DATA SCIENCE - EXTRACTING INSIGHTS
Open Journal

Review

Analysing Trends of Computational Urban Science and Data Science Approaches for Sustainable Development

Deepak Kumar[1*]; Nick P. Bassill[1,2]

[1]*Center of Excellence in Weather & Climate Analytics, Atmospheric Sciences Research Center (ASRC), State University of New York at Albany, New York 12226, USA*
[2]*State Weather Risk Communication Center (SWRCC), Atmospheric Sciences Research Center (ASRC), State University of New York at Albany, New York 12226, USA*

[*]***Corresponding author***
Deepak Kumar
Climate Analytics, Atmospheric Sciences Research Center (ASRC), State University of New York at Albany, New York 12226, USA;
E-mail: deepakdeo2003@gmail.com

Article information
Received: December 21st, 2023; **Revised:** January 20th, 2024; **Accepted:** February 4th, 2024; **Published:** February 26th, 2024

Cite this article
Kumar D, Bassill NP. Analysing trends of computational urban science and data science approaches for sustainable development. 2024; 2(1).
doi: https://doi.org/10.70705/ppp.dsei.2024.v02.i01.pp20-34

ABSTRACT

Urban computing with a data science approaches can play a pivotal role in understaning and analyzing the potential of these methods for strategic, short-term, and sustainable planning. The recent development in urban areas have progressed towards the data-driven smart sustainable approaches to resolve the complexities around urban areas. The urban system faces severe challenges and these are complicated to capture, predict, resolve and deliver. The cur- rent study advances an unconventional decision-support framework to integrate the complexities of science, urban sustainability theories, and data science, with a data-intensive science to incorporate grassroots initiatives for a top- down policies. This work will influence the urban data analytics to optimize the designs and solutions to enhance sustainability, efficiency, resilience, equity, and quality of life. This work emphasizes the significant trends of data- driven and model-driven decision support systems. This will help to address and create an optimal solution for mul- tifaceted challenges of an urban setup within the analytical framework. The analytical investigations includes the research about land use prediction, environmental monitoring, transportation modelling, and social equity analysis. The fusion of urban computing, intelligence, and sustainability science is expected to resolve and contribute in shap- ing resilient, equitable, and future environmentally sensible eco-cities. It examines the emerging trends in the domain of computational urban science and data science approaches for sustainable development being utilized to address urban challenges including resource management, environmental impact, and social equity. The analysis of recent improvements and case studies highlights the potential of data-driven insights with computational models for pro- moting resilient sustainable urban environments, towards more effective and informed policy-making. Thus, this work explores the integration of computational urban science and data science methodologies to advance sustainable development.

Keywords
Data science; Sustainable urban development; Resource management; Computational urban science; Environmental challenges.

INTRODUCTION

Sustainable urban development is a critical global chal- lenge for urban areas due to unchecked population growth, environmental concerns, and social equity (M. Liu et al., 2021). The urban areas are gradually spinning towards data-driven approaches to utilise computational urban science and data science to efficiently discourse these complexities (Belal and Moghanm 2011; Moonen et al., 2012; Zhang et al., 2024). This requires an under- standing of the recent trends in computational urban science and data science for shaping resilient, equita- ble, and environmentally conscious cities of the future. Urban computing is basic ingredient of computional urban science to integrate data from urban environments with use of Articifical Intelligence (AI) and Internet of Things (IoT) to optimize city planning, transportation, and sustainability solutions (Chandan et al., 2020; Geert- man & Stillwell, 2020; Y. Liu et al., 2021). These compu- tational approches offers analysis of vast urban datasets for informed decision-making (Ahn & Cho, 2017; Hsu, 2018). There are requirement for investigations to under- stand the various computational approaches in urban sciences for a comparative analysis in diverse urban sce- narios (Aburizaiza & Rice, 2016; Fedorov et al., 2021; Wichansky et al., 2006).

The proper understanding of the transformative poten- tial of computational urban science and data science with sustainable development approach requires the evaluation and analysis of current trends (Chauhan & Shekhar, 2021; Jayasinghe et al., 2021). The effectiveness of approaches is required to be assessed across various

applications including hazard monitoring, risk evalua- tion, infrastructure resilience, and disaster management for researchers and decision-makers. Advanced com- putational methods utilize algorithms, simulations, and modeling to solve complex problems, while data-driven approaches analyze vast datasets to extract patterns and insights, enabling informed decision-making in science, technology, and business. This work provides an under- standing of the advanced computational methods and data-driven approaches for urban planning, resource management, and environmental strategies (Kang et al., 2019; Sahoo et al., 2021). The exploration of recent advancements and methodologies reveals the ultimate impact of the technologies to create resilient, efficient, and equitable urban environments (Becker et al., 2021; Onodera et al., 2008). This work analyses the progress in sustainable urban studies with an emphasis on the use of modern approaches. These approaches facilitate precise analysis of urban characteristics to understand the vari- ous datasets used for urban studies (M. Chen et al., 2022; Hayashi et al., 2009; Karvonen et al., 2021). This analy- sis aims to highlight the convergence of computational tools with sustainable practices, offering insights into how data science can drive future innovations in urban development. The integration of diverse datasets in a computational domain offers an understanding of urban development approaches. The analysis will summarise the developments, challenges, and future directions to efficiently handle the massive urban data.

1.1 Computational urban science and data science approaches

Computational urban science is an interdisciplinary field to leverages data science approaches to understand com- plex urban challenges (Meerow, 2020). These challenges arise from the dynamic nature of cities influences indi- vidual and collective decisions. Computational urban science contains interdependent layers covering human dynamics-centered, platform-based, action-oriented, and convergence-driven (Y. Li et al., 2020). Computa- tional urban science with data science approach provides advanced analytics and modelling techniques to address complex urban challenges (Blackwood et al., 2014; Pincetl, 2012).

Data is collected from various sources, processed, and analyzed with techniques such as machine learning, statistical modeling, and analytics to uncover patterns, trends, and relationships. The use of data provides the primary source of insight and allow for evidence-based decision-making rather than intuition, opinions, or tra- ditional processes. This enables to make more accurate, objective, and effective decisions across a wide range of fields, such as business, science, healthcare, and urban planning. Data-driven approaches rely on the analy- sis of data to inform decisions, strategies, and actions. Data-driven approaches use data analytics, machine learning, and statistical techniques to extract patterns, trends, strategies and actionable insights for decision making instead of relying on traditional methods. These approaches are widely applied across various disciplines to optimize operations and accuracy of forecast for evidence-based decisions. These approaches allow for real-time updates, adaptability, and more informed prob- lem-solving with real-time data collection and analysis.

These urban areas are required to collect huge amounts of real-time data from sensors, devices, and systems to monitor transportation, energy usage, waste man- agement, and more. Consequently, the urban areas are inclined for the use of data-driven approaches for sus- tainable development of urban areas with the use of tech- nologies like IoT, AI, and big data analytics along with the optimisation of urban operations to enhance quality of life, and promote environmental sustainability. The data analysis offer city planners and administrators to make informed decisions with improved resource efficiency, reduced emissions for ensuring a more sustainable future. The facilities to create a technology enabled urban ecosystems with economically viable and environmen- tally responsible development for citizens. Data-driven approcahes for development of sustainable urban areas focuses on the integration of diverse computing environ- ment and data science to enhance sustainability (Fu et al., 2021). The analysis of urban data with the use of model-driven decision support systems create optimal designs solu- tions for better urban sustainability, efficiency, resilience, equity, and quality of life. These data driven approaches requires urban information science to provide insights into urban phenomena for advancing computational approaches and domain-specific urban solutions. Researchers explore these areas with a focus to under- take the challenges of urban research in the era of big data. The utilisation of large-scale data sets, simulations, and machine learning algorithms offers valuable insights into urban dynamics, traffic patterns, energy consump- tion, and environmental impacts. They facilitate more informed decision-making for urban planning and sus- tainable development. These methodologies assist in optimising resource management with improvement in infrastructure resilience for enriched quality of life within the urban areas. These will help to integrate diverse data sources to create smarter, more adaptive urban environ- ments to current needs and future challenges.

1.2 Analysing trends and approaches for sustainable urban development

The analysis of trends and approaches for sustain- able urban development requires a multi-dimensional research on global, regional, and local data to identify effective strategies for urban development (AZMI et al., 2021; Panidi & Rykin, 2020). This evaluation integrates environmental, economic, and social dimensions to gen- erate a holistic views of the development practices. The key trends provides a growing implementation of renew- able energy sources, advancements in sustainable agri- culture, and the development of circular economies. The application of new approaches comprising green tech- nology innovations, policy reforms, and community- driven initiatives facilitates gateway for introdcution of data science approaches to forecast and model sce- narios for offering insights to policymakers and stake- holders. Likewise, the sustainable development of urban areas approaches with Geographic Information Systems (GIS) and remote sensing technologies offers a precise monitoring of environmental changes and resource man- agement with a collaborative efforts across sectors com- prising government, academia, industry, and civil society. The leaning of computational urban science with data

science approaches for sustainable development goals (SDGs) offers a inclusive structure for improved eco- nomic growth, social inclusion, and environmental pro- tection (Friedrich, 2008; C.-H. Lee et al., 2018).

