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Postsecondary organizations and their role in advancing sustainable smart cities: towards a system-oriented perspective

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Postsecondary institutions such as public and private universities have a key role to play in the development of sustainable smart cities. This paper discusses aspects of this role in terms of historical contributions, examples of contributions from the standpoint of two universities, and potential future contributions. The treatment of these aspects from a system-oriented perspective is also addressed. Researchers working on leading edge technologies have resources that enable them to introduce disruptive solutions that enhance the well-being of society. On the other hand, it is clear that different university realities demand unique actions depending on whether they reside in developing or developed countries, although common social problems have also been identified. Overall, there is an opportunity for universities to test new ideas and implement them in communities, especially where they reside. We discuss the role of universities in a broad sense, where contributions are briefly described and acknowledged. The focus is on applications for sustainability and social good that have been or could be developed in universities as new research opportunities to improve the quality of life of the general population. We also argue that it is essential to consider university contributions to the creation of smart cities in the context of a system-oriented perspective.

KEYWORDS

postsecondary institutions, smart cities, system-oriented approaches, education, technology, research

1 Introduction

Postsecondary institutions such as public and private universities have a key role to play in the development of sustainable smart cities. Postsecondary education institutions generally include universities, colleges, polytechnics, institutes, and university colleges, and others. In particular, universities have a strong potential to introduce disruptive solutions to enhance the well-being of society, and can explore opportunities to test these new ideas and solutions, and implement them in their local communities. The role of universities in discussing, proposing, and developing new technologies is unquestionable. In this sense, societies have benefited from different knowledge areas, such as electricity supply improvement (da Silveira Bezerra et al., 2017), medical diagnosis (Olson and Graber, 2020), system processes (Soysal and Baltaru, 2021), Internet of Things (IoT) (Vinayachandra and Krishna Prasad, 2020) and so many others. Recently, smart cities have become a topic of increasing interest through important governmental, industrial, and academic initiatives. These initiatives have been aligned with the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable

Development, which established critical goals for this millennium (United Nations, 2015).

By definition, smart cities demand information and communication technologies (ICTs) to increase operational efficiency, improving the quality of services and citizen welfare (Vasconcelos et al., 2022a). Unfortunately, many researchers who focus on smart cities' technological aspects have often paid less attention to the latter aspect. Further, numerous papers clearly show that a smart city may be excluding, leaving people behind, and can even lead to increasing the gap between the excluded and included members of society (Malek et al., 2021; Short, 2021). In this context, universities may help define ways to reduce this gap while creating new technologies and opportunities for all the likely stakeholders involved, which include citizens, educational organizations, government, and industry. A smart city must be sustainable, which raises environmental issues such as waste management (Shukla and Hait, 2022). Collecting and recycling waste create a cleaner environment, which helps with the preservation of oceans. As discussed in Landrigan et al. (2020) and Law et al. (2020), untreated waste jeopardizes many aquatic creatures. At the same time, environmental problems are created when waste is exported, giving other countries the burden of hosting contaminated and hazardous material (Browning et al., 2021). However, a society should also be economically and socially sustainable. In this sense, business models to provide an incentive to create sustainable initiatives should be considered, which should also consider including people by ensuring a universal minimum wage so that they can survive (Saad-Filho, 2015; de Bem Lignani et al., 2011). The problem of vulnerable women under domestic violence (Spencer et al., 2020) is also a concern that should be mitigated. Energy inclusion (Zhao et al., 2022) is another issue that should be considered, bringing the excluded to society and enabling them to play a role in the creative community. This will make society and cities more socially sustainable.

Postsecondary organizations such as universities have a key role to play in advancing sustainable smart cities, and they are already involved in a wide range of related initiatives as described in Onu et al. (2023), where several smart city-related solutions have been explored. As one of these solutions, renewable power generation sources have been considered and implemented in so many places (Fernandes et al., 2019), paving the technological way to a clean generation power process. In this paper, however, we propose that universities may take a step forward, offering some policies and discussing some ideas to help advance sustainable smart cities, which also involve promoting an inclusive society. The next sections show how this will happen, opening a wide window of research and development opportunities to which universities, the cradle of creative solutions, may contribute.

