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Article

Transformative technologies: A global Bibliometrci review of artificial intelligence in infrastructure governance and economic outcomes (2000–2024)

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Abstract: This paper investigates the transformative role of Artificial Intelligence (AI) in enhancing infrastructure governance and economic outcomes. Through a bibliometric analysis spanning more than two decades of research from 2000 to 2024, the study examines global trends in AI applications within infrastructure projects. The analysis reveals significant research themes across diverse sectors, including urban development, healthcare, and environmental management, highlighting the broad relevance of AI technologies. In urban development, the integration of AI and Internet of Things (IoT) technologies is advancing smart city initiatives by improving infrastructure systems through enhanced data-driven decision-making. In healthcare, AI is revolutionizing patient care, improving diagnostic accuracy, and optimizing treatment strategies. Environmental management is benefiting from AI's potential to monitor and conserve natural resources, contributing to sustainability and crisis management efforts. The study also explores the synergy between AI and blockchain technology, emphasizing its role in ensuring data security, transparency, and efficiency in various applications. The findings underscore the importance of a multidisciplinary approach in AI research and implementation, advocating for ethical considerations and strong governance frameworks to harness AI's full potential responsibly.

Keywords: artificial intelligence; infrastructure governance; economic outcomes; sustainability; public policy; technology integration; urban development; ethical AI

1. Introduction

In the rapidly changing field of global infrastructure development, the integration of Artificial Intelligence (AI) emerges as a transformative force, redefining the paradigms of governance and economic management (Guo et al., 2014; Henisz et al., 2012). As urban populations swell and the demand for sustainable, efficient infrastructure grows, governments and stakeholders are increasingly turning to AI to address complex challenges in infrastructure development (Wang et al., 2020). This trend is not just a technological evolution; it is a strategic response to the pressing need for enhanced decision-making frameworks that can drive economic growth and ensure transparent governance practices in public projects (Shi et al., 2018).

The justification for studying the role of AI in infrastructure projects emerges from several critical global developments. Firstly, the rapid urbanization seen across various continents necessitates a shift towards more resilient and adaptive infrastructure systems. AI offers sophisticated tools for data analysis, predictive maintenance, and resource management, making it indispensable for modern urban planning and development (Henisz et al., 2012; Wang et al., 2020). Secondly, the escalating complexities of managing large-scale public projects require systems that can operate beyond the capabilities of traditional human-led governance. AI systems provide real-time data processing, risk assessment, and financial management capabilities that can significantly reduce costs, enhance efficiency, and improve overall project outcomes (Guo et al., 2014; Shi et al., 2018).

Moreover, in the context of economic outcomes, AI's potential to streamline operations and introduce cost-saving automations promises substantial financial implications for public infrastructure projects. From optimizing supply chain logistics to automating routine tasks, AI can free up human resources for more critical, value-added activities, thus enhancing productivity and economic gains (Guo et al., 2014; Wang et al., 2020). However, the adoption of AI also brings forth significant governance challenges, including issues related to data privacy, ethical use of technology, and the need for robust regulatory frameworks to manage AI implementations effectively (Henisz et al., 2012; Shi et al., 2018).

Despite these advancements, the academic literature remains fragmented on how AI is reshaping governance and economic strategies specifically in the infrastructure sector. This study aims to fill this gap by providing a comprehensive bibliometric analysis of existing research on AI's impact on infrastructure governance and economic outcomes. By mapping the intellectual landscape, this paper seeks to synthesize key themes, identify influential works, and highlight research gaps. This approach not only enriches the understanding of AI's role in infrastructure but also guides policymakers, practitioners, and scholars in navigating the complexities introduced by AI technologies (Kadefors et al., 2020).

This bibliometric review systematically examines how AI technologies are being integrated into public infrastructure projects globally and evaluates the outcomes of these integrations on governance and economic scales. Furthermore, it explores the policy adaptations that may be necessary to harness AI's full potential while addressing the socio-economic and ethical concerns associated with its deployment in public sectors.

The role of AI in enhancing governance and economic outcomes in infrastructure projects is a critical area of study that promises to contribute significantly to the fields of urban development, public administration, and technology policy. By delving into this nexus, the current study not only broadens the academic discourse but also provides practical recommendations for future AI applications in infrastructure development. However, the adoption of AI in these domains also brings forth important ethical considerations and governance challenges, such as data privacy, bias in decision-making algorithms, and the need for robust regulatory frameworks to ensure responsible and transparent use of AI technologies. These issues will be explored in greater detail later in the manuscript.

This paper conducts a comprehensive bibliometric analysis to identify the most important thematic areas in AI research related to governance and economic management. Through this analysis, the study explores the conceptual framework of AI as depicted in academic literature and provides insights into potential future research directions on AI's role in infrastructure governance and economic outcomes.

2. Literature review

The integration of AI in governance and economic outcomes within infrastructure projects has garnered significant attention in recent literature. Studies have highlighted the Critical Success Factors (CSFs) in Public-Private Partnership (PPP) infrastructure development, emphasizing the importance of government-led initiatives (Wibowo and Alfen, 2015). These factors include a robust legal framework, well-established coordination mechanism, fair risk distribution, efficient contract administration, and a solid political backing (Wang et al., 2020). The role of PPPs has become crucial due to the increasing demand for infrastructure facilities by governments, the limited funds in the public sector, and the need for efficient project delivery (Sehgal and Dubey, 2019).

Research has delved into the governance aspects of infrastructure projects, emphasizing the need for a unified theory that combines economic, sociological, and psychological perspectives to address governance challenges effectively (Henisz et al., 2012). The Organization for Economic Cooperation and Development (OECD) has also contributed by developing Infrastructure Governance Indicators (IGIs) that focus on strategic vision, fiscal sustainability, affordability, value for money, and efficient public procurement (Rivadeneira et al., 2023). Moreover, studies have explored the managerial smart governance model as an evaluation methodology to enhance PPPs in infrastructure projects, emphasizing citizen participation, technology utilization, and sustainable development (Selim, 2021).

The application of AI technologies, such as natural language processing, machine learning, and neural networks, has been examined in enhancing cybersecurity and protecting national infrastructure, showcasing the contributions of AI in bolstering resilience (Adewusi et al., 2024; Vempati and Nalini, 2024). Furthermore, the impact of governance structures on risk management in large infrastructure projects have been analyzed, highlighting the importance of governance in project success (Guo et al., 2014). Additionally, the integration of AI technology in PPP financing models for infrastructure construction has been proposed to ensure high-quality economic development and advanced technological guarantees (Wang and Cui, 2022).