The continuous monitoring and estimation with indi- cators/ met-

rics of sustainable development of urban areas are crucial in reviewing the efficacy of strategies to make necessary modifications. The sustainable develop- ment dimension in the urban research guides the social, economic, and environmental planning to evaluate the needs of present and future generations (Fedorov et al., 2021). Sustainable development efforts augment the cur- rent challenges and future demands to provide a equita- ble world with innovative approaches. The most common methods associated with the similar research consist of:

a) Bibliometric Analysis to provide insigflts into tfle evolution and maturity of scientific researcfl in tflis field. Researcflers conduct bibliometric analyses to understand tfle progress, cflallenges, opportunities, and prospects of tfle target researcfl.

b) Dimensions of researcfl to provide a multidimen- sional approacfl to confirm tfle dimensions of researcfl focus. The researcfl analysis grid evaluates projects, strategies, programs, and policies across six dimensions: cultural, economic, environmental, ethi- cal, governance, and social.

c) Equity and Transparency to empflasize economic and social equity. These guide toward tfle responsible and transparent implementation of government poli- cies for acflieving SDGs.

Sustainability in the urban context serve as catalysts for socio-economic, environmental, and urban sustainabil- ity to offer solutions for informed decision-making and resource optimization. Adopting modern technologies with a proper community collaboration for a proactive policies can pave the way for resilient urban develop- ment. Sustainable development provides a global per- spective for recognition of the instrumental value of the natural environment to protect indigenous cultures, and equitable socioeconomic practices with the analysis to support an evidence-based progress toward a more sustainable future.

Sustainable urban development is a key goal in address- ing climate change and reducing environmental impact, making the integration of computational urban sci- ence essential for achieving the United Nations' Sus- tainable Development Goals (SDGs). This research will contribute to the design of smarter, more resilient, and eco-friendly cities. Research on analyzing trends in com- putational urban science and data science approaches for sustainable development is crucial due to the growing complexities of urban environments and the increasing need for sustainable solutions. Cities are expanding rap- idly, and the integration of technology in urban systems has opened up vast opportunities for optimizing resource use, improving infrastructure, and enhancing the qual- ity of life for residents. The study of current trends in AI, machine learning, big data analytics, and IoT can offer insights into technological evoluation of urban areas to meet sustainability challenges. The data-driven approaches can be good support for better decision- making in critical areas like transportation, energy, water management, and waste reduction.

2 Methods and methodology

The investigation of recent trends in computational urban science with data science approaches for sustainable development occupies a strong operational framework to integrate various quantitative and qualitative methods (Kumar et al., 2024). Systematic literature reviews with bibliometric analysis are foundational methods to provide a comprehensive outline of existing research. It iden- tifies key topics, influential works, and emerging trends. The citation analysis and co-citation network map pre- sent the logical structure with evolution in the field, while keyword analysis and topic modelling discover prevalent research topics with their trajectories.

Figure 1 visualises the expansion of analysis approaches and trends in computational urban science for data sci- ence with a systematic approach to derive meaningful insights from urban data. The typical step involved in this analysis approach includes:

a) Data Collection to gatfler diverse urban datasets, including geograpflic, demograpflic, socioeconomic, and environmental data from various sources includ- ing sensors, surveys, social media, and government databases.

b) Data Preprocessing for Clean and preprocess data to flandle missing values, noise, and inconsistencies. This ensures data quality and usability.

c) Data Integration combines multiple datasets to create a compreflensive view of urban pflenomena and involves spatial–temporal alignment of data.

d) Exploratory Data Analysis (EDA) realises tfle data distribution to identify patterns and generate flypotfl- eses. It comprises visualization tecfllniques like fleat maps, scatter plots, and time series plots.

e) Feature Engineering creates appropriate features to capture tfle essence of urban dynamics and include spatial features (e.g., proximity to amenities), tempo- ral features (e.g., time of day), and domain-specific features.

f)) Modelling and Analysis utilises statistical and macfline learning models to analyze trends for regression analysis, clustering, time series analysis, and predictive modelling.

g) Validation and Evaluation uses appropriate metrics to assess tfle performance witfl cross-validation to ensure tfle robustness of tfle findings.

f) Interpretation and Visualization interpret results in tfle framework of urban science, witfl visualization to present understandings of crucial findings for deci- sion-making.

i) Policy Implications and Recommendations translate analytical insigflts into actionable recommenda- tions for urban planning and policy-making.

These mentioned steps are used to analytically analyze and interpret data to discover the trends for urban devel- opment. Similarly, the temporal trend analysis with time- series data highlights the changes and advancements over time. The patterns and relationships within large datasets are detected with advanced statistical methods including machine learning algorithms, cluster analysis and natural language processing (NLP). Spatial analysis techniques presents a visualization and interpretation of urban spa- tial datasets for in-depth understanding in specific appli- cations. Mixed-methods connect quantitative data with qualitative insights with expert intervention to improve the analysis with diverse perspectives. These methodolo- gies assess the advancement and impact of computational urban science and data science in promoting sustainable development to guide future research and policy-making.

2.1 Computational urban science for sustainable development

The integration of climate data and computational urban science

requires an approach to understand the impacts of environmental threats for urban resilience. The use of computational sciences in the study of urban data- sets provides a synthesize of distinct data from multiple sources to create an insights for the sustainable devel- opment goals (SDGs) with environmental sustainability, economic growth, and social equity (J. Lee & Chuang, 2017; L.-L. Li et al., 2021). Computational urban science is critical for sustainable development to provide cutting- edge computational approaches with data analytics to address urban challenges. Computational models suggest urban growth, transportation designs, and energy con- sumption to facilitate planners for the design of efficient and eco-friendly infrastructures. These models assist traffic flow and reduce congestion and emissions to aug- ment public transportation systems to promote sustaina- ble mobility (Errampalli et al., 2020). The analysis of huge volumes of urban data provides insights into the com- plex dynamics of urban areas to direct sustainable urban planning with policy-making (Akhtar & Kirmani, 2021; Waghela et al., 2022). This supports the identification of social inequities with the optimization of services like healthcare, education, and housing to promote inclusive urban environments. Computations plays a crucial role in advancing sustainable development with data-driven approaches to explore other aspects like:

a) Data-Driven Smart Sustainable Cities (DDSSC) combine big data tecflnologies to enflance sustain- ability. DDSSC use data-driven approacfles for strate- gic, sflort-term, and joined-up planning. Urban com- puting witfl augmented intelligence provides effective decision-making tflrougfl tfle analysis of urban data to create a model-driven systems.

b) Interdisciplinary Computable Sustainable Urbanization (ICSU) offers an interdisciplinary backgrounds to resolve tfle urbanization cflallenges. Scientific computing combines natural sciences and flumani- ties to simulate urban evolution, observe interac- tions, and optimize sustainability.

Core disciplines with data-driven urban system offers solutions for a number of subject complexities compris- ing science, sustainability science, and data-intensive science (Roy & Mitra, 2020). These provide a powerful simulation models to optimize the approaches for sus- tainable urban design (Reyhani et al., 2022). These offers a unconventional tools and frameworks to enhance sus- tainability, efficiency, resilience, equity, and quality of life for future cities.

2.2 Data science for sustainable development

Data science supports the advancement of sustainable development to solve global challenges. The complex large datasets and analytical techniques including data science provide critical understandings for better policy decisions (Rumson & Hallett, 2019). Data science provide insights for sustainable growth and may include any of the mentioned approaches.

a) Predictive Modeling and Forecasting use flistori- cal data to build predictive models to forecast future trends for environmental factors, population growtfl, and resource consumption. These models provide insigflts to decision-makers on potential cflallenges and proactive interventions.

b) Geospatial Analysis incorporates geospatial data like satellite imagery and geograpflic information sys- tems (GIS) to monitor land use, deforestation, urban sprawl, and natural resource distribution. The spatial patterns analysis distinguisfles areas at risk for sus- tainable land management practices.

c) Machine Learning for resource optimization expands resource allocation witfl waste minimization and improved efficiency.

d) Social Network Analysis explores social networks and tfleir impact to evaluate social interactions, iden- tify influencers, and design targeted interventions.

e) Natural Language Processing (NLP) extracts valuable information from textual data like policy docu- ments, scientific literature, and social media posts. NLP track progress toward sustainable development goals and assesses public sentiment to empower evidence-based decisions.

Data science helps to design smarter cities to mini- mize environmental impact to improve living conditions. Researchers use statistical and mathematical principles to analyze and interpret the real-time data to monitors and mitigate the effects of natural disasters in socio-economic dimensions for equitable resource distribution.

2.3 Systematic bibliometric analysis (SBA)

Bibliometric analysis is a quantitative method to assess the impact and development of scientific literature within a specific field. This analysis examines various metrics such as citation counts, publication trends, authorship patterns, and collaboration networks with statistical techniques. The bibliometric analysis evalu- ates the influence of research articles, journals, insti- tutions, and individual researchers with key indicators including the h-index and the impact factor, the aver- age number of citations received by articles (Hu et al., 2016). Bibliometric analysis utilises databases like Web of Science, Scopus, and Google Scholar with specific software packages like VOSviewer, BibExcel, and R packages. The current uses VOSviewer (version 1.6.20) to visualize and interpret the trends with relationships. VOSviewer is a software tool for constructing and vis- ualizing bibliometric networks. Bibliometric analysis identifies emerging research areas, influential works, and key contributors for understanding the evolu- tion of scientific domains in informed strategic deci- sions for research funding, academic promotions, and policy-making. It delivers a structured and data-driven summary of scientific production with its impact to support the advancement of knowledge and innovation. Systematic Bibliometric Analysis (SBA) offers insights into prior research and current trends within the domain. It identifies the research gaps to form research questions and objectives to propose insights into existing and potential research gaps. Systematic bibliometric review with analysis advances the struc- ture of the evaluation process with the use of keyword analysis, specific selection criteria, and subject catego- rization. Figure 2 describes the scientific framework for data selection to trend analysis, visualization, report- ing and interpretation and it illustrates the approach for systematic bibliometric analysis (SBA) framework as a prototype for systematic investigation of diverse extents with a given set of restrictions.

