

KNOWLEDGE AND THE MULTIDIMENSIONAL ROLE OF EDUCATIONAL INSTITUTIONS IN SMART SUSTAINABLE CITIES

CONHECIMENTO E O PAPEL MULTIDIMENSIONAL DAS INSTITUIÇÕES EDUCACIONAIS EM CIDADES INTELIGENTES E SUSTENTÁVEIS

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Luciana Maines da Silva

lucmasi@gmail.com

Programa de pós-graduação em Administração / Mestrado Profissional em Gestão Educacional/Universidade do Vale do Rio dos Sinos – UNISINOS – Porto Alegre/RS, Brasil

<https://orcid.org/0000-0003-1670-0629>

Abstract

Smart sustainable cities (SSCs) demand integrated social, environmental, and technological strategies. While universities are well-studied as urban knowledge hubs, the roles of schools and corporate universities remain underexplored. Based on a systematic literature review, this study proposes a multidimensional framework explaining how different educational institutions contribute to SSCs across five dimensions: knowledge, human capital, innovation, financing, and partnerships. The results show universities as central actors, schools as promoters of civic engagement and community-based innovation, and corporate universities as emerging contributors. Overall, the findings underscore the need for a comprehensive educational ecosystem to foster inclusive and adaptive urban development.

Keywords: Smart sustainable city. Stakeholder. University. School. Corporate university.

Resumo

Cidades inteligentes e sustentáveis (CISs) exigem estratégias integradas nas áreas social, ambiental e tecnológica. Embora as universidades sejam amplamente estudadas como centros de conhecimento urbano, os papéis das escolas e das universidades corporativas permanecem pouco explorados. Com base em uma revisão sistemática da literatura, este estudo propõe um modelo multidimensional que explica como diferentes instituições de ensino contribuem para as CISs em cinco dimensões: conhecimento, capital humano, inovação, financiamento e parcerias. Os resultados mostram as universidades como atores centrais, as escolas como promotoras do engajamento cívico e da inovação comunitária, e as universidades corporativas como contribuintes emergentes. De modo geral, as descobertas ressaltam a necessidade de um ecossistema educacional abrangente para fomentar o desenvolvimento urbano inclusivo e adaptativo.

Palavras-chave: Cidade inteligente e sustentável. *Stakeholders*. Universidade. Escola. Universidade corporativa.

Introduction

Smart sustainable cities (SSCs) represent an evolving paradigm that integrates urban innovation, environmental sustainability, and social inclusion. While numerous definitions have emerged, we adopt the widely recognized understanding of SSCs as urban systems that leverage technology and participatory governance to enhance quality of life, economic competitiveness, and environmental performance (Ahvenniemi et al., 2017). Education plays a critical role in enabling such transformation—not only by developing human capital but also by fostering civic engagement, social cohesion, and local innovation capabilities.

Despite the growing body of literature on SSCs, the role of educational institutions has been predominantly represented by universities. There is still a limited understanding of how other types of institutions—such as primary and secondary schools or corporate universities—contribute to the development of SSCs. This gap constrains the potential of cities to build inclusive and collaborative knowledge ecosystems that are essential for addressing complex urban challenges.

This study aims to fill this gap by proposing a conceptual framework that encapsulates the multifaceted roles of educational institutions in sustainable city strategies (SSCs). We examine the contributions of universities, schools, and corporate universities across five essential dimensions: knowledge generation and transfer, human capital development, innovation, financing, and partnerships. To evaluate the positioning of these institutions within the SSC discourse, we conducted a systematic literature review, identifying their current roles and potential contributions to shaping sustainable and intelligent urban futures.

The relevance of this framework extends beyond academic analysis. Understanding how a broader set of educational institutions engages with urban systems can inform the design of smarter and more inclusive policies, services, and technologies. Such an approach also provides practical guidance for municipal governments, educational authorities, and private stakeholders committed to aligning educational strategies with urban development goals.

The paper is structured as follows: Section 2 presents the literature background on SSCs and their key stakeholders. Section 3 outlines the methodological approach. Section 4 presents the results of the systematic literature review. Section 5 discusses the findings, and Section 6 concludes the study.

Smart Sustainable Cities: Concepts and Challenges

Smart sustainable cities (SSCs) integrate technological innovation, environmental sustainability, and social inclusion to improve urban life. Among the various definitions, this study adopts the perspective of Ahvenniemi et al. (2017), who conceptualize SSCs as urban systems that use advanced technologies and participatory governance to enhance quality of life, economic performance, and environmental outcomes. Beyond infrastructure, SSCs require institutional coordination and multistakeholder engagement to address systemic urban challenges (Fernandez-Anez et al., 2018).

In this context, digital transformation plays a critical role. The deployment of Internet of Things (IoT) technologies, AI-based analytics, and integrated information systems enables data-driven decision-making. However, the effectiveness of these systems depends on the availability and quality of open data, which are widely recognized as limitations in many SSC initiatives (Kim & Feng, 2024). Poor data interoperability and closed architecture constrain innovation, urban planning, and citizen engagement (Myeong et al., 2022).

SSCs are thus increasingly understood as dynamic ecosystems that demand inclusive strategies—particularly in education. Educational institutions are not only producers of human capital but also enablers of digital literacy, social participation, and localized innovation.

Stakeholders in SSCs and the Role of Educational Institutions

The success of SSCs depends on collaboration among diverse stakeholders. Early models such as the triple helix (Etzkowitz, 1993) emphasized the interaction between university, industry, and government. Later frameworks, including the quadruple and quintuple helix, added civil society and environmental sustainability to account for the increasing complexity of innovation ecosystems (Clement et al., 2022).

Within these models, universities are typically seen as knowledge hubs and innovation drivers (Ardito et al., 2019). However, primary and secondary schools and corporate universities remain underrepresented in SSC studies. Few works, such as Alawadhi et al. (2012), even mention the potential role of schools, and none connect corporate universities to smart or sustainable urban development.

This narrow focus limits the potential to build a more comprehensive and collaborative educational ecosystem. Schools, universities, and corporate universities each hold unique capabilities for supporting SSCs, yet literature lacks a framework that organizes these contributions in a comparative and analytical way—a central objective of this study.

Theoretical Foundations for the Five Dimensions of Educational Contribution

To address this gap, this study organizes the role of educational institutions in SSCs into five interconnected dimensions: knowledge, human capital, innovation, financing, and partnerships. Each dimension is grounded in established theoretical models and adapted to include universities, schools, and corporate universities.