AI's role in healthcare is increasingly recognized as a catalyst for improving service delivery and patient outcomes. The urgency for a robust knowledge management system that integrates AI into healthcare governance is underscored by the need for accountability in healthcare expenditure and resource allocation. A recent study emphasizes the importance of a system that facilitates seamless information flow among healthcare entities and government bodies, thereby enhancing decision-making processes at all levels (Posinasetty et al., 2023). The integration of AI technologies allows for the digitization of vast amounts of healthcare data, which can be harnessed to improve clinical decision-making and operational efficiency (Sendak et al., 2020). However, the successful implementation of AI in healthcare requires a thorough understanding of the organizational and computational setups that can support AI-enabled clinical decision support systems (Kashyap et al., 2021). Moreover, AI has the potential to transform healthcare by enabling predictive analytics that can identify patient risks and improve treatment outcomes, as demonstrated by machine learning models developed to predict sepsis, enhancing clinical workflows and patient monitoring (Sendak et al., 2020).

Research has highlighted the crucial role of relational governance in enhancing sustainability in PPP infrastructure projects, showing a strong connection between these practices and long-term project sustainability (Tian et al., 2021). Studies on governance frameworks in large-scale construction projects have examined their impact on overall performance and the risk of opportunistic behavior among stakeholders, revealing the evolving nature of governance strategies in this field (Wang et al., 2019). In addition, investigations into AI's role in facilities management within the energy sector have assessed the opportunities and challenges associated with AI adoption (Mobayo et al., 2021).

In the context of international AI governance, the importance of addressing fragmentation and designing effective architectures for governance has been highlighted, emphasizing the role of academia in providing objective assessments to bridge governance gaps (Cihon et al., 2020). Furthermore, the efficiency analysis of government subsidy and performance guarantee policies in PPP infrastructure projects underscores the importance of sustainable operation and external benefits in such projects (Shi et al., 2018). The role of Chinese international development finance, particularly in infrastructure projects, has been discussed, showcasing the involvement of state-owned companies in implementing Chinese-funded projects globally (Hameiri and Jones, 2018).

The intersection of AI, Internet of Things (IoT) and environmental governance is particularly relevant in the context of sustainable urban development. AI and IoT technologies deployed in urban settings can enhance the management of resources, improve air quality monitoring, and optimize waste management systems (Yiğitcanlar and Cugurullo, 2020). The concept of smart cities, which integrates both AI and IoT into urban infrastructure, is gaining traction as a means to promote sustainability and improve the quality of life for residents (Nikitas et al., 2020). However, the successful implementation of AI and IoT in urban governance necessitates a comprehensive understanding of the socio-technical dynamics at play, including the institutional frameworks that govern the deployment of these technologies (Takeda et al., 2021).

Infrastructure investments have been shown to have a significant impact on public finance, with studies indicating that such investments can boost tax and non-tax revenues by reducing transportation costs and enhancing economic activities along infrastructure projects (Yoshino and Pontines, 2015). Additionally, the design and implementation of procurement requirements for carbon reduction in infrastructure construction have been explored, emphasizing the need for policies that drive long-term innovation and sustainability in procurement practices (Kadefors et al., 2020). In the realm of environmental governance, concerns about the sustainability of AI technologies themselves—such as energy consumption and electronic waste—must also be considered (Nishant et al., 2020). Proactive governance approaches are needed to ensure that AI applications contribute positively to sustainability goals, with an emphasis on stakeholder engagement and ethical guidelines (Stix, 2021).

Furthermore, the COVID-19 crisis has driven a rapid increase in the use of AI technologies across different fields, including environmental management and medical services. The pandemic highlighted the critical need for digital transformation in healthcare, prompting investments in AI-driven solutions that enhance patient care and operational efficiency (Bai et al., 2021). Similarly, the environmental sector has witnessed a surge in the use of AI for monitoring and managing the impacts of the pandemic on urban environments, demonstrating the versatility of AI in addressing complex challenges (Saeed et al., 2023).

As governments increasingly recognize the transformative potential of AI, there is a pressing need for robust governance frameworks that can guide the ethical and responsible deployment of these technologies. With AI systems become increasingly embedded across various sectors, ethical concerns, such as data privacy, algorithmic bias, and transparency, have emerged as critical issues (Floridi et al., 2018). These concerns are compounded by the lack of comprehensive regulations governing AI, raising questions about accountability in AI-driven decision-making processes (Wamba-Taguimdje et al., 2020). The establishment of policies that promote transparency, accountability, and inclusivity in AI governance is essential to mitigate risks associated with AI implementation, such as bias and inequality (Macrae, 2021). One of the primary governance challenges associated with AI is addressing the dichotomy between "easy" and "hard" problems. The former pertains to aligning AI systems with existing legal and ethical norms, while the latter involves navigating the complex societal implications of AI technologies, such as the potential for surveillance and the erosion of personal freedoms (Minkkinen and Mäntymäki, 2023). This complexity is further echoed in the ethical risks highlighted by Klímová et al. (2023), particularly in education, where data privacy and the impact of AI-driven systems on students and educators remain pressing concerns.

The transformative power of AI necessitates a collaborative approach among stakeholders, including researchers, developers, and policymakers, to ensure that AI advancements reflect ethical standards and societal norms (Dwivedi et al., 2021; Williamson, 2024). To address these challenges, there is a need for robust frameworks that balance technological progress with the protection of public interests. Continuous dialogue and the adaptation of governance structures are essential for managing emerging challenges, as highlighted by Duan et al. (2019), who call for a focused research agenda on AI's implications for decision-making processes.

3. Research methodology

This section outlines the research approach used to address the study's questions, focusing on a bibliographic review of existing literature.

The research team utilized Scopus, a comprehensive and widely recognized database renowned for its extensive global research coverage and powerful search capabilities, to conduct a bibliometric analysis of the literature. The process began with the identification of relevant keywords, the formulation of search strings, and the compilation of a database. The search string used was: "artificial intelligence" or "AI" and "infrastructure" or "public projects" and "governance" or "policy" and LIMIT-TO Journal Articles and "English Language".

This search string was carefully crafted to focus on the intersection of AI and infrastructure and governance. The limitations to journal articles, language ("English"), were applied to ensure the relevance and quality of the results. The initial search conducted in June 2024 yielded 937 journal articles. After a thorough review of titles and abstracts to ensure relevance, the number of considered articles was refined to 473.