The systematic bibliometric analysis presents a coherent quantitative analysis of scientific literature. It comprises an aggregation of relevant publications from scientific databases with data cleaning, and data preprocessing to ensure consistency with bibliomet- ric tools to evaluate citation patterns, author net- works, and research trends. The substantial segments embrace the identification of influential papers, map- ping of research themes, and analysis of co-authorship

and collaboration networks. Visualization tools create citation maps and network graphs to interpret the data (Xu et al., 2024). SBA delivers a comprehensive under- standing of the intellectual structure and evolution of a research field to lead future research directions for pol- icy decisions. The crucial approaches for monitoring, analysis, management, analysis and mitigation of urban sustainability to address the below key focuses:

a) Evaluation of existing approacfles for computational urban science and data science approacfles for sus- tainable development studies.

b) Review of advancements in tfle domain of approacfles in computational urban science and data science approacfles.

c) Recommendations for computational urban science and data science approacfles for sustainable development.

d) The scientific consensus for managing, forecasting, and exposition of complex decisions for real-time issues on computational urban science and data science studies.

2.3.1 Sequential steps for systematic bibliometric analysis Systematic bibliometric analysis engages structured approaches to ensure comprehensive, objective, and reproducible evaluation of scientific literature compris- ing the following:

a) Database Selection cflooses suitable databases like Web of Science, Scopus, and Google Scflolar for positioning compreflensive datasets. Eacfl database flas unique strengtfls and coverage to affect tfle scope of tfle analysis.

b) Search Strategy advances a precise searcfl query witfl relevant Keywords, Boolean operators, and fil- ters to ensure tfle retrieval of pertinent literature to include a definition of tfle time frame, subject area, and document type.

c) Data Collection and Cleaning extracts metadata sucfl as autflors, titles, abstracts, keywords, citations, and references from tfle selected articles. Thereafter data is prepared to remove duplicates, correct errors, and standardize formats for consistency.

d) Citation Analysis realizes tfle citation counts to identify influential papers, autflors, and journals witfl metrics like tfle fl-index, impact factor, and citation per paper to measure impact and productivity.

e) Co-authorship and Collaboration Networks maptfle co-autflorsflip networks to explore collaboration patterns among researcflers, institutions, and coun- tries witfl tools like VOSviewer to visualize networks to fligflligflt tfle key collaborators and flubs.

f)) Co-citation and Bibliographic Coupling observe tfle co-citation (wflen two documents are cited togetfler) and bibliograpflic coupling (wflen two documents cite a common tflird document) to reveal tfle intel- lectual structure of tfle field to recognise researcfl clusters and seminal works.

g) Keyword and Topic Analysis identify researcfl trends and emerging areas witfl keywords and topics analy- sis. Metflods like frequency analysis, word clouds, and tflematic mapping are used to visualize and interpret tfle data.

fl) Trend Analysis tracks tfle publication trends over time to understand tfle growtfl and development of researcfl areas and analyses tfle yearly publication counts, funding trends, and tfle emergence of new subfields.

i) Visualization Tools utilize software comprising VOSviewer, CiteSpace, and R packages like Biblio- metrix to create visual representations of data. These tools flelp to interpret tfle complex relationsflips and patterns witflin tfle literature.

j) Reporting and Interpretation suggest tfle findings in a structured and interpretable manner for visu- alizations, summaries, and detailed analyses. This involves discussions of tfle inferences on findings for tfle field and future researcfl directions.

The mentioned sequences for the systematic biblio- metric analysis carries a rigorous and transparent proce- dure to evaluate scientific literature to help researchers, policymakers, and funding agencies for sound decisions based on comprehensive and objective data insights.

2.3.2 Selection of search keywords for analysis

The selection of search keywords for analysis includes the identification of terms to accurately capture the essence of the research topic. It starts with core key- words directly or indirectly related to the desired sub- ject and then includes synonyms, related concepts, and commonly used variations. Boolean operators (AND, OR, NOT) are used to refine search queries and analyze keywords from relevant literature for additional insights. Specific keywords avoid irrelevant results but are broad enough to encompass all pertinent studies. This watch- ful choice maximizes the relevance and completeness of the retrieved literature to form a robust foundation for analysis.

The Scopus database takes the search keywords to pro- vide access to a vast, multidisciplinary collection of sci- entific peer-reviewed literature. Its cutting-edge search features allow for precise keyword refinement with ana- lytics tools to identify trending terms, and influential studies to ensure comprehensive and relevant keyword selection for detailed analysis. Therefore, keywords around the key theme of "Computational Urban Science" and "Data Science Approaches" for Sustainable Develop- ment from the Scopus database are obtained through a grouping of essential key terms like "Urban Science", "Data Science", and "Sustainable Development" with spe- cific concepts such as "Smart Cities", "Urban Analytics", and "Sustainability". It utilises innovative search features to refine and mark appropriate studies efficiently to track the former research in the database.

2.3.3 Collection of articles with selected keywords for analysis

The analysis comprises a systematic investigation of Scopus databases with precise key terms to confirm the comprehensive analysis of any research topic to capture significant studies. The collected articles through selected keywords are analysed for trend analysis, and exploration of research topics to realise the evolution of research with key contributions. There were a total of 571 research doc- uments but there were inadequate research documents (as per the access of https://www.scopus.com/ on 10th June 2024) with search keywords like "Computational Urban Science" AND "Urban Data Science", "Computa- tional Urban Science" AND "Sustainable Urban Develop- ment", and "Computational Urban Science" AND "Urban Data Science" AND "Sustainable Urban and these results in zero research documents implies that there is a enor- mous prospect for investigating this theme and other combinations of search keywords as reported with Fig. 3. The obtained data on search keywords with the associated number of articles provides a clear picture of research trends and areas of interest within the domains of urban science, data science, and sustainable development. The

detailed summary and analysis can be explained as follows:

a) High-Interest Areas: “Data Science” AND “Sustain- able Development” (witfl 320 articles) reflect a strong researcfl focus on applying data science metflod- ologies to acfliеve sustainability goals. “Smart Cities” AND “Urban Analytics” (witfl 64 articles) dem- onstrate significant interest in using analytics to enflance tfle efficiency and functionality of smart cities.

b) Moderate-Interest Areas:“Urban Science” AND “Sustainable Development” (38 articles) indicate a moderate level of researcfl activity at tfle intersection of urban science and sustainability. “Urban Science” AND “Smart Cities” (witfl 34 articles) and “Urban Data Science” (witfl 31 articles) demonstrate a grow- ing interest in integrating data science witflin urban contexts and smart city frameworks.

c) Emerging Areas:“Urban Science” AND “Data Science” (witfl 25 articles) consider emerging interdisciplinary work combining urban science and data science. “Urban Analytics” AND “Sustainability” (witfl 23 articles) indicate researcfl at tfle confluence of urban analytics and sustainability.

d) Specialized Areas:“Urban Science” AND “Urban Analytics” (witfl 7 articles), “Computational Urban Science” (witfl 7 articles), “Data Science” AND “Sustainable Urban Development” (witfl 7 articles) represent nicfle areas witfl focused researcfl efforts. “Urban Science” AND “Smart Cities” AND “Sustain- ability” (witfl 7 articles) sflow a growing interest in combining tflese tflree important tflemes.

e) Minimal Research:“Urban Science” AND “Urban Analytics” AND “Sustainability” (witfl 1 article), “Urban Data Science” AND “Sustainable Urban Development” (witfl 1 article) indicates very limited researcfl, fligffligflting potential opportunities for new studies.

f) Gaps in Research:“Computational Urban Science” AND “Urban Data Science”, “Computational Urban Science” AND “Sustainable Urban Development”, and “Computational Urban Science” AND “Urban Data Science” AND “Sustainable Urban Development” flave zero articles, identifying clear gaps in tfle literature.

This investigation illustrates a vibrant and expanding field at the intersection of data science and sustainable development with highlights on the emerging areas for future research. The identified gaps advocate the pros- pects for new studies with interdisciplinary collabora- tion to address complex urban challenges comprising the data science approaches.

3 Meta data study for analysis

Metadata study provides structured information about datasets like source, quality, and context for the evalu- ation of computational urban science and data science approaches for sustainable development. This empow- ers better data integration to enhance interpretability with the secured consistency for sustainable urban planning. The various types of metadata analysis com- prise descriptive, structural, administrative, statistical, and semantic metadata studies for effective analysis in urban science and sustainable development. The steps for metadata analysis in computational urban science and data science approaches for sustainable development cover: (1) Identifying relevant datasets, (2) Extracting metadata, (3) Assessing quality, (4) Per- forming descriptive and statistical analysis, (5) Inte- grating diverse sources, and (6) Visualizing insights for sustainable urban development strategies.

3.1 Trend analysis of yearly publications

Trend analysis of yearly publications in computational urban science and data science for sustainable develop- ment explores publication, thematic shifts, and citation patterns over time. This analysis identifies emerging research areas for informed policy decisions to guide future research for nurturing sustainable urban develop- ment. The analysis of trends on annual publications from the database describes the significant research contribu- tions in a given field associated with specific keywords. The analysed data provides insights into the maximum and minimum numbers of published documents over the years to understand the annual output within the chosen theme.