For this sake, we show that different realities and localities demand different responses. In this sense, for example, access to electricity and basic sanitation may pose a problem to developing countries but are not an issue to developed ones. Universities may study these problems and help address solutions that fit community needs systematically and scientifically. Further, it is important that universities test and implement new ideas that fit the needs of the communities where they are located, because the solutions need to be value in the context of the requirements, characteristics, and culture of local communities. On the other hand, some common problems may also be identified, even for different cultures and levels of development. For this sake, this paper considers two prominent universities, one in Canada and another in Brazil, to illustrate how the academy may step forward and get even more involved in finding ways to improve social well-being. Because both universities work on a wide range of research areas and social initiatives, covering them all would be unrealistic. Instead, as a disclaimer, we propose to illustrate part of their vast number of initiatives and achievements through examples.

This paper shows that smart cities definition may go beyond the one classically accepted in technological forums, as an urban development using Information and Communication Technology (ICT) and Internet of Things (IoT) to provide useful information to effectively manage resources and assets. This definition embraces monitoring and manage traffic and transport systems, power plants, water supply networks and waste disposal, but does not deepen on social inclusion. The work in Musa (2018) presents a roadmap to build a sustainable community. This paper follows the principles of that reference, showing how different realities demand different efforts.

Thus, the main points raised by this paper are to:

- Contextualize the historical role of universities in the present context.
- Discuss how universities may lead smart cities initiatives in different social scenarios.
- Understand that universities may propose, but not implement technological solutions in a massive manner and, for this sake, discuss potential contributions with the private sector.
- Introduce an innovative approach, under a system-oriented perspective, discussing the problem as a whole, which benefits communities usually left behind in this discussion.

2 Method

The method followed in this study involves a literature review on topics at the intersection of smart cities and universities. These articles contributed to provide support to the study in several aspects, including the identification of smart city dimensions and characteristics and how universities could help support smart city initiatives by promoting social good.

The literature search used electronic databases such as Scopus, IEEEEXplore, and ScienceDirect. The search followed main keywords such as "smart city," "university," and "sustainability." Inclusion criteria required articles peer reviewed in journals and conferences, and articles in English. Manual assessment of the collected articles was conductec to exclude irrelevant papers. Some of the articles were excluded because they were outside the scope of the paper, for instance, those describing technical specifications of specific systems. This assessment led to the selection of over 90 articles that were used to answer the research questions.

The study aims to address the following research questions:

- RQ1: What are the contributions and impact of universities to help address smart city challenges? This is discussed in Section III.
- RQ2: How have universities provided contributions society and help advance smart city initiatives by promoting social good and interacting with local communities? Discussed in Section IV.
- RQ3: What are potential contributions that universities could provide to advance future smart cities? Addressed in Section V.

- RQ4: How have universities partnered with private sector, government agencies, and other institutions to benefit their communities and advance smart cities? This is carried out Section VI.
- RQ5: How can a system-oriented approach help to advance the contributions of universities to help establish smart cities? Discussion presented in Section VII.

Questions RQ2-RQ4 address two specific universities, with different realities, but with some common goals.

3 Contributions of universities and the challenge of smart cities

The rise of smart cities has become a concern for researchers and policymakers worldwide. Montes (2020) provides a deep literature review on this subject. The set of definitions of a smart city leads to the conclusion that a smart city takes advantage of technology to improve life. In this sense, a smart city must be socially, economically, and environmentally sustainable.

For this sake, a smart city should focus on the wellbeing of its inhabitants, for example, by working on eradicating poverty and hunger and creating housing opportunities. Besides, adequate transportation, health, and education infrastructures need to be improved. Thus, universities are invited to place their contribution since the knowledge in areas that span from sociology to engineering have their potential contribution.