The selection criteria were meticulously developed to guide the identification of pertinent papers. The primary inclusion criterion was that papers must explicitly discuss artificial intelligence with a focus on infrastructures. The authors excluded documents that were duplicates, or those that focused solely on the technical aspects of sustainability without discussing their application in the sports industry. The selection process was iterative and involved an initial scan of titles and abstracts for relevance to the research questions. Following this preliminary screening, full-text articles were reviewed for detailed assessment. Any disagreements regarding eligibility were resolved through discussion among the research team members. Backward search was also employed, checking the reference lists of included studies to identify additional articles potentially relevant to the research study.

The selection process was iterative and involved an initial scan of titles and abstracts for relevance to the research objectives. Following this preliminary screening, full-text articles were reviewed for detailed assessment. Articles (n = 5) were excluded because they did not match the inclusion requirements, specifically focusing solely on AI in unrelated fields such as entertainment and arts, or because they lacked sufficient discussion on infrastructure and governance aspects. Any disagreements regarding eligibility were resolved through discussion among the research team members. A backward search was also employed, checking the reference lists of included studies to identify additional articles potentially relevant to the research.

While we aiming for a comprehensive review, the authors acknowledge certain limitations in the data collection process. First, the reliance on specific databases may have excluded relevant studies not indexed in those databases, potentially leading to publication bias. Additionally, the selection process, despite being rigorous, may introduce subjective biases in determining relevance, particularly during the initial screening of titles and abstracts. Finally, language limitations restricted the inclusion of only English-language publications, potentially overlooking valuable insights from studies published in other languages. These limitations highlight areas where future research could further expand and refine the scope of this study.

Figure 1 presents a Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flowchart showing the detailed search procedures used in the review, illustrating the process from the initial identification of studies through to the final selection of articles included in the analysis. This bibliometric investigation was conducted in accordance with PRISMA guidelines, which provide a structured approach to enhance the transparency and detailed reporting of systematic reviews, thus improving the reliability and reproducibility of bibliometric studies (Mkhongi and Musakwa, 2022).

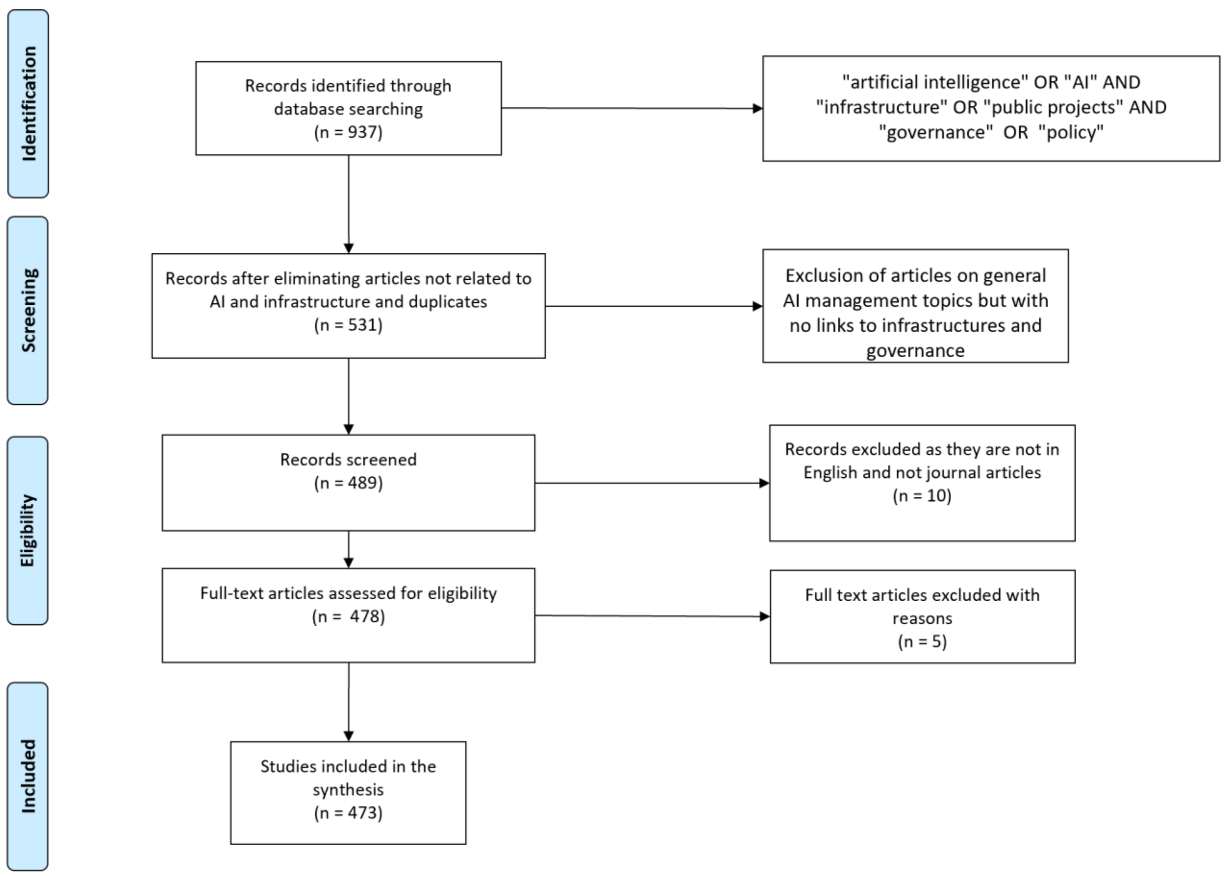

Figure 1. Preferred reporting items for systematic reviews and meta-analysis (PRISMA) flowchart showing the search procedures used in the review.

The review focused on studies related to the integration of artificial intelligence in infrastructure governance and economic outcomes. For data collection, critical publication details such as authors, affiliations, titles, keywords, abstracts, and citation counts were organized in an Excel spreadsheet for initial analysis. VOSviewer software was used to perform bibliometric analysis, employing descriptive statistical techniques to map the landscape of research on the selected topics. Citation, co-citation, and keyword co-occurrence analyses were conducted to evaluate the influence of scholarly works, authors, and journals by tracking the frequency of their citations within other articles (Zupic and Čater, 2015). This approach reveals the underlying connections and trends within the research area, offering a thorough overview of the existing knowledge landscape.

4. Results

This section presents the key findings from the bibliometric analysis, with a focus on the integration of AI in infrastructure projects and its subsequent impact on governance and economic outcomes. The results are categorized by the volume of publications, the growth trajectory over time, and the geographic distribution of research contributions. These aspects are illustrated in the accompanying graphs to provide a clear visual representation of the trends observed in the literature.