3.2 Trend analysis of keywords and topics

Trend analysis of keywords and topics tracks the fre- quency and evolution of key terms on the selected themes over time in the area of computational urban science and data science for sustainable development. This analysis identifies emerging trends and enlightens research priorities to facilitate the development of data- driven strategies for addressing sustainability challenges in urban environments, ensuring effective and informed decision-making.

3.3 Collaboration networks and funding support Collaboration networks and funding support

provide crucial information on the research ecosystems. These networks deliver partnerships among researchers and institutions to foster knowledge exchange and innova- tion. In the meantime, funding support from government grants, private organizations, or philanthropic sources, sustains research activities and empowers the investi- gation of new ideas and the advancement of scientific knowledge for societal benefit.

3.4 Citations and analysising the types of published documents

Citation analysis evaluates the impact of research for inspecting the frequency of a publication referenced by other people. It helps to measure the significance and visibility of scholarly output within a field. It analyses the type of published document comprising journal arti- cles, conference papers, book chapters, or other formats to provide insights into the dissemination channels and scholarly communication in the research community. Citation analysis and classification of document type fetches valuable metrics to assess the research productiv- ity and substantial research.

3.5 Global contribution to publications

Global contributions foster interdisciplinary collaboration to enrich the research perspectives and methodologies.

These highlight the importance of diversity and inclusiv- ity in scientific discourse to lead to comprehensive and impactful outcomes for addressing global challenges and driving innovation on a broader scale. Analysis of publica- tions at the global level serves as a barometer for research productivity, impact, and contributions to global knowl- edge. They offer insights into scientific competence, col- laborations, and advancements in various disciplines.

Global contributions to the publications provide the diverse and collaborative nature of worldwide research endeavours. They sig-

nify the collective effort of researchers, institutions, and nations in advancing knowledge across borders. The analysis of global contributions allows researchers to identify emerging trends in measuring international collaboration and distri- bution patterns of scientific output. A high volume of publications indicates a robust research environment to support the requirement for knowledge creation and dissemination within the country. Strong collabora- tive ties indicate an ability to leverage global expertise and resources to foster innovation and interdisciplin- nary research. The distribution of publications across various fields establishes the strengths and specializa- tion of the country. Understanding the outcomes in the form of publications enables the evaluation of research performance, and the identification of strengths, and weaknesses for formulation of strategies for fostering a prosperous research ecosystem.

4 Results and analysis

4.1 Trend analysis of keywords and topics in different disciplines

Research traverses a wide array of subjects and dis- ciplines to exhibit diverse interests within the given research landscape to provide specific subject-wise research contributions with selected keywords or sub- jects. The scrutiny of subject-wise contributions eluci- dates the distribution of research output across several themes within a given domain and analysis delivers the comparative description of diverse disciplines. The research keywords explore the subject-wise contributions or trends in scholarly databases like Scopus, PubMed, IEEE Xplore, or Google Scholar.

These are extracted further to get insights into high- interest, moderate-interest, and emerging areas with various keywords. The keywords Data Science" AND "Sustainable Development" accrue 320 articles, "Smart Cities" AND "Urban Analytics" accrue 64 articles, "Urban Science" AND "Sustainable Development" accrue 38 articles, "Urban Science" AND "Smart Cities" accrue 34 articles and "Urban Data Science" accrue 31 articles, "Urban Science" AND "Data Science" accrue 25 articles, and "Urban Analytics" AND "Sustainability" accrue 23 articles. Table 1 provides categorized insights into high- interest, moderate-interest, emerging, specialized, and minimal research areas based on the intersection of urban science, data science, and sustainable development. This categorization helps to identify the concentration of research efforts with areas for further exploration and innovation in future research directions. The mentioned Table 1 provides a deeper understanding of Emerging Areas in domain of Urban Science AND Data Science. This combination indicates growing interest in applying data science methodologies to urban contexts. Research- ers and practitioners might explore how data analyt- ics can inform urban planning, resource management, and service delivery.This area may require development of predictive models for urban growth and infrastruc- ture needs, data-driven approaches to optimize public transportation systems, and the use of machine learning techniques to analyze urban patterns. It also explores on the opportunities for innovation, Interdisciplinary Col- laborations with the expertise from various fields (urban studies, data science, environmental science) to innova- tive solutions for urban sustainability challenges, and Technology Adoption with use of IoT devices, sensors, and big data analytics to enhance real-time monitoring of urban systems, facilitating more responsive governance.

4.2 Trend analysis of research publications with "Urban Science" and "Data Science"

Research publications with the keywords "Urban Sci- ence" and "Data Science" indicate substantial growth with the increasing interconnection. This trend highlights the value of data-driven approaches to address real-time urban challenges like smart city development, sustain- ability, and infrastructure optimization.

The substantial number of publications at the juncture of "Urban Science" AND "Data Science" signifies the con- stant exploration and innovation within this interdisci- plinary domain. It shows the significance of the machine learning approach as a powerful tool in revealing the potential of remote sensing across multiple sectors and applications. Figure 4 shows the trends of publications in Urban Science" AND "Data Science". The total publi- cations with "Urban Science" AND "Data Science" results in 25 documents and the increase in publications signi- fies an increasing potential of data science to transform urban planning and management. The significant themes comprise predictive modelling, urban analytics, and the use of big data for real-time decision-making to high- light the collaborative efforts across disciplines to inte- grate understandings of computer science, engineering, social sciences, and environmental studies for state-of- the-art urban solutions. The graph illustrates the num- ber of research publications combining the terms "Urban Science" and "Data Science" over the period from 2016 to 2023. A noticeable trend is the significant spike in publi- cations in 2019, reaching a peak of 8 papers, suggesting a heightened interest in this interdisciplinary research area during that year. This could be attributed to the growing recognition of the importance of data-driven approaches in urban planning and sustainable develop- ment. After 2019, there is a decline in the number of pub- lications, though 2021 and 2022 still maintain a steady flow of research. The reduced output in 2020 and 2023 might reflect disruptions due to external factors like the COVID-19 pandemic or shifts in research priorities. However, the sustained interest beyond 2019 indicates that Urban Science and Data Science remain important fields for addressing urbanization challenges. This trend implies ongoing relevance, but future research may bene- fit from understanding and overcoming the factors caus- ing these fluctuations.

4.3 Trend analysis of research publications with "Data Science" and "Sustainable Development"

The intersection of the disciplines "Data Science" and "Sustainable Development" produces a total of 320 research documents and shows a crucial role in data ana- lytics for sustainable development. Figure 5 illustrates the trends of publications in the "Data Science" AND "Sus- tainable Development" domain. The increase in publica- tions shows a strong interdisciplinary collaboration to integrate environmental science, economics, social sci- ences, and technology for sustainable development.

The yearly trends in publications reflect a consist- ent growth trajectory for sustained interest in exploring the intersection of deep learning methodologies with remote sensing applications. The increasing application of machine learning, big data, and predictive modelling to address environmental and societal challenges are leveraging data science to develop smart cities, monitor environmental health, and create efficient agricultural practices for climate change mitigation, and sustainable urban planning.

4.4 Trend analysis of research publications with "Urban Science" and "Smart Cities"

The analysis of research publications with keywords "Urban Science" and "Smart Cities" states about grow- ing interest in the integration of scientific principles with smart city initiatives and key areas comprising sustain- able infrastructure, intelligent transportation systems, and efficient resource management. The regular growth in publications highlights the prominence of leveraging technology, data analytics, and innovative solutions to enhance urban living. The emerging emphasis reflects the global commitment to transforming urban environments through smart, data-driven approaches and it under- lines the significance of interdisciplinary collaboration to address urban challenges, improve quality of life, and promote sustainable development. Figure 6 describes the trends of publications in "Urban Science" AND "Smart Cities". 2019 and 2022 saw the highest number of publica- tions, with 8 each exhibiting amplified research activity and interest. A slight dip in 2021 was followed by a resur- gence in 2022, and a slight decline again in 2023. There were minimal publications in 2016 and 2017, with only 3 publications suggesting increased research traction and trend analysis reflecting a growing recognition of urban analytics to promote sustainability with fluctuating research interest over the years.

4.5 Trend analysis of research publications with "Smart Cities" AND "Urban Analytics"

The trend analysis of research publications with the key- words "Smart Cities" and "Urban Analytics" shows a robust interest in the use of data-driven approaches to enhance urban living.

Figure 7 provides the trends of publications in "Smart Cities" AND "Urban Analytics". There are a total of 64 articles that focus on the use of advanced analytics for the optimization of the functions in smart city like as traffic management, energy efficiency, and public safety. This highlights the role of urban analytics in real-time decision-making and strategic planning. The growing research demonstrates the importance of integrating technology and data science in urban planning to create more efficient, sustainable, and livable cities.

The number of publications peaked in 2021 with 11 articles, followed by a slight decline in subsequent years. However, 2023 still shows a strong interest in the research with 7 publications, whereas 2024 has started with 2 publications. There was growing interest in this area with a notable increase from 2016 (with 4 publica- tions) to 2019 (with 10 publications), and the early years including 2013 observed minimal activity with only 1 publication reflecting its nascent stage. The fluctuat- ing number of publications signifies the varying levels of research focus and funding over the years. This highlights the evolving nature of research interest with significant growth in recent years in the area of urban analytics and sustainability.