This section describes how universities helped to shape modern societies. We focus on technological advances, but the design of inclusive smart cities demands some social discussion. Thus, we include how university researchers and thinkers have helped understand societies and human behavior. These points are briefly discussed next and describe university initiatives in several domains.

3.1 The context of universities within cities

The role of universities in the shape and design of cities has been thoughtfully discussed in the literature. Brennan and Cochrane (2019) for example, points to the importance of a university being part of a community and not only located in the community. The same issue is discussed in Liu (2019), where the transformation between the relation university-community is discussed based on the tension among them. The knowledge-based function of universities may be a barrier to integration, but the advent of smart cities demands new perspectives, as discussed ahead.

3.2 Architecture and the role of inclusive cities

The role of architecture in designing houses has been long acknowledged as vital for the satisfaction of owners and the appropriate use by city dwellers. Pesce and Bagaini (2019) how cities may be affected by immigration, which is a critical issue in Europe. In this sense, housing the immigrants may create a welcoming and inclusive environment. Quoting the authors, "Innovative strategies for dealing with immigration are based on flexible tools, typically from temporary habitat (housing modules, light construction systems, customized solutions) that find a place inside the city." This could be applied not only in countries in Europe. Regarding public areas, Melton (2020) describes some examples of public spaces designed to provide comfort for the users, while exhibiting pleasant aesthetics.

3.3 The American space program

In the early 1960s, the American government prioritized the race to the Moon. For this sake, as described in Homer and Newell (1980), universities were invited to help design a new space project. Symbolically, a university was the place where President Kennedy's legendary speech took place in 1962 R. University and NASA (1962), when the goal to reach the Moon before the end of that decade was publicly announced. In contrast, space exploration is currently seeking to achieve new goals. Recently, NASA established a program to enable human beings to live and work on the Moon. Once again, universities are enrolled, and three top ones have been selected to work on this design. Quoting (NASA, 2022), "Missouri University of Science and Technology, led by principal investigator Leslie Gertsch, will use magnetic and electrostatic technologies to more efficiently separate calcium-and aluminum-containing minerals from the Moon's soil, called regolith, to extract materials suitable for construction on the lunar surface." Also, "Auburn University, led by principal investigator Michael Hamilton, will take advantage of knowledge from recent lunar missions and other cold-temperature projects to create new electronics that are highly reliable and tolerant of low temperatures."

3.4 Research on infectious diseases

Humankind had a significant advance when penicillin and vaccines became available. Mercer (2021) shows in the progress in fighting infectious disease, responsible for most deaths in England at the beginning of the twentieth century. The importance of research is highlighted in that paper since it stresses that hunter-gatherer humans acquired pathogens from other species when the advances in agriculture enabled them to settle, becoming sedentary. On the other hand, infectious diseases are still present in so many countries, and the COVID pandemic led to adverse consequences for the global economy. The role of universities in fighting infectious diseases in the 21st century is described in Bryant and Velji (2011), where not only collaborations among universities are addressed but also reforms in the medical systems worldwide.

3.5 Studies on power systems

Power systems are a particular area of interest in universities. Providing energy continuously with good quality is the major drive of utilities. For this sake, power systems must operate in a stable manner while following quality standards. For this sake, several issues, like power flow, voltage and angular stability, and power quality, among others, are analyzed in planning and operating scenarios. Indeed, this progress would not be possible without a historical effort of the academy, ranging from publications from the 1930s (Butler and

Concordia, 1937) to thinkers of modern hybrid power systems (Wang et al., 2023).