The analysis reveals a significant increase in the volume of AI-related research in infrastructure projects over the past two decades, reflecting the growing recognition of AI's potential to transform governance and economic management. Additionally, the geographic distribution of the literature highlights the global nature of AI research in this field, with notable contributions from countries leading in technological innovation and infrastructure development. The findings underscore the widespread relevance of AI technologies across different regions and the importance of continued research in this evolving domain.

4.1. Volume and growth trajectory of the literature

The bibliometric analysis, conducted using Scopus, reveals a robust and rapidly increasing trend in publications related to the integration of AI in infrastructure governance and economic management.

As illustrated in the graph represented by **Figure 2** has seen a steep rise in scholarly interest, particularly over the past decade.

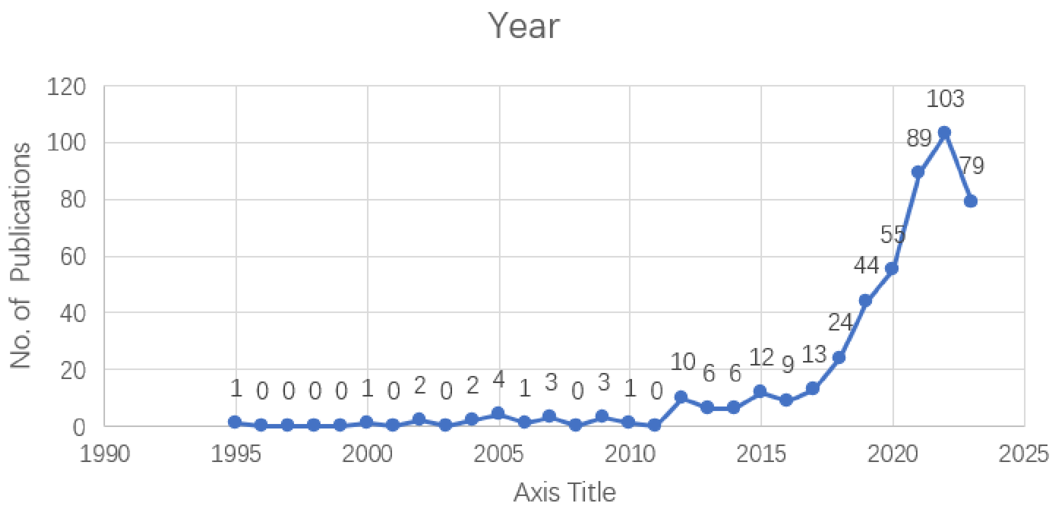

Figure 2. Number of publications by year on AI and infrastructure and governance (n = 473).

Early publications were sparse from 1995 to 2010, indicating nascent interest and exploratory studies in the application of AI technologies within infrastructure sectors. During this period, publications remained in single digits, reflecting the early developmental stage of AI applications in this field.

A gradual increase in publication numbers is observed from 2011 to 2015, with figures slowly rising to double digits. This growth aligns with advancements in AI technology and its preliminary adoption in infrastructure projects, as discussed in foundational studies by Guo et al. (2014) and Henisz et al. (2012).

The most substantial growth occurred from 2016 onwards, with a dramatic rise to 44 publications in 2020 and peaking at 103 in 2023. This surge corresponds to the wider acceptance of AI technologies and their recognized potential to dramatically enhance efficiency and transparency in infrastructure projects. Notable contributions during this period include Adewusi et al. (2024) on AI in cybersecurity for national infrastructure and the discussions by Cihon et al. (2020) on the need for international governance frameworks to manage AI's integration into public infrastructures.

The geographic distribution of these publications largely centers around developed economies where AI infrastructure initiatives are most feasible, with significant contributions from the United States, European Union, and increasingly, China, as evidenced by studies focused on global governance impacts (Hameiri and Jones, 2018) and specific AI applications in public sector projects (Kondylakis et al., 2023).

4.2. Geographic distribution of the literature

The geographic distribution of publications reflects significant international contributions, underscoring the global interest in and varied applications of AI in infrastructure projects. **Figure 3** illustrates this distribution. The United States leads with 93 publications, highlighting its pioneering role in AI technologies and their integration into governance and infrastructure systems. This leadership can be attributed to the country's advanced technological infrastructure, strong investment in AI research, and well-established public-private partnerships that foster innovation in infrastructure development.

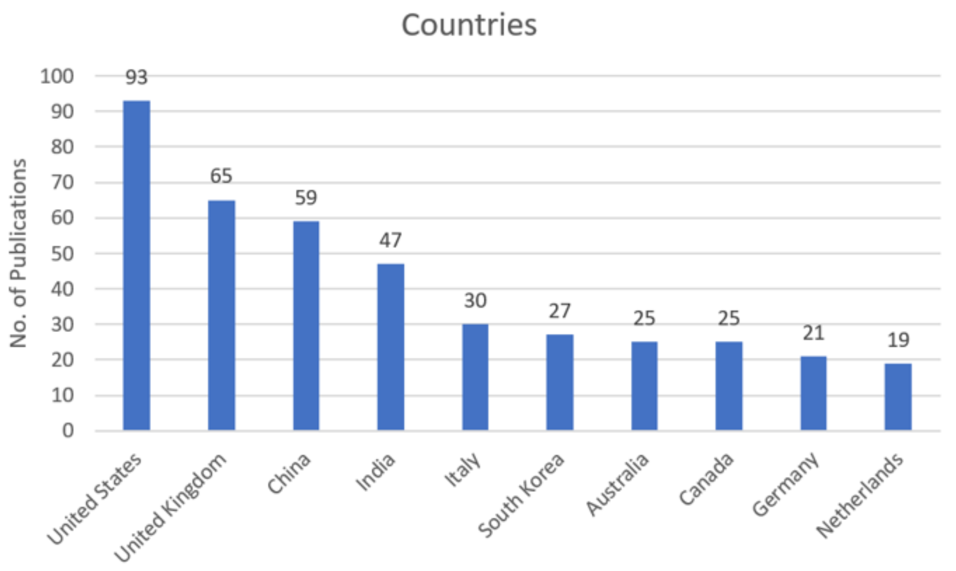

Figure 3. Geographic distribution of AI-related publications in infrastructure projects.