Knowledge

Theories of knowledge management (Nonaka & Takeuchi, 1995) highlight the centrality of knowledge creation and transfer for innovation. Universities function as gatekeepers and evaluators (Ardito et al., 2019), translating academic research into urban solutions. Schools foster scientific literacy and sustainability awareness, while corporate universities adapt specialized knowledge to the needs of industry and cities.

Human Capital

Rooted in human capital theory (Becker, 1964), this dimension addresses the development of technical, cognitive, and civic competencies. Universities offer professional and interdisciplinary training aligned with SSC demands. Schools build foundational skills and critical thinking, and corporate universities provide lifelong learning and upskilling, especially in the digital and sustainability domains.

Innovation

Innovation in SSCs requires multilevel experimentation and collaboration. The triple helix and open innovation (Chesbrough, 2003; Etzkowitz & Leydesdorff, 2000) frameworks describe how universities stimulate applied research and knowledge diffusion. Schools foster innovation through active pedagogies, whereas corporate universities promote internal R&D and cocreation with external stakeholders (Ferraris et al., 2020).

Financing

Financing mechanisms supports research, infrastructure, and community initiatives. Universities act as facilitators of access to national and international funding (Santos, 2022). Schools benefit from project-based partnerships, while corporate universities may invest in education through CSR or ESG-aligned initiatives (Meister, 1999), supporting urban transformation through skill development.

Partnerships

Educational institutions are strategic actors in collaborative governance. Knowledge transfer partnerships (KTPs) illustrate the role of universities in linking academia, government, and industry (Hope, 2016). Schools can connect with NGOs and local agencies, while corporate universities foster cross-sector alliances to scale innovation and urban impact.

Based on the theoretical foundations discussed above, this study proposes a multidimensional framework to explain how educational institutions contribute to smart sustainable cities. The framework is organized around three analytical elements: the types of educational institutions involved, the dimensions through which they contribute, and the expected contribution to smart sustainable city development. In this model, universities, schools, and corporate universities are not treated as homogeneous educational actors, but as institutions with differentiated capacities to generate knowledge, develop human capital, foster innovation, mobilize resources, and build partnerships.

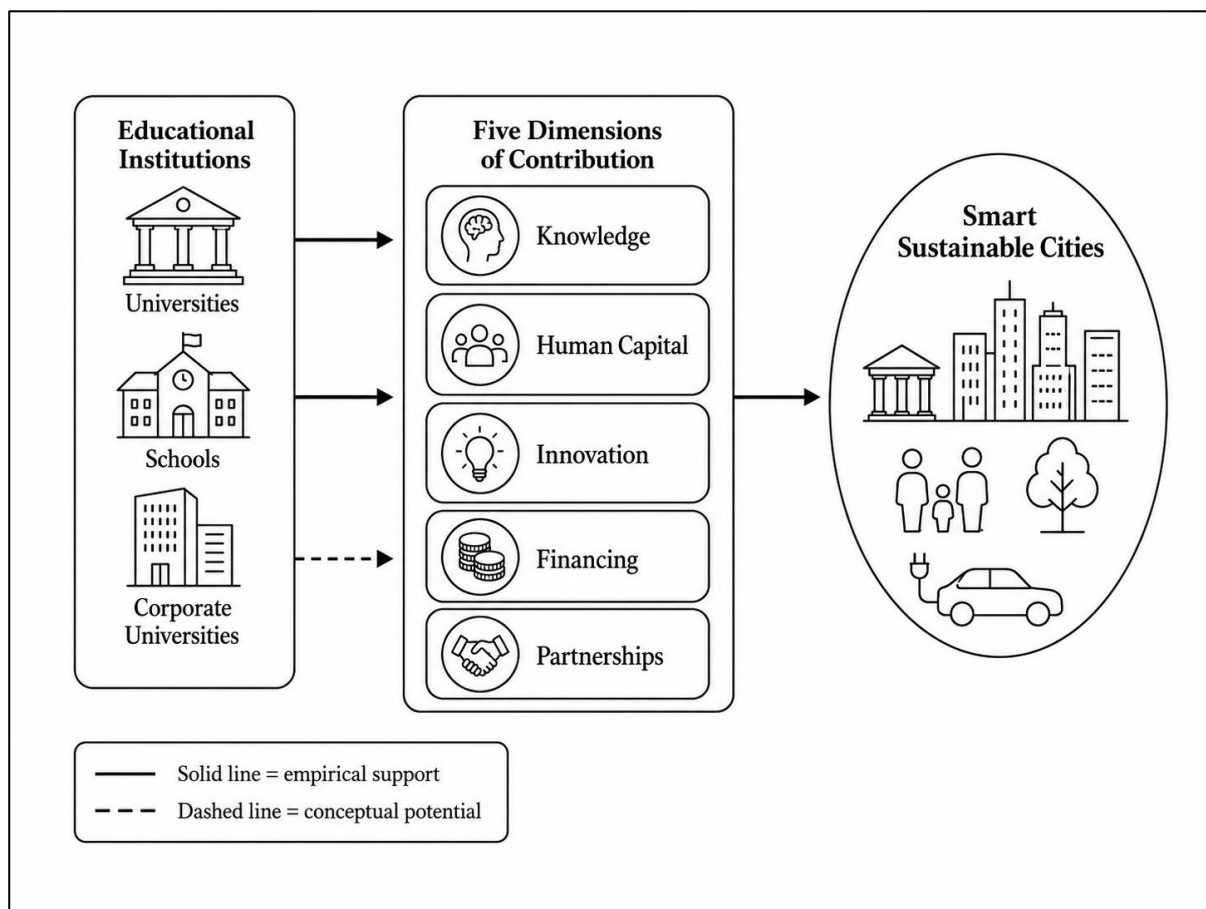


Fig. 1. Multidimensional framework of educational institutions' contributions to smart sustainable cities.

As shown in Figure 1, the proposed framework positions the five dimensions—knowledge, human capital, innovation, financing, and partnerships—as the mechanisms through which educational institutions contribute to smart sustainable cities. Universities and schools are represented with solid lines because their roles were empirically identified in the reviewed literature. Corporate universities, in contrast, are represented with a dashed line because their contribution remains conceptually relevant but empirically underexplored in the SSC literature. This distinction is important because it allows the

framework to synthesize existing evidence while also indicating an emerging research agenda.

