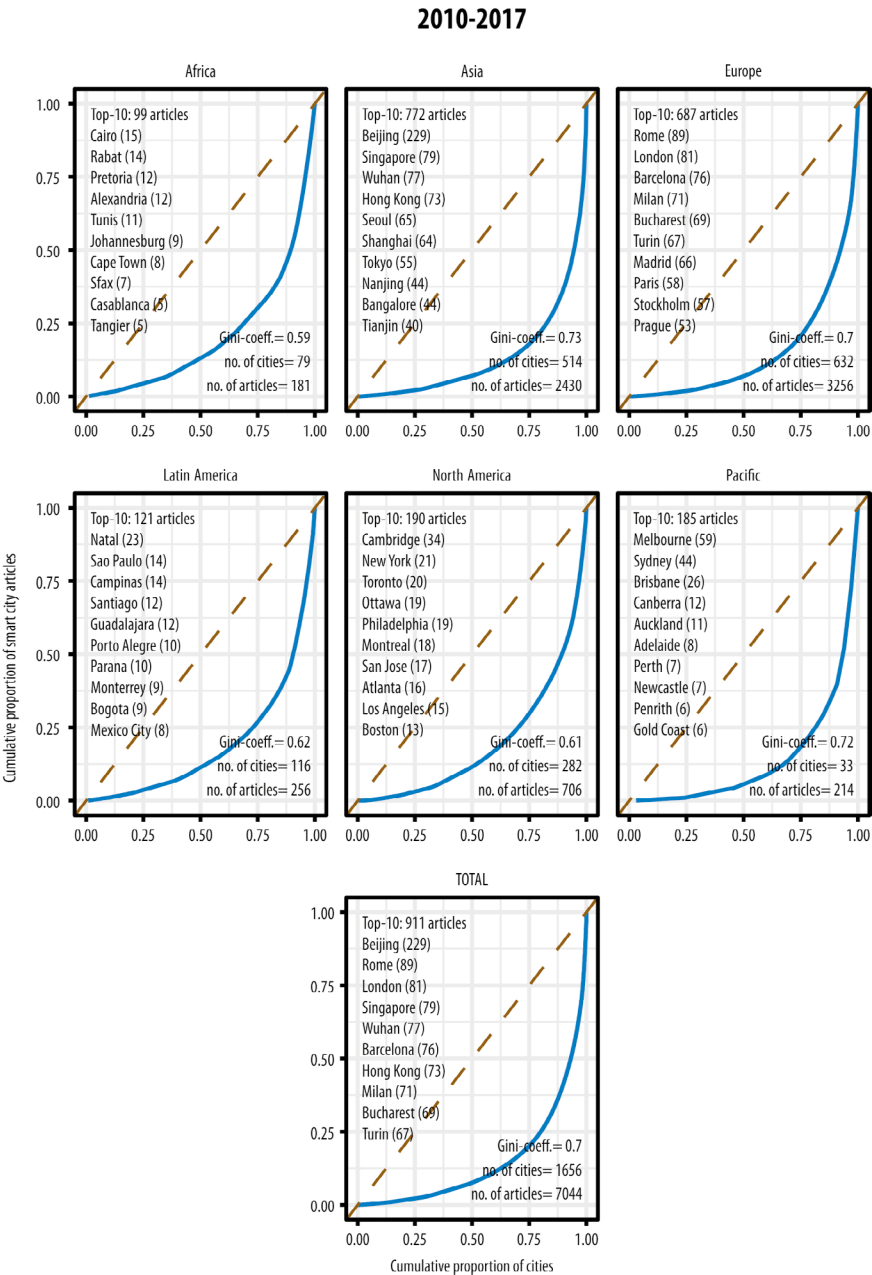


Fig. S3a. Concentration of SC knowledge in cities, 2010–2017. Note: Lorenz curves are shown for major regions and summarized in the TOTAL chart, across two periods. These curves plot the cumulative proportion of cities (x-axis) against the cumulative proportion of smart city articles produced (y-axis). Each regional chart includes the Gini coefficient, the total number of cities, and the total number of articles at the bottom-right. At the top-left, the top 10 cities and their respective article counts are listed. Fractional counts were applied; for instance, if an article involved three cities, each city was assigned a count of 0.33. Source: Authors' own elaboration.