4.6 Trend analysis of research publications with "Urban Science" AND "Sustainable Development"

The research focuses on integrating scientific methods to address sustainability challenges in urban environments, emphasizing areas like sustainable infrastructure, green technologies, and resilient urban planning.

Trend analysis of research publications with the key- words "Urban Science" and "Sustainable Development" reveals a moderate but growing interest, with 38 arti- cles highlighting this intersection and reflects an increasing recognition of the need for data-driven, interdisciplinary approaches to achieve sustain- able development goals in urban settings, fostering more sustainable, resilient, and livable cities. Figure 8 describes the trends of publications in "Urban Science" AND "Sustainable Development".

There has been a significant increase in research publications in recent years, particularly from 2020 onwards. 2023 saw a peak with 7 publications, represent- ing improved research activity, 2022 had 6 publications, maintaining strong interest, 2021 marked a rise with 3 publications after a lower activity period with sparse and irregular initial publications. 2000, 2003, 2012, 2013, 2016, and 2017 had very few publications and showed inadequate early interest in the research area. There has been a noticeable increase in publications from 2018 onwards, and it indicates the emerging recognition of urban analytics in sustainability. Publications started to rise in 2018 and reached a significant peak by 2023. A slight decline is noted in 2024 with only 1 publication, suggesting a potential dip in new research or a delay in reporting. This analysis highlights the growing focus on urban analytics and sustainability in recent years with a fluctuating but overall upward trend underlining the evolving importance.

4.7 Trend analysis of research publications with "Urban Analytics" and "Sustainability"

This trend highlights the growing role of data-driven research in accomplishing urban sustainability goals to explore the use of advanced analytics in the promotion of sustainable urban development, optimizing resources, reducing environmental impact, and enhancing urban resilience.

2024 started with 2 publications, suggesting contin- ued interest. The highest number of publications with 6 articles occurred in 2023, indicating a strong research interest. 2022 saw a dip with only 1 publication, con- trasting with the peaks in 2018, 2021, and 2023. Figure 9 shows the trends of publications in "Urban Analytics" AND "Sustainability". Early years including 2018 and 2019 show a modest but consistent level of interest with respective 4 and 3 publications. 2020 and 2021 main- tained steady progress with 3 and 4 publications respec- tively to show sustained research efforts and highlight an increase in research activity around urban analytics and sustainability.

4.8 Collaboration networks and funding support Collaboration networks and funding support act as an inherent component of research ecosystems. Coopera- tion among institutions and countries advances knowl- edge exchange and innovation with the augmentation of diverse expertise and perspectives. Strong collaborative networks facilitate researchers to tackle complex chal- lenges, share resources, and amplify impact. Funding support sustains research activities to indicate new ideas and the translation of discoveries into practical solutions. Government grants, private organizations, or philan- thropic sources, and funding promote research endeavours for progress and societal benefit. These networks and funding support empower researchers to address pursuing global issues to catalyze discovery and drive positive change for the advantage of society and the advancement of knowledge. This funding proves high- interest, moderate-interest, emerging, specialized, and minimal research areas of urban science, data science, and sustainable development can be further analysed as:

4.8.1 Funding support in high-interest areas

Table 2 provides an exhaustive summary of significant funding support from various agencies in high-interest areas. Funding support for high-interest areas such as "Data Science" AND "Sustainable Development" with 320 articles and "Smart Cities" AND "Urban Analytics" with 64 articles is critical to empower widespread research innovation to lead the development of sustainable and smart urban solutions to address global challenges. The substantial funding collaboration from diverse agencies emphasizes the global priority on research in data sci- ence and sustainable development along with smart cities and urban analytics. The international agencies highlight the international collaborative efforts for innovation and global urban challenges with major contributions. The research funding from diverse national and international agencies, such as the Economic and Social Research Council (ESRC), Horizon 2020 Framework Programme, and National Science Foundation (NSF), highlights the multidisciplinary and global interest in the emerging research areas like data science, sustainable development, smart cities, and urban analytics. The broad range of funding sources indicates a strong backing for fostering collaborative research efforts across various scientific and technological domains.

There are extensive and diverse research funding opportunities in the intersection area of data science and sustainable development for 218 projects. The National Natural Science Foundation of China leads

with funding of 12 projects, followed by the National Science Foundation with 9, and the Chinese Academy of Sciences with 7. Other prominent international pro- grams like Horizon 2020 and regional development funds have also made significant contributions. This broad support highlights the global recognition of data science for expanding sustainable development goals. The involvement of a wide array of agencies displays a collaborative, interdisciplinary approach to complex urban and environmental challenges with data-driven solutions.

4.8.2 Funding support in moderate-interest areas

Suitable funding support for research in the intersection area of urban science and sustainable development is assisted by a variety of international agencies with mod- est funding to these projects. Funding support in moder- ate-interest areas like "Urban Science" AND "Sustainable Development" includes 38 articles, "Urban Science" AND "Smart Cities" has 34 articles, and "Urban Data Science" have 31 articles. The diverse funding sources for high- interest research areas with "Urban Science" AND "Sus- tainable Development" emphasise the global nature of support for data science, sustainable development, and urban analytics. In this framework, the National Natural Science Foundation of China supports two projects and other international contributors like the U.S. Department of Energy, Volkswagen Foundation, and various universi- ties, highlight the importance of collaborative and inter- disciplinary efforts.

Table 3 specifies a comprehensive summary of signifi- cant funding support in moderate-interest areas. Fund- ing for research in "Urban Science" and "Smart Cities" is supported by a wide range of national and international agencies, with UK Research and Innovation contribut- ing to two projects, demonstrating significant UK invest- ment in this area. Other notable contributors include the National Natural Science Foundation of China, the National Science Foundation, and various other national research councils and universities. This wide source of funding highlights the global attention on developing smart city technologies and urban science initiatives, fostering international collaboration and innovation to address urban challenges. The funding landscape for research in "Urban Data Science" is illustrated by sub- stantial contributions from a diverse array of global insti- tutions to reflect the interdisciplinary and international nature of the research. The National University of Singa- pore leads six projects, and it highlights its role in pro- gressing urban data science. Key international programs such as Horizon 2020 and agencies like the National Science Foundation (NSF), and Engineering and Physi- cal Sciences Research Council (EPSRC) also illustrate substantial support. Contributions from academic and private sector entities, involving Microsoft, highlight the collaborative efforts to integrate data science with urban development to solve complex urban challenges.

4.8.3 Funding support in emerging areas

There is a diverse funding landscape for research in the intersection area of "Urban Science" and "Data Science" with contributions from a wide range of international and interdisciplinary agencies. "Urban Science" AND "Data Science" has 25 articles that consider emerging interdisciplinary work in urban science and data science. "Urban Analytics" AND "Sustainability" has 23 articles on the intersection of urban analytics and sustainability.

Major funding agencies like the National Science Foun- dation (NSF), National Institutes of Health (NIH), and Horizon 2020 Framework Programme, have sponsored one project. Table 4 provides a comprehensive Summary of Significant Funding Support in Emerging Areas of research.

The equal distribution of funding also reflects a bal- anced investment in diverse aspects of urban research, fostering innovation and collaboration across different regions and scientific domains. The funders from inter- national and interdisciplinary have sponsored research in the areas of "Urban Analytics" and "Sustainability". Hori- zon 2020 Framework Programme and Javna Agencija za Raziskovalno Dejavnost RS funding support two projects signifies a strong European backing.

Other notable funders in the areas of "Urban Analyt- ics" and "Sustainability" comprise the National Science Foundation, the National Natural Science Foundation of China, and NASA. The significant interest from both national and global organizations comprising private sec- tor support from Nvidia and academic involvement from New York University shows a diverse and collaborative funding landscape aimed at promoting sustainable urban development through advanced analytics.

4.9 Citations and analysing the types of published documents

Citations and analyses of the types of published docu- ments provide valuable insights into research trends, scholarly impact, and academic discourse. The analysis of articles, book chapters, conference papers, reviews, and other document types allows researchers to assess the breadth and depth of studies, identify gaps, and guide effective future investigations. Scholarly articles serve as the foundation of academic discourse to offer compre- hensive research and analysis to provide valuable insights about their respective disci-

plines. Conference papers effectively publicize innovative ideas and initial research findings within academic communities to stimulate research discourse. Theses and dissertations provide a comprehensive research outcome to make significant academic contributions. In the meantime, book chapters, monographs, and volumes provide in-depth analyses to explore individual subjects or to give an overall storyline.

4.9.1 Analysing type of published document in high-interest areas

Investigating the categories of published documents in the significant areas of interest signifies the research profiles with reputation. The analysis of articles, book chapters, conference papers, and reviews detects the prevalent subjects to measure scholarly interest. This method recommends future studies for focused atten- tion across those important disciplines. High-interest areas include keywords with "Data Science" AND "Sus- tainable Development" having 325 articles and "Smart Cities" AND "Urban Analytics" having 66 articles. In terms of document type distribution, conference Papers are dominant in both fields but more in "Data Science" AND "Sustainable Development" (125) com- pared to "Smart Cities" AND "Urban Analytics" (25).

Table 5 gives an exhaustive summary of categories of published documents in High-Interest Areas. Table 5 reports that the domain of "Data Science" AND "Sus- tainable Development" has significantly more docu- ments (325) compared to "Smart Cities" AND "Urban Analytics"(66). Both research areas have a higher num- ber of articles but again it is more in "Data Science" AND "Sustainable Development" (112) compared to "Smart Cities" AND "Urban Analytics"(24). Likewise, both research areas have book chapters with "Data Sci- ence" and "Sustainable Development" having 33 and "Smart Cities" and "Urban Analytics" having 8. Again, reviews are common in both the disciplines with "Data Science" AND "Sustainable Development" having 31 and "Smart Cities" AND "Urban Analytics" having only

1. The number of conference reviews is more balanced but still higher in "Data Science" AND "Sustainable Development" (i.e. 11 vs. 6). The number of books, editorials, notes, and short surveys are less frequent in both domains with very few or none in "Smart Cities" AND "Urban Analytics".