This overview supports the development of the conceptual framework and guides the analysis in the following sections.

Method

This study adopts a systematic literature review (SLR) to develop a conceptual framework that explains the multidimensional role of educational institutions in smart sustainable cities (SSCs). The review followed established procedures for identifying, selecting, and analyzing peer-reviewed articles from a major international database.

The Web of Science (WoS) database was selected because of its comprehensive coverage of high-impact journals across multiple disciplines, including urban studies, education, and innovation. The search was conducted in January 2025, using the following string, according to Table 2.

Descriptor	Quantity of items
"smart cit*" and "universit*"	38
"smart cit*" and "school"	19
"sustainable cit*" and "universit*"	12
"sustainable cit*" and "school"	19
"smart cit*" and "corporate universit*"	0
"sustainable cit*" and "corporate universit*"	0
Total	88

Only peer-reviewed articles published between 2010 and 2024 were included. The year 2010 was chosen as the starting point because it marked a significant increase in global publications and policy attention related to smart cities (Albino et al., 2015), and because the concept of smart sustainable cities gained traction in academic and policy discourse during that decade.

To ensure relevance and focus, the following inclusion criteria were applied: articles were published in English; addressed smart (and/or sustainable) cities and explicitly discussed the role of at least one type of educational institution; and were published in peer-reviewed journals indexed in WoS.

Articles were excluded for the following reasons: focused exclusively on technical aspects (e.g., ICT infrastructure) without any educational dimension; addressed education in a nonurban context; presented reviews or meta-analyses unrelated to the role of institutions.

The initial search returned 88 articles. Titles and abstracts were screened to exclude irrelevant publications. This step was followed by a full-text analysis of the remaining articles to verify adherence to the inclusion criteria. After this process, 80 articles were selected for analysis. Finally, 29 articles were selected.

The selected articles were coded using a matrix organized around the five key dimensions proposed in this study: knowledge, human capital, innovation, financing, and partnerships. For each article, we identified which type(s) of educational institution it addressed (university, school, or corporate university) and how these institutions were positioned within the SSC literature.

The analysis also identified the roles played by these institutions within each dimension (e.g., knowledge evaluator, talent developer, innovation catalyst) and used as the basis for the framework discussed in

Sections 4 and 5.

The screening and coding process was conducted by a single reviewer, which introduces a potential source of bias. To mitigate this limitation, the selection criteria were applied consistently across all steps, and decisions were documented to ensure transparency and replicability. The study acknowledges that additional reviewers could improve intersubjective reliability and recommends this for future research.

The selection process is summarized in Figure 2, which follows a simplified PRISMA-style flow diagram to ensure transparency regarding the inclusion and exclusion steps.

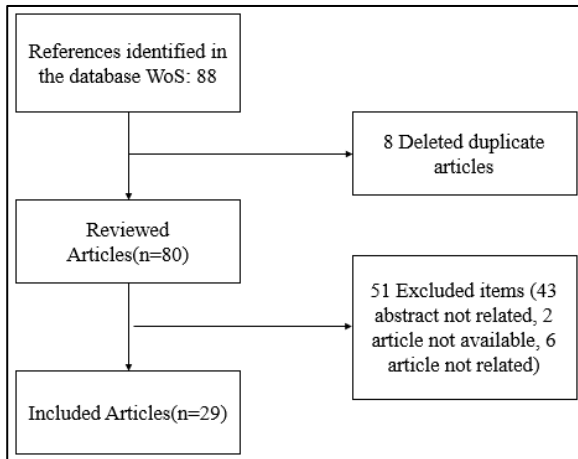


Fig. 2. Selection process

The next section presents the analysis of the results.

The Role of educational institutions (EIs) in smart sustainable cities

In this section, we present the findings obtained from the content analysis. As previously presented in the methodology section, 29 articles were analyzed. The studies were published between 2010 and 2024.

As mentioned in the methods section, the author did not find studies examining the role of corporate universities. The analysis is divided into universities and schools, considering the categorization of dimensions and their respective roles.

The role of universities

Knowledge

Knowledge Manager & Evaluator

Universities play a fundamental role in structuring, assessing, and applying internal and external knowledge to drive innovation and urban governance in smart cities. These institutions contribute to knowledge creation, engaging in interdisciplinary research and fostering collaborations that support technological and sustainable advancements. The Sejong Smart City project illustrates how universities actively participate in the innovation cycle, generating knowledge through complex university campuses and facilitating knowledge spillover via cyberspace platforms and geographical proximity (Han, 2024). Furthermore, universities engage in collaborative research in advanced manufacturing, artificial intelligence, cybersecurity, and environmental sustainability, reinforcing their role in local development (de Souza et al., 2024). These institutions test and implement innovative solutions, contributing to addressing social challenges, such as violence in low-income neighborhoods and teenage pregnancy.

They also strengthen ties with private enterprises, governments, and multinational corporations to enhance socio-technical transformations. Despite their critical contributions, universities still face challenges in adapting their academic programs to meet the demands of smart city development. A gap persists in preparing undergraduates for the professions required in this context, as traditional university structures often do not support interdisciplinary and business-oriented education (Grimaldi & Fernandez, 2017). Smart city initiatives require universities to adopt an integrated approach, connecting business applications with citizen needs and bridging the technological and managerial knowledge gap.

Additionally, these institutions play key roles as cocreators and evaluators in smart city projects, ensuring knowledge transfer among stakeholders (Ardito et al., 2019). While they may not always occupy leadership positions in urban projects, their role in design and implementation has become increasingly relevant. Universities also facilitate cocreation processes, strengthening stakeholder collaboration by offering scientific insights and contributing to the selection and evaluation of urban innovation proposals (Steils et al., 2021).