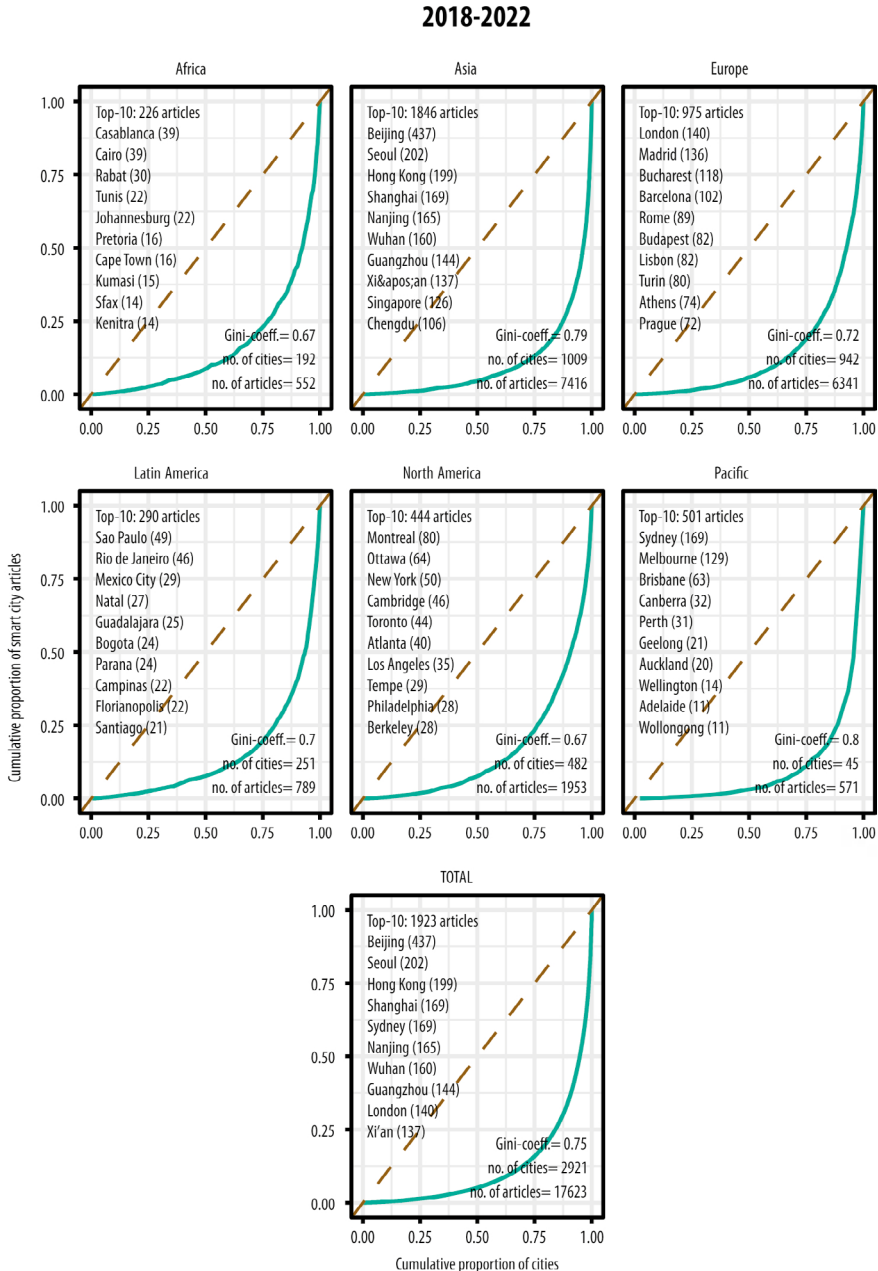


Fig. S3b. Concentration of SC knowledge in cities, 2018–2022. Note: Lorenz curves are shown for major regions and summarized in the TOTAL chart, across two periods. These curves plot the cumulative proportion of cities (x-axis) against the cumulative proportion of smart city articles produced (y-axis). Each regional chart includes the Gini coefficient, the total number of cities, and the total number of articles at the bottom-right. At the top-left, the top 10 cities and their respective article counts are listed. Fractional counts were applied; for instance, if an article involved three cities, each city was assigned a count of 0.33. Source: Authors' own elaboration.