Following the United States, the United Kingdom and China show strong research outputs with 65 and 59 publications, respectively. The United Kingdom's focus on enhancing infrastructure governance through AI innovations can be linked to its robust academic research ecosystem and government initiatives supporting smart city development and infrastructure modernization. China's significant contribution reflects its strategic national policies aimed at rapid urbanization and its substantial investments in AI as a key component of its infrastructure development plans, particularly in mega-projects and urban management.

India emerges as an important contributor with 47 publications, indicating its growing focus on incorporating AI into its rapidly expanding infrastructure sector. This trend is likely driven by India's ongoing urbanization efforts and the increasing need for smart infrastructure solutions to manage its large population and urban centers efficiently. The country's push towards digital transformation and government-led initiatives like the Smart Cities Mission have further accelerated AI research in this domain.

Italy and South Korea also show notable research activity, with 30 and 27 publications, respectively. Italy's engagement with AI technologies reflects its focus on modernizing aging infrastructure and improving the sustainability of public projects, particularly in the energy and transport sectors. South Korea's contributions align with its broader national strategy of leading in advanced technologies, with a specific emphasis on integrating AI into smart city infrastructure and public services.

Australia, Canada, and Germany, each with 25, 25, and 21 publications, respectively, demonstrate the widespread recognition of AI's potential across different governance frameworks and economic conditions. These countries benefit from strong academic-industrial collaboration and government policies promoting AI as a tool for innovation in infrastructure management. The Netherlands, with 19 publications, is similarly focused on leveraging AI for public transport systems and energy management, reflecting a commitment to sustainable development and technological innovation.

This diverse geographic distribution underscores a significant alignment between national AI capabilities and the priorities set forth in public infrastructure development. Countries with advanced technological infrastructures and strong policy frameworks, such as those leading in publication numbers, are better positioned to integrate AI effectively into their infrastructure projects. This trend is supported by findings from various studies indicating a critical intersection between technological advancement and policy development in AI governance (Cihon et al., 2020; Guo et al., 2014).

Moreover, contributions from countries like China and India highlight the role of AI in supporting rapid urbanization and addressing the infrastructure needs of emerging economies. These contributions align with global governance challenges and opportunities, as discussed by Hameiri and Jones (2018). The broad spread of countries involved in this research illustrates the universal appeal and applicability of AI technologies in tackling both common and unique challenges faced in infrastructure development across the globe. The observed trends are shaped by each country's strategic priorities, infrastructure needs, and policy support for AI innovation.

4.3. Influential authors

Several researchers have made notable contributions to the academic discourse and practical application of AI in infrastructure governance and economic management. Among them, Gulson has been instrumental in advancing our understanding of the intersection between AI and urban policy, particularly through his exploration of data infrastructures and education policy in urban environments. His work (Gulson and Sellar, 2019) investigates the role of AI in shaping educational landscapes and urban development strategies. Meanwhile, Allam, recognized for his work in Australia, focuses on AI's role in optimizing city management and promoting sustainable urban practices, as seen in studies like Allam and Jones (2022).

Muduli from Papua New Guinea extends the discussion into the context of developing countries, focusing on optimizing infrastructure operations to enhance governance efficiency and economic outcomes (Muduli et al., 2021). His research is crucial for regions facing rapid urbanization and infrastructure challenges, offering insights into how AI can contribute to more effective infrastructure management.

Bibri from Switzerland and B. Bodó from the Netherlands focus on AI's impact on environmental and economic sustainability within large-scale infrastructure projects. Bibri's work (Bibri, 2021) is pivotal in illustrating how AI can promote green infrastructure initiatives, while Bodóet al. (2019) explores the influence of digital technologies, including AI, on data governance and media ecosystems.

Further enriching this academic discourse are Deng from China, Harou from the United Kingdom, and Hastak from the United States. Deng's research (Deng et al., 2019) explores AI's applications in water management and energy systems, focusing on enhancing operational efficiency and resilience in infrastructure systems. Harou et al. (2020) and Hastak similarly contribute by examining AI's role in improving maintenance and reducing waste in construction and infrastructure projects.

Table 1 below summarizes the most influential authors in this field, providing details on their publication counts, total citations, and citations per year.

Table 1. Influential authors in AI and infrastructure governance research.

Rank	Author	Country	Articles in the Database	Total Citations	Total Citations per year
1	K.N. Gulson	Australia	6	3382	422.75
2	Z. Allam	Australia	5	7520	1074.28
3	K. Muduli	Papua New Guinea	5	2767	345.87
4	T. Swist	Australia	4	752	94
5	H.S. Al-Raweshidy	United Kingdom	4	6169	771.12
6	S.E. Bibri	Switzerland	4	8206	1025.75
7	B. Bodó	Netherlands	4	3013	376.62
8	T. Deng	China	3	1079	134.87
9	J.J. Harou	United Kingdom	3	4662	582.65
10	M. Hastak	United States	3	5670	708.75

4.4. Intellectual structure

The exploration into the conceptual structure surrounding the use of AI in infrastructure governance and economic outcomes is vividly visualized through a co-citation analysis depicted in **Figure 4**. This analysis reveals the interconnections among authors frequently cited together within the field, suggesting a shared research focus and intellectual alignment. In this visual representation, individual researchers are denoted by nodes, with the prominence of each node—determined by the volume of co-citations it receives—indicating the extent of its influence. Larger nodes suggest a higher frequency of co-citations, and nodes positioned closely together indicate related scholarly content. This co-citation analysis categorizes the literature into three distinct thematic clusters:

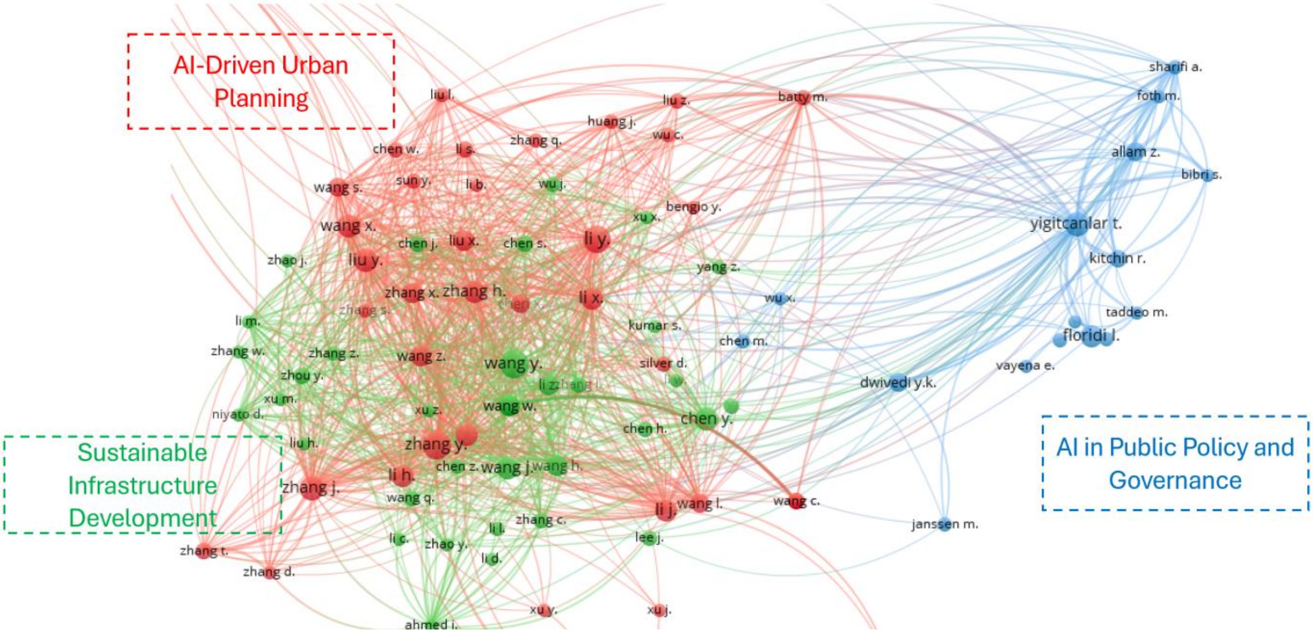

Figure 4. Authors co-citation analysis.

1) AI-Driven Urban Planning (Red Cluster);
2) Sustainable Infrastructure Development (Green Cluster);
3) AI in Public Policy and Governance (Blue Cluster).

In the red cluster, Researchers like Zhang and Wang have made significant strides in exploring how AI can be effectively utilized to enhance urban planning and smart city developments. Their work often focuses on employing machine learning algorithms and data analytics to improve traffic management, energy distribution, and public safety systems within urban settings. This cluster examines various AI-driven strategies such as predictive analytics for urban growth, AI in managing public transportation systems, and IoT applications in smart buildings. These studies not only contribute to academic discussions but also offer practical solutions for cities aiming to become more efficient and responsive to the needs of their populations.

While in the green cluster, scholars like Chen and Han focus on the sustainability aspect of infrastructure. Their research addresses how AI can support the design and operation of energy systems, including the integration of renewable energy sources and the optimization of resource use. Their work also delves into the development of AI tools for monitoring and maintaining infrastructure health, promoting longevity, and reducing the environmental impact of construction and maintenance. Furthermore, these authors explore how AI can aid in water resource management, ensuring sustainable practices that align with global environmental goals and policy directives.

Lastly the blue cluster features influential researchers such as Jansen and Nagy, who investigate the intersection of AI and public policy. Their work critically examines the ethical, legal, and social implications of deploying AI in public administration. Topics include the development of regulatory frameworks to govern AI usage, the impact of AI on privacy and civil liberties, and the ways AI can enhance transparency and accountability in government operations. Additionally, their research explores the potential of AI to improve decision-making processes, enabling more efficient and equitable public services and fostering a more informed citizen engagement in governance.

4.5. Keyword co-occurrence

To address the research question regarding the principal themes within the literature on AI applications in infrastructure governance and economic outcomes, a keyword co-occurrence analysis was conducted. This method identifies central research themes by analyzing how often keywords appear together across a broad spectrum of academic publications. Using VOSviewer software, the analysis revealed that the most commonly occurring keywords include 'artificial intelligence', 'machine learning', 'internet of things', and 'blockchain', as detailed in **Table 2** below.

Table 2. Frequency of occurrence of top keywords.

Keyword	Occurrence
Artificial Intelligence	150
Machine Learning	135
Internet of Things	120
Blockchain	110
Smart Cities	90
Deep Learning	85
Big Data	80
Digital Health	75
Renewable Energy	70
Network Security	65

The results are grouped into three major clusters, as visualized in the co-occurrence map linked to **Figure 5**:

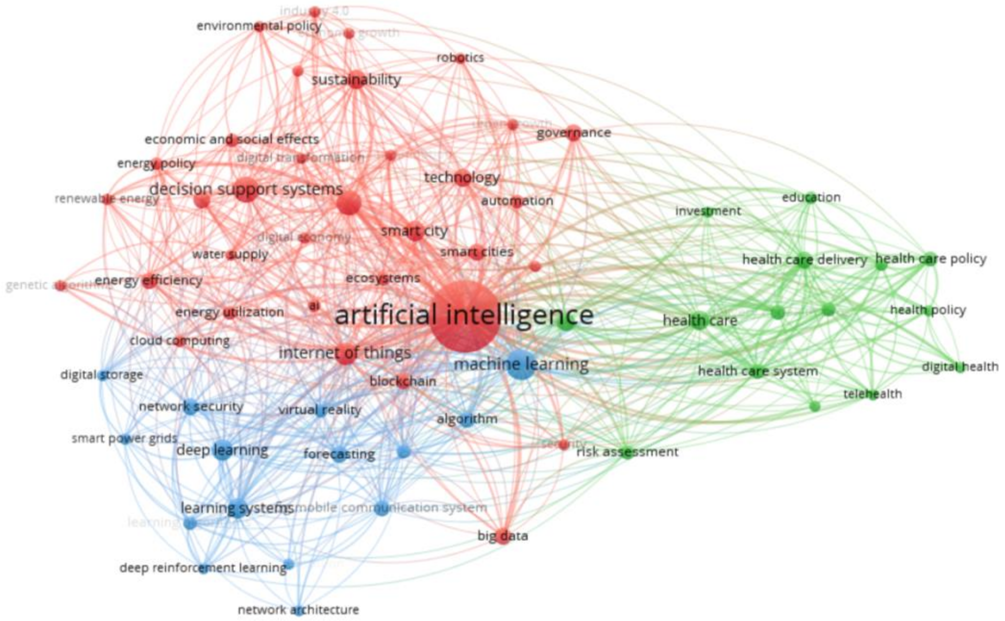

Figure 5. Keyword co-occurrence map (threshold: Five co-occurrences).

Red Cluster—Smart Urban Development: This cluster focuses on keywords such as ‘smart cities’, ‘internet of things’, and ‘smart grid’, highlighting areas such as city automation, energy management, and infrastructure efficiency. It reflects studies on how cities can integrate AI and IoT to enhance urban living and resource management, promoting smart urban growth.