Knowledge Provider & Gatekeeper

Universities play a central role in generating and disseminating knowledge that supports innovative urban and environmental solutions. Their contribution extends to knowledge transfer within sustainable entrepreneurial ecosystems, fostering collaboration with science and technology parks, government entities, and incubators to drive sustainable innovation (Chaudhary et al., 2023). They also act as facilitators of knowledge exchange, directly supporting local authorities in capacity-building efforts to develop sustainable cities (Hope, 2016). In addition to research, universities play a key role in education, particularly by bridging GovTech and Civic Tech, and equipping students with transformative skills in design thinking, agile methodologies, and lean principles (Yoshida & Thammetar, 2021). Their engagement in interdisciplinary research spans artificial intelligence, cybersecurity, blockchain, and environmental sustainability, allowing them to test and implement disruptive solutions directly benefiting local communities (de Souza et al., 2024). Beyond these roles, universities are key actors in smart city projects, acting as knowledge providers to support urban innovation (Ardito et al., 2019). Their participation goes beyond research, extending to promoting student awareness and fostering stakeholder collaboration to create a shared vision for smart city development (Ferraris et al., 2020). Additionally, universities influence decision-making processes by generating applicable research, often working with SMEs and other organizations (Anttila & Jussila, 2018). Through cocreation and engagement with multiple stakeholders, they contribute scientific insights that refine smart city strategies, ensuring that decision-making is well-informed and effective throughout project implementation (Steils et al., 2021).

Human Capital

Talent Developer

Universities play a key role in preparing professionals to work in public management, innovation, and sustainability within smart cities. The University of Coimbra exemplifies this contribution through its partnership with Instituto Pedro Nunes Incubator, which supports high and medium technology startups, some of them the university's spin-offs (Santos, 2022). Likewise, the University of New Mexico (UNM) promotes experiential learning through interdisciplinary collaboration in spaces such as the Innovation Plaza and WHY Lab, equipping students with industry-relevant tools and offering programs such as Peace Engineering, which integrates sustainability, conflict management, and technology management (Jordan et al., 2021). Additionally, universities serve as a bridge between GovTech and Civic Tech, training students in methodologies such as design thinking and agile approaches and ensuring that they are prepared to act as engaged citizens in smart societies (Yoshida & Thammetar, 2021). Universities also play a role in fostering entrepreneurship, as evidenced by studies

on entrepreneurial education in AI and its impact on self-efficacy and competency in smart cities such as Neom, Saudi Arabia, where university students are key drivers of innovation and business creation (Nuseir et al., 2020). Universities also shape education and training programs focused on sustainability and urban management. They integrate diverse stakeholders—including municipal planners, businesses, and advisory boards—into their curricula, ensuring that students apply their knowledge in practical contexts, such as business models, urban mobility, and environmental sustainability (Arnold, 2022). However, universities still face challenges in aligning academic programs with the evolving demands of smart cities, as traditional structures often fail to incorporate essential emerging technologies for public administration and business (Grimaldi & Fernandez, 2017). To address these challenges, universities such as the University of Valladolid lead training initiatives that develop transversal competencies for smart city projects, bridging the gap between academia and industry while promoting lifelong learning systems adapted to urban challenges (Adiego & Martín-Cruz, 2021). Additionally, universities play a role in environmental education, implementing projects such as food gardens that encourage pro-environmental behaviors and integrate sustainability topics into science education (Eugenio-Gozalbo et al., 2021).

Culture & Engagement Promoter

Universities create dynamic spaces for innovation, culture, and entrepreneurship, fostering academic communities that are actively engaged in urban and sustainable transformation. Universities act as conduits for knowledge exchange, facilitating partnerships with local authorities and industry to develop sustainability-focused solutions, such as low-carbon economies and improved urban housing (Hope, 2016). Educational programs equip students with transformative competencies in areas such as design thinking and agile methodologies, enhancing their capacity to navigate and contribute to smart societies (Yoshida & Thammetar, 2021). Additionally, interdisciplinary platforms for hands-on learning, such as the University of New Mexico's Innovation Plaza and WHY Lab, integrate sustainability, diplomacy, and technology management into education, further reinforcing their role in preparing future professionals (Jordan et al., 2021). Universities also bridge civic engagement, entrepreneurship, and sustainability through collaborative projects that connect students with stakeholders, ensuring the practical application of sustainable city concepts (Arnold, 2022). Initiatives such as the CITADEL project highlight their role in fostering civic participation among young people (Sánchez-Serrano, 2022), while environmental sustainability efforts, such as urban gardening programs, enhance students' ecological awareness and pro-environmental behaviors (Eugenio-Gozalbo et al., 2021). A significant example is the University of Łódź, which pioneers natural capital projects, collaborates with government and NGOs, and actively participates in conservation programs to drive urban sustainability (Ratajczyk et al., 2017).

Innovation

Innovation Developer & Catalyst

Universities play a fundamental role in driving applied research, incubating startups, and fostering the development of emerging technologies. The University of Coimbra exemplifies this through its partnership with the Instituto Pedro Nunes Incubator, which has supported high and medium-tech startups, many of them university spin-offs, enabling a shift towards applied research and entrepreneurship and transforming Coimbra into a knowledge-based economy (Santos, 2022). Similarly, universities facilitate knowledge transfer within sustainable entrepreneurial ecosystems, collaborating with stakeholders such as science parks, accelerators, and government organizations to address sustainability challenges (Chaudhary et al., 2023). The Sejong Smart City project further illustrates its role in knowledge creation and innovation, leveraging both digital and physical spaces to enhance urban development (Han, 2024). Beyond entrepreneurship, universities engage in multidisciplinary research and education to support smart city initiatives, as seen in institutions such as the University of New

Mexico, which integrates experiential learning and interdisciplinary collaboration to train professionals in sustainability, technology management, and conflict resolution (Jordan et al., 2021).

Additionally, universities contribute to advancements in artificial intelligence, cybersecurity, and environmental sustainability, testing and applying disruptive solutions to enhance societal well-being (de Souza et al., 2024). Universities also serve as hubs for lifelong learning and professional development, ensuring that students and industry professionals acquire essential skills for smart city projects (Adiego & Martín-Cruz, 2021). Their role in research, education, and strategic partnerships allows them to influence the development of intelligent urban environments, directly impacting governance and technological progress (Anttila & Jussila, 2018).

Financing

Investment & Funding Facilitator

Universities play a key role in connecting researchers and entrepreneurs to national and international funding for innovation and sustainability projects. The University of Coimbra exemplifies this through its partnership with the Instituto Pedro Nunes Incubator, which has supported the emergence of high and medium-tech startups, many of them university spin-offs, while also shifting the university's research focus to applied activities and fostering entrepreneurship among students and researchers (Santos, 2022). Similarly, universities act as knowledge providers and cocreators in smart city projects, leveraging their expertise to secure national and supranational funding for urban innovation (Ardito et al., 2019). By facilitating knowledge transfer and expertise recombination among stakeholders, they ensure that smart city initiatives receive financial funding and are effectively implemented. Beyond securing resources, universities foster cocreation and collaboration among public and private organizations, integrating knowledge and strengthening smart city ecosystems (Ferraris et al., 2020). Their partnerships extend to research teams that support small and medium-sized enterprises (SMEs) in developing innovative solutions for urban sustainability (Anttila & Jussila, 2018). Additionally, universities contribute scientific insights that help stakeholders refine proposals and select the most viable projects, ensuring efficient use of funding and resources (Steils et al., 2021).