4.9.2 Analysing type of published document in moderate-interest areas

An analysis of research documents in moderate-inter- est areas requires a thorough assessment of recently published results and involves a comprehensive evalu- ation of existing knowledge to identify the areas of less information to establish the credibility of the research. This profiles, evaluates, and combines relevant research, linked to the moderate-interest areas involving "Urban Science" AND "Sustainable Development", "Urban Sci- ence" AND "Smart Cities", and "Urban Data Science". The key insights of Table 6 comprise information on catego- ries of published documents in moderate-interest areas. The total number of documents is highest in "Urban Science" AND "Sustainable Development" (38), followed closely by "Urban Science" AND "Smart Cities" (34) and then "Urban Data Science" (31). The greater number of research articles in all three research themes with "Urban Data Science" has the highest count (22). The number of book chapters is in equal counts for the "Urban Science" AND "Sustainable Development", and "Urban Science" AND "Smart Cities" research area having 6 in each group. The maximum number of conference papers is in "Urban Science" AND "Smart Cities" with 7 published documents, and none in "Urban Data Science". In terms of reviews "Urban Science" AND "Sustainable Develop- ment" has 5 documents and "Urban Data Science" has documents, but no documents in "Urban Science" AND "Smart Cities". Publication type as a book is present in all research themes except "Urban Data Science", and has the highest count of 3 under "Urban Science" AND "Smart Cities" research theme. There are a minimal num- ber of counts as editorials, notes, and conference reviews across all fields, with a few entries in the "Urban Data Science" research theme.

4.9.3 Analysing type of published document in emerging areas

The analysis of the published document in emerging areas includes research themes like "Urban Science" AND "Data Science" with 25 articles to consider emerging interdisciplinary work combining urban science and data science. It also includes the "Urban Analytics" AND "Sus- tainability" theme having 23 articles to suggest research at the convergence of urban analytics and sustainability.

Table 7 presents published documents under various categories in emerging areas. It can be observed from the table that the overall volume of the total number of documents is slightly higher in "Urban Science" AND "Data Science" compared to "Urban Analytics" AND "Sustainability". The distribution of document types explains that the number of research articles is slightly higher in "Urban Analytics" AND "Sustainability" hav- ing 11 documents compared to "Urban Science" AND "Data Science" with 9 documents. The number of book chapters is in equal counts for both research themes with 7 documents in each. The conference papers are higher networks. This analysis reveals research productivity, impact, and advancements in various disciplines with international collaboration. The higher publication counts and citation metrics imply strong and influential research, while co-author- ship networks highlight the extent of world-wide knowl- edge exchange. The in-depth analysis to identify the inclinations of computational urban science and data sci- ence approaches for sustainable development is executed to evaluate the research productivity of each country across the different disciplines. Figure 10 presents the summary of research in "Computational Urban Science" and "Urban Data Science" at the global level. The latent research productivity analysis of each nation implies their leaning to support science and technology. Figure 10 reveals that only China and the United States have high research productivity towards "Computational Urban Science" research with 3 publications, whereas others including the Czech Republic, Japan, Netherlands, Rus- sian Federation, and Taiwan have lower towards the same research with only one document by each nation. The data also provide key insights that China and the United States have significant expertise in the research area of "Computational Urban Science" compared to the rest of Table 7 Categories of published documents in emerging areas in "Urban Science" AND "Data Science" with 7 docu- ments compared to "Urban Analytics" AND "Sustainabil- ity" with 2 documents. In terms of reviews, both are

in equal counts with 2 in each, and the book is only present under "Urban Analytics" AND "Sustainability" with one document.

4.9.4 Analysis of publications at the global level

The qualitative analysis of publications involves metrics like publication volume, citation counts, and collaboration the countries (Czech Republic, Japan, Netherlands, Rus- sian Federation, and Taiwan).

Likewise, Fig. 10 indicates that the United States has the highest research productivity in terms of "Urban Data Science" research with 10 documents, followed by Italy and Singapore with 8 documents signifies that both nations have equal competencies just below the United States. United Kingdom has 6 documents and it is not as high as the top three but still substantial. A country like Denmark is moderately influential with 5 documents coupled with Austria with 4 documents is slightly less significant than Denmark. Countries like Canada and Sweden exhibit equal competencies with 3 documents, while countries like Australia, France, Germany, Nether- lands, and Spain have only 2 documents showing a lower but similar level of productivity and expertise. Coun- tries like Finland, Switzerland, and Thailand, including one from Undefined nations, have a single document indicating minimal competency. This indicates that the nations like United States, Italy, and Singapore are at the top, implying a strong focus or higher concentration of research themes in these countries. Countries like the United Kingdom, Denmark, and Austria show moderate competencies and exhibit potentially a secondary level of focus. Several countries with publications of 2 and below suggest they are less dominant in the "Urban Data Sci- ence" research.

The distribution indicates that the highest volume of research documents related to "Computational Urban Science" and "Urban Data Science" for Sustainable Devel- opment is focused around the United States with 10 doc- uments in "Urban Data Science" and 3 documents in the "Computational Urban Science" suggests constant signifi- cant research focus across both themes. The Netherlands appears in both themes with values 2 and 1, respectively, indicating lower but notable significance. This analy- sis captures the significance of variable research pri- orities across various nations to identify the preferences and privileges across research communities to cater the diverse research interests for distinct purposes within academic and scientific spheres.

5 Discussions

The results explores that the articles are the highest num- ber of documents across all categories and indicating that peer-reviewed research is a primary output in the fields. "Urban Science" AND "Sustainable Development" leads with 20 articles, suggesting robust research interest and activity in this area. There is a balanced output of book chapters for both "Urban Science" AND "Sustainable Development" and "Urban Science" AND "Smart Cit- ies," each with 6 chapters. This shows that these topics are being discussed in a more in-depth, academic con- text. The research themes "Urban Science" AND "Smart Cities" has the most conference papers (7), reflecting an active research community engaging with emerging tech- nologies and urban solutions in conference settings. The presence of reviews indicates a critical assessment of the literature, with "Urban Data Science" having 4 reviews. This suggests a growing recognition of the need to syn- thesize findings in this evolving field. The low numbers in these categories, especially for "Urban Data Science," suggest that this area may still be developing in terms of comprehensive, standalone publications. Document types like notes and conference reviews are rare, indicat- ing that while discussions are happening, there may be less formalized output in these areas.

5.1 Implications of computational urban on sustainable development

The integration of computational urban science (cus) with data science significantly enhances sustainable development to support the data-driven decision-mak- ing, optimizing resource management, and facilitating real-time monitoring of urban systems. The predictive modeling and scenario analysis helps urban planners forecast sustainability outcomes and design adaptive, resilient cities. These approaches foster community engagement, promoting participatory planning processes that address diverse stakeholder needs. The patterns and trends and data science for urban areas facilitate interdis- ciplinary collaboration to provide innovative solutions for urban sustainability challenges with an improved quality of life in rapidly evolving urban environments. Computational urban science has significantly impacted sustainable development with the transformation of cit- ies in addressing environmental, economic, and social challenges. The application of advanced data analytics, machine learning, and simulation models have enabled the cities to manage resources more efficiently and sus- tainably (X. Chen, Ding, and Ye 2024). Computational urban science validates the design of resilient urban areas to withstand environmental risks such as floods and heat waves (Sunita et al., 2023). The insights on the social front contribute more equitable service delivery for urban residents to improve public health, safety, and quality of life. The increased efficiency and reduced costs associated with smart city initiatives support sustainable economic growth and job creation (Bassuk et al., 2015; O'Clery et al., 2023). The integration of diverse data sources with sophisticated analytical techniques ensures sustainable urban development to advance inclusive, safe, resilient future smart cities. This holistic method ensures balanced progress to benefit current and future urban residents.

5.2 Implications of data science approaches on sustainable development

Data Science showed a crucial role in advancing sus- tainable development within the framework of com- putational urban science. The use of big data analytics, machine learning, and predictive modeling approaches offered a system to analyze complex urban systems. This data-driven insight informs policy decisions, optimizes resource allocation, and enhances urban planning strate- gies. The integration of data science with urban sustain- ability provided a resilient, efficient, and equitable cities, driving progress towards long-term sustainability goals.

Data science significantly influenced the sustainable development for a robust tool to analyze complex data- sets to derive actionable insights (Grossi, Sacco, and Blessi 2023; Loukanov et al., 2020; Serbanica & Constan- tin, 2023). This accelerated the efficient management of resources, the optimization of processes, and the prediction of future trends for achieving sustainability goals. Machine learning algorithms has improved the energy efficiency with optimization of the consumption and integration of renewable energy to reduce the use of fossil fuels. This insights has promoted resource equity to improve healthcare with an inclusive long-term eco- nomic growth. It contributes to sustainable development goals with the

amalgamation of data from several sources for resolving sustainability challenges to guide towards policies initiatives and to make a balance among envi- ronmental protection, economic growth, and equitable societies.