3.6 Development of safe and less pollutant cars

The early years of the automobile industry have already revealed some problems that affect population health. Hoekman and Welstand (2021) describe that control actions were taken in the 1950s to prevent smog in Los Angeles since it caused respiratory problems in children. This was only possible because of the improvements in catalytic and non-catalytic exhaust after-treatment systems. Thus, reducing pollutant emissions from vehicles is essential in environmental control. Universities have played a role in solving this problem, as described in Dey and Mehta (2020), by introducing a catalytic process to reduce pollution. This is an essential topic for the economy, environment, and health. Alexander and Schwandt (2022), for example, the effects of pollution on children. In contrast, Mazza et al. (2020) shows that this problem may be mitigated with the help of software that enables tracking polluted regions and public policies to take control actions. Gupta et al. (2017) emphasize the role of sustainable health centers by using Internet of Things for preventing some diseases, like diabetes, blood pressure, heart, and kidney. Since it lies on data stored in clouds, the concerns discussed in Gugnani et al. (2016) should be considered. In that paper, a selective encryption of XML elements is proposed, preventing them from improper disclosure.

3.7 Studies in social inclusion

That is a field widely addressed in the academy. It ranges from the association between health care and the wealth of a nation (Maskileyson, 2014) to wealth inequality (Killewald et al., 2017). Even though inequalities are a fruit of economic burden, which depends on specific countries and people involved, they deserve special attention from policymakers. Caragliu and Del Bo (2022) claim that smart cities are less unequal, but we understand that smart cities may even enlarge the gap between the rich and the poor. For example, the homeless is increasing in developing and developed countries. Studies show that different variables may worsen the problem, such as family disaggregation, alcohol problems, and access to affordable houses, among others (Heinze et al., 2012). This problem must be treated under smart city proposals (Khayyatkhoshnevis et al., 2020; Virani, 2023), which includes defining the role of teachers as a beam of social inclusion (Gasser et al., 2022).

3.8 Sustainability

It may sound surprising that in 1953, someone had already proposed that corporations should consider the social impact of their actions (Bowen, 2013). It is essential to state that researchers who nowadays deal with some engineering systems consider stakeholders, employees, and customers, just like Bowen proposed. These principles made him the "Father of Corporate Social Responsibility" and led him to preside over three universities. Thus, society must stand on environmental, economic, and socially sustainable pillars.

3.9 Information of Technology (IoT)

IoT impacts all the items mentioned above. In this sense, recent applications in health may be cited (Paganelli et al., 2022). This is a recent research topic compared to the previously described one, and Sarmah et al. (2017) provides an overview of this topic. We acknowledge, however, that although IoT is a leading trend in modern technologies that enables people and machines to connect across the world, these vital systems are also susceptible to hackers and other security issues. Saini et al. (2011) does not focus on this issue, but helps searching information by using a genetic algorithm-based platform. The authors conclude that no significant improvement has been seen in average fitness, and propose fuzzy theory to refine their work.

3.10 The role of universities and smart cities

To be sustainable became a mandatory smart city goal in designing and implementing inclusive modern cities. In this sense, Ferrarisa et al. (2020) proposes using the Triple Helix model (Etztzkowitz and Leydesdorff, 2000) to assess universities' enrolment in smart cities in two universities, one in Russia and another in Italy. Interviews were conducted in two steps to get the perception of students about the role of universities in smart cities. Both countries' participants point to business as the integrator and developer of smart cities. On the other hand, Italian students blame the integration between private and public sectors as a barrier. Anttila and Jussila (2018) acknowledges the role of information technology in smart cities but also addresses issues related to the urban characteristics of smart cities. For this sake, Onu et al. (2023) shows that a rural community may become smarter by taking advantage of local resources, as also reported in Souza (n.d.).

The neutrality of technology has long been a matter of debate, allowing people to salute the benefits of technology while acknowledging the political implications of technological artifacts and devices. The neutrality of universities, however, can also be considered. Quoting (Kanai et al., 2021) "Universities play a neutral yet catalytic role in social innovation and the knowledge economy." The report describes several universities worldwide collaborating with entrepreneurs and the industrial sector, proposing solutions and using university infrastructures as testbeds.