Partnership

Partnership & Knowledge Transfer Facilitator

Universities act as strategic connectors between local governments, businesses, and communities, fostering knowledge transfer partnerships (KTPs) to drive sustainable urban development. They facilitate collaboration within sustainable entrepreneurial ecosystems by engaging stakeholders such as science parks, accelerators, and government organizations, strengthening the foundations of innovation and sustainability (Chaudhary et al., 2023). A clear example is their role in knowledge exchange initiatives, where they enhance local governance capacities and implement sustainability-driven projects, such as low-carbon economies and improved urban housing (Hope, 2016). Universities also create spaces for interdisciplinary collaboration, as seen in the University of New Mexico's Innovation Plaza and WHY Lab, which integrates hands-on learning with industry partnerships to train future leaders in sustainability and technology management (Jordan et al., 2021). Additionally, they serve as crucial knowledge providers and cocreators in smart city projects, ensuring the effective transfer and application of external knowledge (Ardito et al., 2019). Engaging municipal planners and industry leaders strengthens economic education, sustainable construction, and urban mobility planning (Arnold, 2022) while facilitating networking and stakeholder collaboration to build integrated smart city ecosystems and secure financial resources for research and implementation (Ferraris et al., 2020). For example, the University of Łódź has led projects focused on preserving natural capital and collaborating with government entities and NGOs to promote urban sustainability (Ratajczyk et al.,

2017).

The role of schools

Knowledge

Knowledge Manager & Evaluator

Schools play an important role in fostering science and technology literacy from an early age, equipping students with the skills needed for a digital and sustainable future. In Copenhagen, a collaborative project between schools and university researchers integrated sustainability into language education, demonstrating how interdisciplinary approaches can enhance students' engagement with global challenges (Svarstad & Risager, 2024). Similarly, primary schools in Malta have incorporated outdoor teaching and nature-based education to strengthen environmental awareness among children, providing empirical insights into how space and teacher attitudes shape science education from an early stage (Falzon et al., 2024). Beyond formal classroom instruction, schools also create opportunities for hands-on learning experiences that connect students to sustainability practices. A school-led farming project, for example, engaged students in composting organic waste, teaching them practical applications of environmental science while fostering a deeper understanding of sustainable practices (Dutta & Chandrasekharan, 2024).

Knowledge Provider & Gatekeeper

Schools play a role in disseminating essential concepts of sustainability and innovation, ensuring that future generations are equipped with the knowledge and skills necessary to address global challenges. An example is the integration of smart sustainable city concepts into the school curriculum, where students engage in programming, electronic components, and urban sustainability through hands-on projects using Arduino technology (Hsiao et al., 2024). Similarly, schools utilize their proximity to green spaces to enhance environmental education, thereby facilitating field excursions and experiential learning that foster a deeper understanding of ecological sustainability (Wolsink, 2016). These initiatives illustrate how schools serve as active agents in embedding sustainability principles into formal education. Beyond environmental education, schools also prepare students for careers in sustainable industries. The *From Farm to Fork* program, implemented in a hotel-management high school in Italy, exemplifies this by training students in sustainable food practices and bridging dietary science with gastronomy to promote sustainability in the restaurant sector (Pedrini et al., 2024). Additionally, the smart school initiative in Korea is redefining the educational landscape by integrating technology, space redesign, and career development strategies to cultivate future-ready citizens (Cho et al., 2020).

Human Capital

Talent Developer

Schools create the foundation for critical thinking and the formation of engaged citizens, equipping students with the skills necessary for urban and environmental transformation. In Northern Uganda, schools have played a significant role in fostering student engagement by integrating critical thinking and civic participation into education, as seen in a study conducted with students across multiple districts, highlighting how schools cultivate knowledge and awareness to shape proactive citizens (Nuwategeka et al., 2024). Similarly, initiatives such as the Hispanic Entrepreneurial Program for Innovation (HEPI) at Universidad del Turabo embed entrepreneurship into the curriculum, encouraging students to develop problem-solving skills that contribute to their communities (Ortiz-Fournier et al., 2010). Schools also collaborate with municipal governments to reduce dropout rates and provide self-sufficiency training, reinforcing the role of education in social mobility and civic engagement. Beyond entrepreneurship and academic excellence, smart school initiatives are critical in preparing students for active participation in society. In Korea, a government-led program seeks to

modernize educational environments by redesigning school spaces, integrating educational technology, and offering lifelong career development opportunities (Cho et al., 2020). This initiative strengthens students' critical thinking and adaptability by fostering collaboration among academia, government, and technology startups, ensuring that they are well-prepared to engage in sustainable urban transformation.

Culture & Engagement Promoter

Schools play a role in disseminating sustainable values and practices from an early age, shaping conscious and participatory citizens. One approach is leveraging proximity to green spaces for environmental education excursions, as seen in secondary schools where students engage in experiential learning that deepens their understanding of sustainability (Wolsink, 2016). Additionally, sustainability is integrated into specialized curricula, such as the *From Farm to Fork* program in Italy, which trains students to apply sustainable food practices in the restaurant sector, enhancing technical skills while fostering a culture of responsibility towards environmental and gastronomic sustainability (Pedrini et al., 2024). Beyond curriculum design, schools embed sustainability into everyday learning experiences, integrating environmental principles into subjects such as language education and outdoor activities, such as school gardens, which promote environmental literacy and character formation (Rosyadi, 2024). These initiatives empower students to become change agents in their communities. Furthermore, sustainable school projects actively involve teachers, students, and external experts in collaborative initiatives, ensuring that sustainability education extends beyond theory to real-world applications (Curto et al., 2021).