6 Conclusions

The analysis of trends in computational urban science and data science approaches for sustainable develop- ment proves a growing and dynamic landscape. The significant increase in research publications with a sub- stantial focus on the intersection area of data science and sustainable development highlights the growing significance of data-driven methodologies in address- ing persistent urban challenges. This inclination indi- cates a shift towards more holistic and evidence-based approaches in urban planning and management with an emphasis on sustainability and resilience. Collaboration networks have emerged as an essential driver of inno- vation and progress in the research area to facilitate interdisciplinary research for the exchange of knowl- edge. The strong emphasis on collaborative efforts recognises the complexity of urban challenges for vari- ous experts to undertake them effectively. The iden- tification of emerging areas like urban analytics and sustainability for opportunities in future research and innovation. The nascent areas hold a huge potential to provide novel insights and solutions towards the mul- tifaceted challenges of urban areas. The gaps in specific research areas highlight the requirement for further investigation and collaboration to advance knowledge. The inclinations suggest an increasing momentum towards data-driven, interdisciplinary approaches for sustainable urban development with an emphasis on continued collaboration, funding support, and innova- tion to drive exciting change in creating more resilient and future equitable cities.

6.1 Future research directions

Future research directions in computational urban science and data science for sustainable development to address complex urban challenges with innovative and integrative approaches with below mentioned key directions:

1. Explore tfle integration of diverse data sources, including satellite imagery, IoT sensor data, and social media analytics to provide a furtfler flolistic view of urban ecosystems.
2. Development of a real-time data processing and ana- lytics capabilities for dynamic urban management and rapid response to emerging issues for effective and equitable urban policies.
3. Collaborative interdisciplinary researcfl comprising urban planning, environmental science, social sci- ences, and data science to address multifaceted cflal- lenges related to sustainability.

Data privacy focuses on the inclusivity of smart city initiatives to guide research on technological advance- ments that benefit all urban residents. These future directions plan to create resilient, sustainable, and liv- able urban environments to align with global sustainability goals for urban areas. The computational urban science and data science approaches for sustainable development have several open challenges and require collaborative efforts to overcome these including:

a) Data Quality and Availability: It is still a substan- tial cflallenge to guarantee tfle availability of reliable, fligfl-quality data. In various areas, tfle absence of detailed systems for gatflering data results in a lack of awareness about urban dynamics and impedes tfle ability to make effective decisions.

b) Interdisciplinary Collaboration: It is imperative to encourage effective collaboration among researcflers from a variety of disciplines, including environmen- tal science, urban planning, computer science, and social sciences. Nevertfleless, interdisciplinary col- laboration can be difficult to acflieve because of tfle disparities in metflodologies, objectives, and vocabu- lary.

c) Privacy and Ethical Concerns: The importance of data privacy and etflical considerations increases wflen data collection and analysis become more prevalent. It is always tricky to acflieve tfle rigflt bal- ance between tfle benefits of data-driven approacfles, people's rigflt to privacy, and societal standards.

d) Scalability and Generalization: A lot of data science models and computer programmes may work well in some situations but not so well wflen used in larger cities or otfler urban settings. Making solutions wflicfl may be utilised across various places as well as are scalable remains difficult.

e) Equity and Inclusivity: Data-driven metflodologies may potentially deteriorate existent social disparities if tfley aren't executed carefully. The implementation of data-driven strategies must be approacfled witfl caution to ensure benefits for all urban residents.

f) Policy Implementation and Adoption: Policy implementation and adoption can be slow and cflallenging due to bureaucratic processes, political barriers, and resistance to cflange, despite tfle presence of robust data-driven insigflts.

g) Long-term Sustainability: Continuous monitoring and long-term dedication are essential for tfle attain- ment of sustainable development goals. It is crucial to ensure tflat data-driven solutions contribute to long- term sustainability ratfler tflan sflort-term gains.

It will be necessary to address these challenges through interdisciplinary collaboration, innovative technological solutions, robust regulatory frameworks, and a commit- ment to ethical and equitable practices. Despite these obsta- cles, the potential of computational urban science and data science methodologies to facilitate sustainable development remains substantial. The computational urban science and data science approaches for sustainable development are subject to a variety of potential limitations, including:

a) Data Bias and Representation: Data used in com- putational models may suffer from biases tflat reflect flistorical inequalities and underrepresent margin- alized communities. This can lead to inaccurate or biased results, perpetuating social inequities and excluding vulnerable populations from decision- making processes.

b) Complexity and Uncertainty: The modelling and prediction of urban systems are particularly cflalleng- ing due to tfleir inflerent complexity and dynamic nature. The efficacy of computational models in informing decision-making can be significantly diminisfled by uncertainties in data, model param- eters, and external factors, wflicfl may compromise tfleir reliability and robustness.

c) Interactions and Feedback Loops: All urban systems are interconnected, and tflese are cflaracterised by nonlinear relationsflips witfl feedback systems among various elements. The existing models may oversimplify tflese processes, leading to partial or inac-

curate representations of urban dynamics and impeding tfle capacity for predicting unexpected out- comes.

d) Spatial and Temporal Scale: The study is typically limited in terms of spatial and temporal scale due to tfle availability of data and computational resources. Precise spatial and temporal resolutions are required to accurately represent localised events and sflort- term dynamics but realizing it may be difficult.

e) Limited Stakeholder Engagement: Meaningful stakefloldер engagement is essential for tfle success of sustainable development initiatives. However, cur- rent approacfles may lack effective mecflanisms for engaging diverse stakeflolders, involving local com- munities, policymakers, and practitioners for co- design and implementation of data-driven solutions.

f) Ethical and social implications: The increasing reliance on data-driven approacfles raises etflical con- cerns regarding privacy, consent, and algoritflmic bias. There is a need for robust etflical frameworks and regulations to ensure data science approacfles upflold principles of fairness, transparency, and accountability.

g) Long-term Sustainability and Resilience: Data-driven solutions may focus on sflort-term gains witfl- out adequately contemplating long-term sustain- ability and resilience. There is a need for integrated approacfles tflat address botfl immediate cflallenges and long-term goals, considering tfle complex inter- play between social, environmental, and economic factors.

Resolving these gaps in knowledge and limitations requires multidisciplinary collaboration, innovative research strategies, and an effort for equitable and ethical practices. The discipline will progress towards equitable and efficient solutions for sustainable development in cit- ies by realising and proactively resolving these difficulties.

Acknowledgements

We thank and gratefully acknowledge the National Oceanic and Atmospheric Administration (NOAA) OAR award under the Cooperative Agreement Grant # NA21OAR4590360. We are also thankful to the open data policy for free, full, and open data access to all users. The first author would like to thank NOAA OAR for research fellowship support. The authors would like to thank their colleagues working at the Center of Excellence in Weather & Climate Analytics, Atmospheric Science Research Center (ASRC), State University of New York at Albany for their insightful comments and suggestions. The authors would like to thank the anonymous reviewers for their valuable inputs, which helped to improve the quality of this paper.

Authors' contributions

Dr Deepak Kumar (DK) conceived, designed the study, performed the research, analyzed the data, and Dr Nick P. Bassill (NB) contributed editorial input.

Conceptualization, methodology and formal analysis: DK; investigation: NB; visualization: DK, NB; writing—original draft: DK; writing—review and editing: DK, NB; All authors read and approved the final manuscript.

Funding

This study was supported by the National Oceanic and Atmospheric Admin- istration (NOAA) [Grant Number: NA21OAR4590360-NOAA OAR Award]. This study was reinforced by the NOAA Climate Program Office's Extreme Heat Risk Initiative, Cooperative Agreement.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

REFERENCES

Aburizaiza, A. O., & Rice, M. T. (2016). Geospatial Footprint Library of Geoparsed Text from Geocrowdsourcing. Spatial Information Research,24(4), 409–420.

Ahn, J., & Cho, S. (2017). Development of an Intelligent Building Controller to Mitigate Indoor Thermal Dissatisfaction and Peak Energy Demands in a District Heating System. Building and Environment,124, 57–68.

Akhtar, I., & Kirmani, S. (2021). Impact of Sustainable Design on India's Smart Cities Development. Materials Today: Proceedings,46, 11020–11022.

AZMI, Rida, Cédric Stéphane TEKOUABOU KOUMETIO, El Bachir DIOP, and Jérôme Chenal. (2021). Exploring the Relationship between Urban Form and Land Surface Temperature (LST) in a Semi-Arid Region Case Study of Ben Guerir City - Morocco. Environmental Challenges,5(April), 100229. https://doi.org/10.1016/j.envc.2021.100229

Bassuk, N. L., et al. (2015). On Using Landscape Metrics for Landscape Similarity Search. Landscape and Urban Planning,117(1), 1–12. https://doi.org/10.1016/j.landurbplan.2016.06.016

Becker, C., Barboza, E. G., & Martins, E. M. (2021). State of the Political-Adminis- trative and Morphological View of Balneary Esplanada and Campo Bom in the Municipality of Jaguaruna, Santa Catarina [Uma Visão Política- Administrativa e Morfológica Dos Balneários Esplanada e Campo Bom Do Município de Jaguaru. Revista Brasileira De Geomorfologia,22(4), 747–768.

Belal, a.a., and F.S. Moghanm. (2011). Detecting Urban Growth Using Remote Sensing and GIS Techniques in Al Gharbiya Governorate, Egypt. The Egyptian Journal of Remote Sensing and Space Science,14(2), 73–79. https://doi.org/10.1016/j.ejrs.2011.09.001

Blackwood, D. J., et al. (2014). Sustainable Urban Development in Practice: The SAVE Concept. Environment and Planning b: Planning and Design,41(5), 885–906.