The neutrality issue, however, is an invitation to discuss universal basic income openly (Hasdell, 2020), given that the labor structure is under deep transformations. The problem of machines replacing the human labor force is addressed in Dubbeldeman and Ward (2015), which also discusses the role of universities in this changing world by emphasizing the role of smart education. This demands a dynamic syllabus that addresses the current needs and considers the available technologies to educate future students. This work aligns with the one presented in Ardito et al. (2019), which discusses knowledge-based projects involving smart cities, placing universities at the core of the discussion. They provide insightful comments about the role of universities and define the following criteria to carry out research: (i)

at least one university must be involved; (ii) it should have the Involvement of the private sector and the government; (iii) a big MNE should be involved; (iv) the project must have the objective of leading to a socio-technical and sustainable transformation of a specific urban-city area; and (v) the urban-city transformation must involve knowledge-intensive activities.

Even though the paper presents essential contributions to the role of universities in designing smart cities, the limitations imposed by local realities are not explored. This is partially overcome in AlQaoud et al. (2021), which addresses the implementation of smart cities in the United States, Europe, and Far East countries. No developing country, however, is analyzed. This gap is addressed in this paper, since different social conditions and realities may shape the contributions of each university. In this sense, we acknowledge that different cultures demand different solutions. Thus, even though technological advances are based on universal scientific knowledge, their application depends on the environment and people's expectations.

The city of London also acknowledges the role of university plans (Mayor, 2018), which aim to make London the world's smartest city. Several factors, like digital inclusion, transport, education, and environment, are addressed for this sake. The problem of energy poverty may be overcome by relying on data availability and analysis, making the measurements more precise and the inferential capabilities more robust. On the other hand, the problem of affordable housing needs to be addressed and remains a burden for Londoners.

4 An example of two universities in different realities

The previous sections showed that smart cities may benefit from universities. Conversely, universities have provided insightful contributions to society, rendering themselves adequate candidates for helping design smart cities. This section focuses on two universities, one in a developed country (University of Waterloo (UofW) - Canada) and another in a developing country (Federal University of Itajuba (UNIFEI)- Brazil). They are placed among the best universities in their countries, and their critical roles in making the cities in which they reside smarter are addressed. First, the profile of each one is depicted, followed by a discussion on some recent technological contributions of each one to smart cities. Table 1 describes the general data of both universities.

To structure our study, we have identified several dimensions of smart cities (Colombo et al., 2021), and use these dimensions to guide the discussion in this section and the subsequent sections of this paper. Smart cities can be identified along six main axes or dimensions. These dimensions are: smart economy, smart governance, smart living, smart mobility, smart people, and smart environment. These dimensions are illustrated in Figure 1. Further, in Table 2 we present these dimensions, describe each one of them in terms of their focus areas, and show how each of the universities we focus on contribute to each of the dimensions (Sections IV, V and VI).

The Smart Economy dimension involves actions aimed at improving a city's economy, and includes the use of digital and innovative technologies for achieving economic prosperity, the implementation of efforts to take advantage of the circular and sharing economy, and the establishment of strong startup ecosystems. The Smart Government dimension involves strengthening the interactions between government and citizens, businesses and other stakeholders of the civil society, and the use of digital technologies to improve these interactions. The Smart Living dimension aims at increasing the quality of life for residents and visitors, and includes efforts to improve digital inclusion, housing, and safety. The Smart Mobility dimension aims at increasing the quality of urban transportation, and involves the adoption of new forms of transportation, such as electric vehicles, autonomous vehicles, and bike sharing. The Smart People dimension focuses on creating social inclusion by providing, for example, educational offers, vocational training, and talent development. The Social Environment dimension aims at improving the management of the built and natural environment to improve livability for citizens, and includes reducing waste production, monitoring and decreasing pollution, and achieving energy efficiency and energy transition to more sustainable forms of energy. *Affordable Housing and Education*: A university's major contribution lies in the quality of the professionals they make available to the productive sector every year. However, the characteristics of each university are based on its academic scope. In this sense, UNIFEI supports its low-income students by providing monthly financial support to afford housing and free meals in its restaurant. In a different social condition, the UofW annually promotes a Youth Retreat, where young people from Ontario exchange experiences and are taught, for example, resume` development, open studio art creation, yoga, budgeting, and tenant rights. Some specific contributions are highlighted below.