Blue Cluster—AI-Driven Technological Innovation: This cluster is strongly associated with keywords like ‘machine learning’, ‘deep learning’, and ‘blockchain’. It suggests a focus on the technological advancements in AI that can be applied to infrastructure. The research in this cluster covers how AI algorithms and blockchain technology can revolutionize data handling and security within infrastructure systems, enhancing operational efficiencies and predictive analytics.

Green Cluster—AI in Healthcare and Environmental Management: This cluster is interlinked with terms like ‘digital health’, ‘telehealth’, and ‘environmental policy’. It concentrates on the application of AI in managing healthcare systems and promoting environmental sustainability. It covers how AI technologies can aid in healthcare delivery, patient management, and also play a crucial role in monitoring and promoting environmental health.

5. Discussion

The findings from our authors’ co-citation and keyword co-occurrence analysis on AI applications in infrastructure governance and economic outcomes provide significant insights into the intersection of AI and IoT technologies in smart urban development. This analysis revealed a strong thematic focus on the integration of these technologies within the domain of smart cities and smart grids, aligning closely with recent academic literature and technological advancements in the field.

5.1. Enhancing urban infrastructure with AI and IoT

As identified in our results in **Figure 4**, the Smart Urban Development underscores the pivotal role of AI and IoT in enhancing urban infrastructure systems. This is consistent with the observations made by Zanella et al. (2014), who emphasize the tailored application of urban IoT systems to support the Smart City vision. These systems utilize sophisticated communication technologies to provide innovative services to city officials and residents, enhancing the overall quality of urban life.

The extensive application of IoT and AI technologies, as noted in the works of Meng et al. (2023), has significantly advanced the construction and development of smart cities. This technological convergence is not just about automation but about creating intelligent networks that can learn and adapt. Our analysis reflects this dynamic, highlighting the integration of AI with IoT to facilitate data-driven decision-making, predictive analytics, and optimization in smart city frameworks as noted by Deep and Verma (2023).

Furthermore, the role of big data in this context is crucial. It extends beyond mere data collection to encompass next-generation information technology applications across various urban domains. Hashem et al. (2016) highlight the embedding of sensors and equipment in critical infrastructure elements, which aligns with our findings that point to the importance of data integration and analysis in smart urban planning. This approach enables cities to not only collect vast amounts of data but also to extract meaningful insights that drive efficient urban management and development.

Additionally, our findings touch upon the concept of “Green AI,” which Yiğitcanlar et al. (2021) discuss as a critical approach to support smart city transformations. This concept addresses fundamental shortcomings in mainstream AI systems by advocating for a more sustainable and efficient AI framework. The emphasis on Green AI reflects a growing awareness of the need for sustainable technology solutions that minimize environmental impact while maximizing efficiency—principles that are foundational to the development of smart cities.

These insights suggest several implications for future urban development. Policymakers and urban planners should consider these technologies not just as tools for improving infrastructure but as integral components of a broader strategy to enhance urban environments sustainably. This requires a concerted effort to integrate ethical considerations into technology deployment, ensuring that AI and IoT applications in urban settings do not compromise public trust or lead to social disparities.

Moreover, as cities continue to evolve into smarter and more interconnected environments, the role of interdisciplinary research becomes increasingly important. Future studies should explore the interplay between technology, urban sociology, and environmental science to provide a holistic approach to smart city development.

5.2. AI-Driven technological innovation

Our analysis identified a strong emphasis on the role of blockchain in various domains, mirroring the findings of Saberi et al. (2018) who discuss the decentralized and secure nature of blockchain and its applications in supply chain management, data security, and transaction management. The transformative potential of blockchain to redefine data management frameworks aligns with the themes we observed, where blockchain enhances transparency, security, and traceability in supply chains (Junaid et al., 2024; Venkatesh et al., 2020).

The integration of blockchain in systems such as the blood cold chain, as explored by Kim et al. (2020), exemplifies innovative solutions to complex logistical challenges, highlighting blockchain’s ability to maintain critical quality parameters across distributed networks. This aligns with our findings on the application of blockchain for enhancing privacy preservation in vehicular trust management systems, where the decentralized nature of blockchain provides secure solutions for managing sensitive data without central oversight (Qin et al., 2020).

Further, the role of deep learning within this technological convergence is profound, as evidenced by the significant focus on its capability to process and model large datasets, such as in satellite imagery analysis (Ritwik et al., 2018). Our results underscore the critical integration of deep learning with infrastructure considerations, facilitating advanced data processing and modeling tasks that drive forward AI technologies. Neural network-based quantization techniques, which enable the development of complex cognitive algorithms, also reflect our analysis’s emphasis on the synergy between AI and cutting-edge technological tools (Kajo et al., 2021).

The impact of blockchain on enhancing the sustainability performance of supply chains, as discussed by Park and Li (2021), corroborates our findings on the digitalization of traditional supply chain management practices. Blockchain's decentralized framework not only improves the efficiency and security of supply chain operations but also fosters enhanced sustainability performances. The application of blockchain technology in energy management systems for renewable energy microgrids (Wang et al., 2021) further exemplifies its role in revolutionizing traditional practices by ensuring independent transaction management through smart contracts.

In database management, the deployment of blockchain-based systems addresses traditional databases' limitations by offering scalable, fault-tolerant, and consistent solutions (Maiyya et al., 2018). By incorporating blockchain as a data store in larger software systems, developers can leverage its benefits in terms of security and governance (Paik et al., 2019), enhancing overall data management practices.

5.3. Transformative impact of AI in healthcare

The bibliometric review highlights AI's expanding role in transforming healthcare by improving diagnostic accuracy, optimizing treatment strategies, and enhancing care delivery. This mirrors the observations of Jiang et al. (2017), who note the potential of AI to revolutionize medical practice by leveraging the growing availability of healthcare data and advanced analytics. The shift towards AI-augmented systems in healthcare, as detailed in our findings, is further exemplified by Kelly et al. (2019), who discuss the clinical impact of AI across various medical domains.

Recent breakthroughs in AI, as highlighted by Bajwa et al. (2021), are paving the way for systems that improve patient outcomes and streamline healthcare processes. These developments resonate with our analysis, emphasizing AI's capacity to enhance operational efficiencies in healthcare settings. Moreover, efforts to mitigate bias in AI applications, as discussed by Abràmoff (2023), underscore the importance of promoting health equity through AI, enhancing access to quality care for underserved populations, and reducing healthcare costs.