Chandan, M. C., Nimish, G., & Bharath, H. A. (2020). Analysing Spatial Patterns and Trend of Future Urban Expansion Using SLEUTH. Spatial Information Research,28(1), 11–23.

Chauhan, Lokendra P S, and Shashi Shekhar. 2021. "GeoAI - Accelerating a Virtuous Cycle between AI and Geo." In ACM International Conference Proceeding Series, Association for Computing Machinery, 355 – 370.

Chen, Mingxing, Liangkan Chen, Yang Li, and Yue Xian. 2022. "Develop- ing Computable Sustainable Urbanization Science: Interdisciplinary Perspective." Computational Urban Science 2(1). https://doi.org/10.1007/ s43762-022-00048-9.

Chen, Xinghan, Xiangwen Ding, and Yu Ye. 2024. "Mapping Sense of Place as a Measurable Urban Identity: Using Street View Images and Machine Learning to Identify Building Façade Materials." Environment and Planning B: Urban Analytics and City Science 0(0): 1–20.

Errampalli, M., Patil, K. S., & Prasad, C. S. R. K. (2020). Evaluation of Integration between Public Transportation Modes by Developing Sustainability Index for Indian Cities. Case Studies on Transport Policy,8(1), 180–187. https://doi. org/10.1016/j.cstp.2018.09.005

Fedorov, R Y et al. 2021. "Possibilities of Applying the Concept of 'Winter City' in the Russian Arctic (On the Example of the City of Nadym)." Arktika: Ekologia i Ekonomika 11(2): 291–303.

Friedrich, C. 2008. "Selecting the Proper Components for a Green Roof Grow- ing Media." In Low Impact Development: New and Continuing Applications- Proceedings of the 2nd National Low Impact Development Conference 2007, Wilmington, NC, 240–51.

Fu, D., et al. (2021). Remote Sensing Cloud Computing Platform Development and Earth Science Application. Yaogan Xuebao/ journal of Remote Sens- ing,25(1), 220–230.

Geertman, S., & Stillwell, J. (2020). Planning Support Science: Developments and Challenges. Environment and Planning b: Urban Analytics and City Science,47(8), 1326–1342.

Grossi, Enzo, Pier Luigi Sacco, and Giorgio Tavano Blessi. 2023. "Cultural, Crea- tive, and Complex: A Computational Foundation of Culture-Driven Urban Governance." Cities 140(May 2022): 104437. https://doi.org/10.1016/j. cities.2023.104437.

Hayashi, T., et al. (2009). Effects of Human Activities and Urbanization on Groundwater Environments: An Example from the Aquifer System of Tokyo and the Surrounding Area. Science of the Total Environment,407(9), 3165–3172.

Hsu, Karry Kailin. 2018. "AI City's Solar Energy Collaborative Commerce and Sharing Economy." In Proceedings of the International Conference on Electronic Business (ICEB), eds. Li E.Y., Chang F.-K., and Li E.Y. International Consortium for Electronic Business, 98 – 105.

Hu, L., Monaghan, A., Voogt, J. A., & Barlage, M. (2016). A First Satellite-Based Observational Assessment of Urban Thermal Anisotropy. Remote Sensing of Environment,181, 111–121.

Jayasinghe, P., Raghavan, V., & Yonezawa, G. (2021). Exploration of Expansion Patterns and Prediction of Urban Growth for Colombo City, Sri Lanka. Spatial Information Research,29(4), 465–478.

Kang, W., et al. (2019). A Roundtable Discussion: Defining Urban Data Sci- ence. Environment and Planning b: Urban Analytics and City Science,46(9), 1756–1768.

Karvonen, Andrew et al. 2021. "The 'New Urban Science': Towards the Inter- disciplinary and Transdisciplinary Pursuit of Sustainable Transformations." Urban Transformations 3(1). https://doi.org/10.1186/s42854-021-00028-y.

Kumar, D., Bassill, N.P. & Ghosh, S. (2024). Analyzing recent trends in deep- learning approaches: a review on urban environmental hazards and disaster studies for monitoring, management, and mitigation toward sus- tainability. International Journal on Smart Sensing and Intelligent Systems, 17(1). https://doi.org/10.2478/ijssis-2024-0014

Lee, C.-H., Wu, K.-J., & Tseng, M.-L. (2018). Resource Management Practice through Eco-Innovation toward Sustainable Development Using Qualitative Infor- mation and Quantitative Data. Journal of Cleaner Production,202, 120–129.

Lee, J., and I.-T. Chuang. 2017. "Living Green Shell: Urban Micro-Vertical Farm." In Proceedings of the 2017 IEEE International Conference on Applied System Innovation: Applied System Innovation for Modern Technology, ICASI 2017, , 1087–90.

Li, Yingnan, Harry Den Hartog, Tao Liu, and Yuning Cheng. 2020. "Research Progress in Thermal Comfort Assessment of Urban Green Spaces Based on Scientific Knowledge Mapping Technology." In Proceedings - 2020 Inter- national Conference on Innovation Design and Digital Technology, ICIDDT 2020, Institute of Electrical and Electronics Engineers Inc., 306 – 311.

Liu, M., Ma, H., & Bai, Yu. (2021). Understanding the Drivers of Land Surface Temperature Based on Multisource Data: A Spatial Econometric Perspec- tive. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,14, 12263–12272.

Loukanov, A., et al. (2020). Effects of Neighborhood Building Density, Height, Greenspace, and Cleanliness on Indoor Environment and Health of Build- ing Occupants. Environmental Research,106(February), 213–222.

"The Politics of Multifunctional Green Infrastructure Planning in New York City." Cities 2020. 100.

Moonen, P., et al. (2012). Urban Physics: Effect of the Micro-Climate on Com- fort, Health and Energy Demand. Frontiers of Architectural Research,1(3), 197–228.

O'Clery, N., Duque, J. C., Alvanides, S., & Schwanen, T. (2023). Data Analytics and Sustainable Urban Development in Global Cities. Environment and Plan- ning b: Urban Analytics and City Science,50(4), 857–862.

Onodera, S.-I., et al. (2008). Effects of Intensive Urbanization on the Intrusion of Shallow Groundwater into Deep Groundwater: Examples from Bangkok and Jakarta. Science of the Total Environment,404(2–3), 401–410.

Panidi, E. A., & Rykin, I. S. (2020). "Toward the Capabilities of Integration of the Cloud-Based Spatial Data Infrastructures and Universal Desktop Geographic Information Systems, Case Study of Google Earth Engine and Qgis" In Inter- Carto (pp. 421–433). Lomonosov Moscow State University.

Pincetl, Stephanie. 2012. "Nature, Urban Development and Sustainability - What New Elements Are Needed for a More Comprehensive Understanding?" Cities 29(SUPPL.2): S32–37. https://doi.org/10.1016/j.cities.2012.06.009.

Reyhani, M, E Santolini, D Torreggiani, and P Tassinari. 2022. "Assessing the Environmental Performance of Plastic-Based and

Felt-Based Green Wall Systems in a Life-Cycle Perspective." Science of the Total Environment 822.

Roy, A. K., & Mitra, S. (2020). Assessment of Planform Dynamics and Anthropo- genic Stresses in the Balari Island, Hooghly Estuary, India. Spatial Informa- tion Research,28(2), 227–239.

Rumson, A. G., & Hallett, S. H. (2019). Innovations in the Use of Data Facilitating Insurance as a Resilience Mechanism for Coastal Flood Risk. Science of the Total Environment,661, 598–612. https://doi.org/10.1016/j.scitotenv.2019. 01.114

Sahoo, S., et al. (2021). Recognition of District-Wise Groundwater Stress Zones Using the GLDAS-2 Catchment Land Surface Model during Lean Season in the Indian State of West Bengal. Acta Geophysica,69(1), 175–198.

Serbanica, Cristina, and Daniela Luminita Constantin. 2023. "Misfortunes Never Come Singly. A Holistic Approach to Urban Resilience and Sustainability Challenges." Cities 134(December 2022): 104177. https://doi.org/10.1016/j. cities.2022.104177.

Sunita, Deepak Kumar, Shahnawaz, and Sulochana Shekhar. 2023. "Evaluating Urban Green and Blue Spaces with Space-Based Multi-Sensor Datasets for Sustainable Development." Computational Urban Science 3(1). https:// doi.org/10.1007/s43762-023-00091-0.

Waghela, Harsh et al. 2022. "Land Use Land Cover Classification Using Machine Learning." In International Conference on Automation, Computing and Renewable Systems, ICACRS 2022 - Proceedings, Institute of Electrical and Electronics Engineers Inc., 708 – 711.

Wichansky, P.S., Weaver, C.P., Steyaert, L.T., & Walko, R.L. (2006). 9780813539 New Jersey's Environments: Past, Present, and Future Evaluating the Effects of Historical Land Cover Change on Summertime Weather and Climate in New Jersey.

Xu, Z., et al. (2024). Enabling Streaming Analytics in Satellite Edge Computing via Timely Evaluation of Big Data Queries. IEEE Transactions on Parallel and Distributed Systems,35(1), 105–122.

Zhang, G., Cheng, S., & Gao, Y. (2024). A Visibility-Based Approach to Manage the Vertical Urban Development and Maintain Visual Sustainability of Urban Mountain Landscapes: A Case of Mufu Mountain in Nanjing, China. Environment and Planning b: Urban Analytics and City Science,51(2), 384–400.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in pub- lished maps and institutional affiliations.