TABLE 1 General university data.

	UNIFEI (Itajuba)	UofW (Waterloo)
Undergraduate students	7,213	38,166
Undergraduate programs	34+	100+
Graduate students	852	6,451
Graduate programs	23+	190+
Faculty members	502	1,352
City population	97,334	121,436

4.1 Economic stability

That is undoubtedly one of the most appealing points of universities. While companies, sports franchises, and other commercial facilities may change their transitory operation basis, universities, on the other hand, are perennial. For this sake, itemizing some indirect contributions of a perennial university is essential. Student fees result in substantial contributions to the local economy. After covering university expenses, these fees are invested in its infrastructure, enhancing its environment and attracting additional students. Besides this expense, students also spend money at the local shops and restaurants, creating a circular economy environment. Another positive consequence of the stability of universities regards the indirect economic signs. In this sense, one could even claim that the quality of services is increased, because university staff, faculty members, and postsecondary students demand services of better quality.

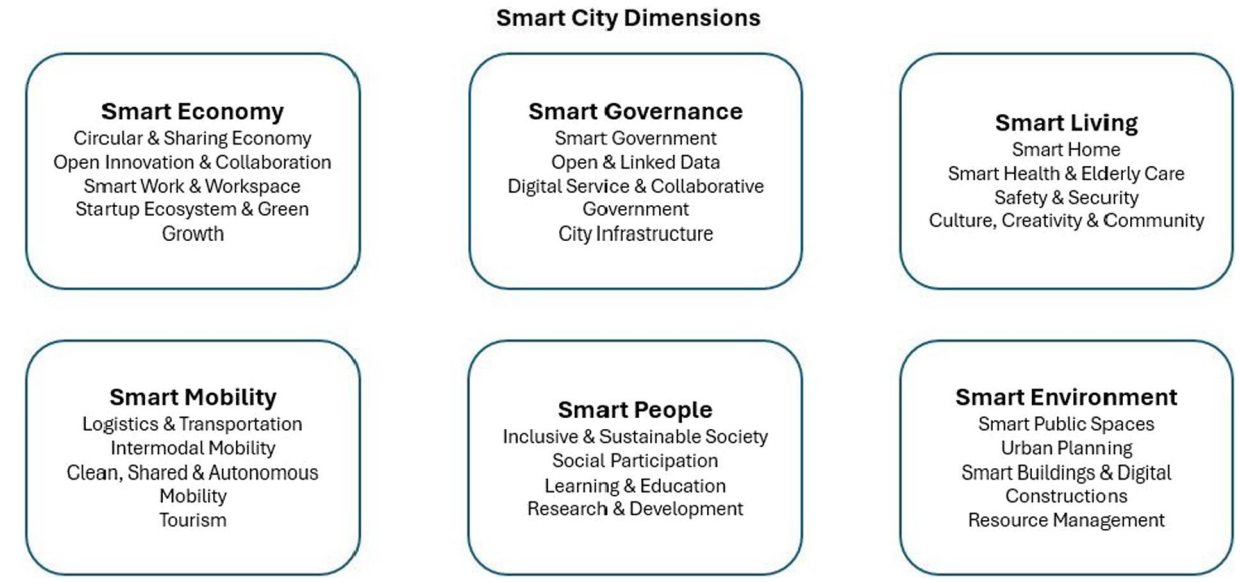

FIGURE 1
Smart city dimensions.

TABLE 2 Smart city dimensions and the universities.