Innovation

Innovation Developer & Catalyst

Schools encourage active methodologies and experimentation to stimulate innovative thinking from an early age, integrating hands-on learning into diverse curricular areas. A clear example is the incorporation of smart city concepts into the information technology curriculum, where students engage in programming and electronics projects using Arduino boards, connecting theoretical knowledge with real-world problem-solving (Hsiao et al., 2024). Similarly, institutions such as Huertas Junior College and Universidad del Turabo emphasize experiential learning through initiatives such as the Hispanic Entrepreneurial Program for Innovation (HEPI), which fosters entrepreneurial skills among students and strengthens collaboration among academia, government, and businesses (Ortiz-Fournier et al., 2010). Additionally, environmental education initiatives reinforce the role of experiential learning in shaping critical thinking and responsibility. Schools integrate sustainability themes into various subjects, using outdoor activities such as school gardens to enhance environmental literacy and values education (Rosyadi, 2024). Moreover, they engage students in real-world sustainable projects through collaborative efforts with teachers and external experts, ensuring that learning extends beyond traditional classrooms into applied, community-driven experiences (Curto et al., 2021).

Financing

Investment & Funding Facilitator

Schools encourage educational and environmental projects that can receive financial support from public and private initiatives, fostering long-term sustainability and innovation. An example is the collaboration between Huertas Junior College and Universidad del Turabo, which integrates research and entrepreneurship into the curriculum through initiatives such as the Hispanic Entrepreneurial Program for Innovation (HEPI). This program enhances students' entrepreneurial skills and strengthens connections between academia, government, and businesses, creating opportunities for financial support and strategic partnerships (Ortiz-Fournier et al., 2010). Additionally, these institutions have established agreements with enterprises and public agencies to address human capital needs,

ensuring that students' education aligns with economic and social demands. The development of an Interactive Center of Science and Technology exemplifies how schools can leverage collaborations for funding and infrastructure expansion. Environmental projects in schools also benefit from financial and institutional support, as seen in Malta's primary schools, where outdoor teaching and nature-based education initiatives enhance sustainability awareness among young students (Falzon et al., 2024). These programs require investment in outdoor spaces, teacher training, and curriculum development, making public and private funding essential for their success.

Partnership

Partnership & Knowledge Transfer Facilitator

Schools develop collaborative networks with community organizations, fostering learning about sustainable practices and emerging technologies. An example is the partnership among Huertas Junior College, Universidad del Turabo, and various government and business entities, which has led to educational programs integrating entrepreneurship, technology, and sustainability. The Hispanic Entrepreneurial Program for Innovation (HEPI) equips students with entrepreneurial skills, while the Employment and Micro Enterprise Center facilitate collaboration between academia and industry to address local workforce needs. Additionally, the development of an Interactive Center of Science and Technology in partnership with the Liberty Science Center exemplifies how schools can leverage networks to create impactful learning environments (Ortiz-Fournier et al., 2010). Schools also promote sustainable practices through partnerships that enhance environmental education. In Malta, primary schools collaborate with researchers to study the impact of outdoor teaching and nature-based education, reinforcing the importance of experiential learning in sustainability (Falzon et al., 2024). Similarly, schools integrate environmental principles into multiple subjects, using hands-on activities such as school gardens to strengthen students' environmental literacy and promote values-based education that positions them as future change agents for sustainability (Rosyadi, 2024).

While the role of corporate universities in this dimension is conceptually relevant, particularly in advancing ESG agendas and strategic innovation, most findings remain propositional. The current literature lacks robust empirical evidence of how corporate universities are integrated into SSC strategies. Their potential is highlighted here based on theoretical insights and indirect references, rather than field-based studies.

The next section discusses the findings and highlights the gains and contributions to smart sustainable cities.

Dimensions of the role of educational institutions in smart sustainable cities

Building on the proposed framework, this section discusses how the five dimensions identified in literature (knowledge, human capital, innovation, financing, and partnerships) help explain the contribution of educational institutions to smart sustainable cities. Rather than treating universities and schools as isolated actors, the analysis shows how their roles are connected to broader urban innovation ecosystems, particularly through knowledge generation, competence development, collaborative projects, resource mobilization, and stakeholder engagement. Although the reviewed empirical literature focuses mainly on universities and schools, the discussion also indicates the conceptual space for corporate universities as emerging actors in SSC-oriented training, innovation, and sustainability agendas.

Knowledge - The research findings reinforce the primary concept of schools and universities as generators and disseminators of knowledge, as well as their established role in the triple or quadruple helix frameworks. (Ortiz-Fournier et al., 2010 ; Lombardi et al., 2012 ; van der Hoogen et al., 2019, 2020). Despite this prevalence, academic programs are still distancing themselves from the city's

objectives for implementing innovative smart city services (Grimaldi & Fernandez, 2017). The authors emphasise that there is a gap in preparing undergraduates for the professions required for smart city implementation

Human Capital - In the same way as knowledge, the formation of human capital is the core of schools and universities. The studies analysed demonstrate that both seek to develop hard skills (knowledge of technology or ecology) and soft skills based on civic education (Mayangsari & Novani, 2015; van der Hoogen et al., 2019).

Innovation - Innovation is intrinsically related to the generation and dissemination of knowledge. New models, methodologies, or solutions emerge from the knowledge generated and shared with other stakeholders, contributing to the development of a smart economy, smart people, smart governance, smart mobility, a smart environment and smart living (Giffinger et al., 2007).

Financing - The analysis of the cases suggests a connection with the proposal by Ferraris et al. (2020), indicating that the university is responsible for financing projects by presenting smart city research proposals to national or supranational funds. Certainly, schools do not have this financing capacity, but they can articulate with other stakeholders who support the costs of the initiatives. Additionally, many of the actions developed in schools involve studies or projects developed by universities that support the funding.

Partnership – The findings suggest that, in addition to knowledge, the dimension of partnerships has the greatest potential for university achievement. Once again, a connection with the triple or quadruple helix framework (Lombardi et al., 2012) is perceived (van der Hoogen et al., 2019; 2020). However, universities are not in a leadership position in smart city projects, but their other novel roles are becoming more prevalent in the design and implementation of such projects (Ardito et al., 2019). On the other hand, the school has a more limited role but has the potential for expansion for universities, ICTs and companies. Finally, the main objective is to offer hands-on methodologies connected to the needs of smart sustainable cities.

The contributions of educational institutions to smart sustainable cities

The findings of this study highlight the differentiated yet complementary contributions of universities, schools, and corporate universities to the development of Smart sustainable cities (SSCs), structured according to the five dimensions of the proposed conceptual framework: knowledge, human capital, innovation, financing, and partnerships.