In the realm of environmental management, our findings underscore the growing adoption of AI technologies as critical tools for addressing complex global health and environmental crises. This aligns with the work of Lobova et al. (2022), who advocate for the application of Sustainable AI in environmental economics and management as a long-term solution for crisis management. The shift from flexible to stable AI applications, as noted in our analysis, supports the strategic alignment and infrastructure development necessary for achieving global sustainability goals, a theme further explored by Kulkov et al. (2024).

AI-based systems are becoming increasingly standard in environmental management, as evidenced by innovative solutions for monitoring and conservation efforts highlighted by Sira (2024). Our findings align with Shuford (2024), who illustrates AI's potential to revolutionize environmental monitoring practices, including the detection and management of pollution such as heavy metal contamination. Additionally, the integration of AI technologies with green supply chain management practices, as discussed by Das et al. (2023), can enhance market competitiveness and contribute to sustainable development, particularly in the face of global crises such as the COVID-19 outbreak.

5.4. Ethical considerations and governance challenges of AI

The incorporation of AI across various domains, including healthcare, urban development, and environmental management, presents significant ethical considerations and governance challenges. One of the primary concerns is data privacy, particularly in sectors like healthcare, where sensitive personal information is processed by AI systems. Ensuring that AI applications comply with data protection regulations and maintain transparency in their decision-making processes is essential to safeguarding individual privacy and rights (Wamba-Taguimdje et al., 2020).

Another ethical concern involves the risk of AI algorithms perpetuating bias, potentially resulting in unjust or unequal treatment. As AI becomes more embedded in decision-making processes, addressing bias in AI-driven systems is critical to preventing the perpetuation of existing inequalities and ensuring equitable outcomes across all sectors (Floridi et al., 2018). Additionally, the lack of comprehensive regulations governing AI technologies presents governance challenges, particularly in ensuring accountability for AI-driven decisions and maintaining public trust in these systems.

To mitigate these risks, there is a need for robust regulatory frameworks that provide clear guidelines for the ethical deployment of AI. Such frameworks should address both “easy” governance challenges, such as aligning AI systems with existing legal and ethical norms, and “hard” problems, like navigating the complex societal implications of AI technologies (Minkkinen and Mäntymäki, 2023). A collaborative approach among stakeholders—researchers, developers, policymakers, and civil society—is essential to creating these frameworks and ensuring that AI innovations are aligned with societal values (Williamson, 2024).

6. Future research avenues

The integration of AI in various domains offers numerous opportunities for future research, particularly in addressing the ethical issues and governance obstacles involved in the deployment of AI technologies. First, further studies should explore the development of regulatory frameworks that balance technological innovation with the protection of individual rights, particularly in the areas of privacy, accountability, and transparency. This includes investigating how to effectively mitigate bias in AI systems and ensure that these technologies promote fairness and equity.

Second, in the realm of smart urban development, future research should delve deeper into the socio-economic impacts of AI-driven cities, assessing both the benefits and potential disparities introduced by such technologies. Studies could also explore the challenges of integrating AI into older infrastructure systems, providing insights into solutions for smart city retrofits and ensuring that AI contributes to inclusive urban development.

Third, in healthcare, future research should examine the long-term impacts of AI on patient outcomes and healthcare delivery. This includes exploring how AI can be scaled in resource-limited settings to bridge health equity gaps and assessing the potential of AI to enhance personalized medicine by tailoring treatments to individual genetic profiles. Research should also focus on how AI technologies can be deployed ethically, ensuring that advancements in healthcare do not exacerbate existing disparities or infringe on patient privacy.

Finally, in environmental management, research should continue to push the boundaries of how AI can aid in large-scale environmental monitoring and crisis management. This could include investigating AI's role in predicting and mitigating the effects of climate change, as well as its potential applications in biodiversity conservation and sustainable resource management (McKenzie and Gulson, 2023). Future studies should also consider the ethical implications of AI-driven environmental interventions, ensuring that technological solutions align with global sustainability goals.

This paper has explored the expansive role of AI across various sectors, emphasizing its transformative potential in urban development, healthcare, and environmental management. Through a detailed keyword co-occurrence analysis, we identified significant themes that demonstrate how AI technologies are not only enhancing operational efficiencies but also addressing complex global challenges.

In urban development, AI's integration into smart city initiatives highlights a shift towards more responsive, sustainable, and efficiently managed urban environments. The deployment of IoT and AI in urban infrastructures, such as traffic systems, utilities, and public services, facilitates a higher quality of urban life through improved data-driven decision-making and resource management.

In healthcare, AI has proven instrumental in revolutionizing care delivery by enhancing early detection of diseases, refining therapeutic strategies, and tailoring medical interventions to individual needs. The advancement of AI innovations in healthcare promises to significantly enhance patient outcomes, reduce operational costs, and streamline healthcare processes while also addressing challenges related to health equity and access to care.

In environmental management, AI offers innovative solutions for monitoring, conservation, and sustainability efforts that are crucial for combating environmental crises. The application of AI in these domains supports more effective management of natural resources, enhances the precision of environmental monitoring, and ensures sustainable practices that align with global environmental goals.

The integration of blockchain technology with AI has also emerged as a key driver of innovation, providing secure, transparent, and efficient solutions across sectors. This synergy is poised to redefine traditional practices, from supply chain management to transaction systems, ensuring that digital advancements foster broader societal benefits.

Future research should focus on several critical areas to ensure AI's potential is fully realized while mitigating risks. Research on ethical AI implementation is needed to develop regulatory frameworks that balance innovation with ethical considerations, particularly concerning data privacy, bias, and transparency in AI-driven decision-making processes. The socio-economic impacts of AI-driven urban development require further investigation, particularly to address potential disparities and ensure inclusive development in both new and retrofitted infrastructure systems. In healthcare, exploring the scalability of AI solutions, especially in resource-limited settings, will be crucial to bridging health equity gaps and enhancing personalized medicine. Environmental management research should expand to include AI's role in predicting and mitigating the effects of climate change, as well as in large-scale environmental monitoring, conservation, and biodiversity protection. Finally, the long-term implications and benefits of integrating AI with blockchain technology across sectors warrant further investigation, particularly regarding transparency, security, and efficiency in governance systems.

As AI continues to develop, it is imperative that stakeholders across industries—academics, policymakers, and practitioners—collaborate to ensure that AI advancements are guided by a balanced consideration of technological capabilities and ethical imperatives. The ongoing exploration of AI should not only drive technological innovation but also promote a sustainable, equitable, and ethically conscious future for all.

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