To make the proposed framework more explicit, Table 3 synthesizes how each type of educational institution contributes, or may potentially contribute, to SSC development across the five dimensions. The table also indicates the level of empirical support identified in the reviewed literature, distinguishing between roles supported by previous studies and roles that remain conceptually relevant but empirically underexplored.

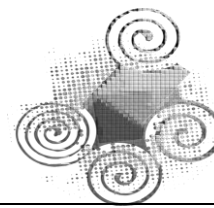
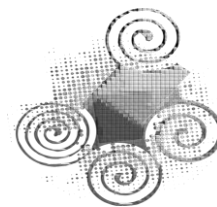


Table 3. Multidimensional roles of educational institutions in smart sustainable cities

Dimension	Universities	Schools	Corporate universities	Contribution to SSCs	Empirical support
Knowledge	Generate, evaluate, and transfer scientific and applied knowledge to support urban problem-solving, public management, sustainability, and technological innovation.	Promote scientific literacy, sustainability awareness, and early understanding of urban and environmental challenges through formal and experiential learning.	Adapt and diffuse strategic, technical, and managerial knowledge aligned with organizational capabilities, ESG agendas, and urban sustainability needs.	Strengthens evidence-informed decision-making, knowledge circulation, and local capacity to address complex urban challenges.	Strong for universities; moderate for schools; limited/conceptual for corporate universities.
Human capital	Train professionals with interdisciplinary, technical, managerial, and civic competences required for SSC development.	Develop foundational skills, critical thinking, citizenship, environmental awareness, and future-oriented competences from early education.	Provide upskilling, reskilling, and lifelong learning programs aligned with digital transformation, sustainability, and workforce development.	Develops the individual and collective capabilities needed for inclusive, adaptive, and sustainability-oriented urban transformation.	Strong for universities; moderate for schools; limited/conceptual for corporate universities.
Innovation	Foster applied research, experimentation, incubation, cocreation, and technology transfer in collaboration with government, industry, and society.	Encourage active methodologies, project-based learning, experimentation, and community-oriented innovation practices.	Support internal innovation, organizational learning, and potential cocreation with external stakeholders around sustainability and urban challenges.	Enhances urban innovation ecosystems, experimentation capacity, and the development of solutions for smart and sustainable urban problems.	Strong for universities; moderate for schools; limited/conceptual for corporate universities.
Financing	Attract, manage, and connect research, innovation, and sustainability projects to national and international funding opportunities.	Mobilize resources mainly through educational, environmental, and community-based projects, often in partnership with universities, public agencies, NGOs, or private actors.	Potentially invest in professional training, ESG-related initiatives, and sustainability-oriented innovation through CSR, corporate education, or strategic partnerships.	Expands the resource base for educational, technological, social, and environmental initiatives linked to SSC development.	Moderate for universities; limited for schools; limited/conceptual for corporate universities.
Partnership	Connect academia, government, industry, and civil society through knowledge transfer partnerships, research networks, urban projects, and innovation ecosystems.	Build local networks with families, communities, NGOs, public agencies, and universities to support civic engagement and sustainability learning.	Potentially create cross-sector alliances connecting firms, workers, educational actors, and public agendas around sustainability, innovation, and urban transformation.	Strengthens collaborative governance, stakeholder integration, and the coordination required to address systemic urban challenges.	Strong for universities; moderate for schools; limited/conceptual for corporate universities.



The synthesis presented in table 3 shows that universities are the most extensively examined educational actors in SSC literature, particularly in relation to knowledge generation, innovation, partnerships, and the mobilization of resources. Schools appear as relevant but less explored actors, especially in the development of human capital, civic engagement, sustainability awareness, and community-based innovation. Corporate universities, in contrast, are not directly addressed in the reviewed empirical literature, but their inclusion in the framework is theoretically justified by their potential role in workforce development, organizational learning, ESG-oriented training, and cross-sector collaboration. Therefore, the framework both consolidates existing evidence and identifies an important research gap regarding the contribution of corporate universities to smart sustainable city development.

Universities play a central role in knowledge transfer and in the creation of collaborative environments with local stakeholders. Successful cases, such as the partnership between the University of Coimbra and the IPN-Incubator demonstrate how university-industry-government cooperation fosters knowledge-based startups, urban competitiveness, and innovation ecosystems (Santos, 2022). Similarly, knowledge transfer partnerships (KTPs) have proven essential for building urban sustainability capacity, supporting low-carbon transitions, and enhancing social and environmental performance (Hope, 2016). These initiatives expand the traditional academic role, positioning universities as hubs for GovTech and Civic Tech solutions that improve public service efficiency while aligning with the Sustainable Development Goals (Yoshida & Thammetar, 2021). Programs such as those at the University of Łódź, which link natural capital preservation to economic development, illustrate how universities integrate environmental management into urban innovation strategies (Ratajczyk et al., 2017). A practical example is the SMARTWB project (Erasmus+, 2023), an EU-funded initiative aimed at modernizing university curricula in climate-smart urban planning through interdisciplinary approaches, the integration of sustainability principles into teaching, and the upskilling of academic staff. This case illustrates how universities can proactively connect higher education with the governance needs of sustainable urban development.

In addition, universities strengthen human capital by preparing students for the complexity of SSC through interdisciplinary programs in sustainable urbanism, emerging technologies, and applied innovation (Grimaldi & Fernandez, 2017). These programs encourage cross-sectoral collaboration and the adoption of applied innovation, reinforcing the role of universities as transformative agents in urban ecosystems.

Schools, in turn, contributed by embedding sustainability principles into early education and fostering a culture of civic engagement. Projects based on hands-on learning, such as those carried out in Oslo, allowed students to explore dimensions of smart cities, such as renewable energy use, sustainable food systems, and urban planning (Svarstad & Risager, 2024). Other initiatives including Italy's "From Farm to Fork" and Mumbai's school garden programs, link classroom learning to pro-environmental action (Pedrini et al., 2024; Dutta & Chandrasekharan, 2024). By integrating emerging technologies into curricula, as observed in South Korea, schools prepare students with Industry 4.0 skills, reinforcing the alignment between education and future workforce demands (Cho et al., 2020). Outdoor learning and environmental education programs in Malta and India demonstrate how integrating green spaces and local knowledge into curricula promotes environmental governance and supports urban sustainability strategies (Falzon et al., 2024; Nuwategeka et al., 2024).

While corporate universities are recognized in the literature for their strategic potential in aligning professional training with ESG goals, empirical evidence of their contribution to SSC remains scarce. This gap underscores the need for field-based research to assess how such institutions can effectively

influence urban governance and sustainability outcomes.

Overall, the evidence compiled in this study demonstrates that educational institutions play a relevant role in advancing smart, sustainable, and inclusive urban futures. By acting synergistically across the five framework dimensions, educational institutions not only educate citizens to become more aware but also catalyze innovation, foster cross-sector partnerships, and contribute to the systemic transformation of cities.

Conclusions

This study advanced the understanding of the multidimensional role of educational institutions in the development of smart sustainable cities (SSCs) by proposing a framework structured around five dimensions: knowledge, human capital, innovation, financing, and partnerships. Rather than treating education as a peripheral component of urban development, the findings show that educational institutions operate as strategic actors in the construction of more inclusive, innovative, and sustainable urban systems. In this sense, the study responds to the call for broader and more integrated approaches to SSCs, which emphasize not only technological infrastructure but also participatory governance, institutional coordination, stakeholder engagement, and social inclusion (Ahvenniemi et al., 2017; Fernandez-Anez et al., 2018; Kim & Feng, 2024).

The findings dialogue directly with the literature on knowledge-based urban development and helix models of innovation. Previous studies have emphasized the role of universities as knowledge hubs, innovation drivers, and connectors between government, industry, and society (Etzkowitz, 1993; Etzkowitz & Leydesdorff, 2000; Lombardi et al., 2012; Ardito et al., 2019; Ferraris et al., 2020). This review confirms that universities are the most consolidated educational actors in SSC literature, especially in relation to knowledge generation, knowledge transfer, applied research, innovation ecosystems, and cross-sector partnerships. However, the findings also extend this literature by showing that the educational contribution to SSCs cannot be fully understood through the university-centered perspective alone. Schools and corporate universities, although less explored, reveal the need to broaden the analytical lens from isolated institutions to an educational ecosystem connected to urban transformation.

In relation to knowledge and human capital, the results reinforce the importance of education for developing the cognitive, technical, civic, and sustainability-oriented capabilities required by SSCs. The literature on knowledge management highlights the role of knowledge creation, transfer, and application in innovation processes (Nonaka & Takeuchi, 1995), while human capital theory emphasizes education and training as drivers of individual and collective development (Becker, 1964). The reviewed studies show that universities contribute by producing and translating scientific and applied knowledge into urban solutions, while schools contribute by developing scientific literacy, environmental awareness, critical thinking, and civic engagement from early education. This finding is important because it shifts the debate from the idea of education as workforce preparation alone to education as a foundation for citizenship, social participation, and sustainability-oriented urban learning.

Regarding innovation, the findings support the view that SSCs depend on collaborative and open innovation arrangements involving multiple stakeholders. The triple and quadruple helix perspectives emphasize the interaction among universities, industry, government, and civil society in the production and diffusion of innovation (Etzkowitz & Leydesdorff, 2000; Lombardi et al., 2012; Clement et al., 2022). The evidence reviewed in this study shows that universities contribute through applied research, incubation, experimentation, and cocreation with public and private actors, while schools contribute through project-based learning, active methodologies, environmental education, and community-oriented experimentation. Thus, innovation in SSCs is not limited to technological development or university-industry relations; it also involves pedagogical practices and community-based learning

processes that prepare citizens to participate in urban sustainability transitions.

The financing and partnership dimensions further demonstrate that educational institutions contribute to SSCs by mobilizing resources and connecting actors. Universities are particularly relevant in accessing research funding, structuring innovation projects, and linking local initiatives to national and international funding opportunities (Ardito et al., 2019; Ferraris et al., 2020; Santos, 2022). Schools, in contrast, usually have more limited financial autonomy, but they can mobilize support through partnerships with universities, public agencies, NGOs, families, and local communities. This distinction reinforces the importance of collaborative governance in SSCs, as urban transformation depends not only on individual institutions but on their capacity to articulate complementary resources, knowledge, and legitimacy across sectors (Hope, 2016; Clement et al., 2022).

A central theoretical contribution of this study lies in organizing these differentiated roles into a multidimensional framework. The framework shows that universities, schools, and corporate universities contribute to SSCs in different but complementary ways. Universities are strongly represented in literature as knowledge managers, innovation catalysts, funding facilitators, and partnership builders. Schools appear as relevant actors in the formation of civic awareness, sustainability values, foundational skills, and community-based innovation. Corporate universities, in turn, remain underexplored in the empirical SSC literature, but their inclusion in the framework is theoretically justified by their potential contribution to lifelong learning, workforce development, ESG-oriented training, organizational innovation, and cross-sector collaboration. Therefore, the framework not only consolidates existing evidence but also identifies a research gap concerning the role of corporate universities in SSC-oriented strategies.

From a practical perspective, the framework can support policymakers, education leaders, urban managers, and private organizations in designing integrated educational strategies aligned with SSC goals. Municipal governments can use the framework to identify how different educational institutions may contribute to local urban challenges. Universities can redesign curricula, research agendas, and extension projects to address climate-smart urban planning, digital transformation, and sustainability governance. Schools can adopt project-based and community-oriented learning to connect students with real urban problems from an early age. Corporate universities can align professional development programs with ESG priorities, smart city innovation, and sustainability-oriented capabilities.

This study has limitations. The review relied on peer-reviewed articles indexed in a single database, which may have excluded relevant studies from other databases, policy reports, institutional documents, and practice-oriented publications. The analysis was also limited by the scarcity of empirical studies on corporate universities and their relationship with SSCs. As a result, their role was treated as conceptually relevant but empirically underexplored. In addition, the screening and coding process was conducted by a single reviewer, which may have introduced selection and interpretation bias, despite the use of explicit inclusion and exclusion criteria.

Future research should expand the empirical basis of the framework by including additional databases, grey literature, policy documents, and case studies. Comparative and longitudinal studies could examine how different educational institutions contribute to SSCs across diverse socioeconomic, cultural, and institutional contexts. Further research is also needed to investigate how schools can be more effectively integrated into educating city agendas and how corporate universities can contribute to ESG-oriented training, digital upskilling, and innovation ecosystems. By advancing these questions, future studies can deepen understanding of how educational ecosystems support inclusive, resilient, and sustainable urban transformation.

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