Smart city dimensions	Description	UNIFEI (Itajuba)	UofW (Waterloo)
Smart economy	Circular and sharing economy; open innovation and collaboration; smart work and workspace; startup ecosystem and green growth	Economic stability; Circular economy; Collaborative research projects using new technologies (e.g., green hydrogen)	Economic stability; Circular economy; Collaborative research projects using new technologies (e.g., AI, robotics, nanotechnology)
Smart governance	Smart government; open and linked data; digital service and collaborative government; city infrastructure	Digital services using new technologies	Digital services using new technologies
Smart living	Smart home; smart health and elderly care; safety and security; culture, creativity and community	Projects to provide affordable housing and meals to low-income students; Alternatives to decrease construction costs; Projects related to subsidies of energy costs; Solutions to deal with violence in low-income neighborhoods; Cultural and heritage-oriented projects; Digital inclusion projects involving emerging technologies	Alternatives for building affordable houses and smart buildings; Projects involving psychological support (e.g., ad-diction, mental health); Solutions to deal with violence in low-income neighbourhoods; Cultural and heritage-oriented projects; Digital inclusion projects involving emerging technologies
Smart mobility	Logistics and transportation; intermodal mobility; clearn, shared and autonomous mobility; tourism	Navigation systems for driverless vehicles	Driverless vehicles
Smart people	Inclusive and sustainable society; social participation; learning and education; research and development	Courses to improve job qualifications of low-income population	Youth-related education and talent development projects
Smart environment	Smart public spaces; urban planning; smart buildings and digital constructions; resource management	Energy efficiency and transition projects	Energy transition and efficiency projects

4.2 Energy

The energy transformation the world is undergoing demands more research. Renewable sources have become a source of interest to many researchers due to increased wind and solar-based energy penetration. Both universities have been working in this area (Calero et al., 2022; de Souza et al., 2023; Alonso and Zambroni de Souza, 2023). Besides, electric vehicles, low-consumption products, and

hydrogen (Preston, 2022; Restrepo et al., 2022) have also been of increasing interest.

4.3 Mobility

Electric and hydrogen-fueled vehicles will play a key role in transportation soon. For this reason, much research is currently conducted about public and private transport in these areas. The advent of online maps has made more straightforward the navigation for drivers. The energy transition poses a challenge since gasoline and diesel will be replaced with cleaner fuels. As for public transportation, besides electricity and hydrogen, other features, like flywheels and regenerative systems, will have their place. However, driverless cars have become a reality in specific situations. In this sense, University of Waterloo (2016) describes the driverless car project conducted at UofW, which considers the following cases: passenger vehicles, automated driving, connected (V2X) vehicles, ADAS, driverless shuttles, commercial trucks, warehouse and industrial robots and field platform vehicles. UofW has been the testbed of an all-weather driverless shuttle bus that will operate on the university's Ring Road. Researchers from UofW are also working on the severe problem of crash mitigation (Wang et al., 2019) to address issues such as injuries, material damages, and legal problems that may arise. On the other hand, as cited in Gonc¸alves (2010), UNIFEI is developing a navigation system for driverless vehicles, whereas the navigation process and collision avoidance are addressed in Jesus and Barbosa (2009).

4.4 Universities and the circular economy environment

The concept of circular economy is vital to understanding the production chain and interconnections among the players in societies. It is an area of increasing interest among researchers, and the university is certainly an appropriate testbed for testing ideas and their effects on the circular economy. At UNIFEI, the relation between circular economy and the fourth industrial revolution has been addressed (Teixeira et al., 2022). The results of energy produced from biogas in a poultry farm and its effects on the circular economy are studied in Ribeiro et al. (2016). Incentives on renewable energy enable production based on economy of scale, with beneficial consequences to the circular economy. Researchers at the UofW have also worked on issues related to the circular economy. For example, Sanchez and Haas (2018) focuses on sustainability in conceptualizing new building projects. The authors propose a shift from linear to circular principles. Shifting from linear to circular economy models is also the goal in MacNeill et al. (2020), this time applied to the medical device industry. In that paper, the authors claim that the "just-in-time" process may not be adequate to deal with manufacturing shortages and emergencies like those during the COVID pandemic.

5 Potential contributions of universities to future smart cities: what is next?

Section III briefly discussed the importance of universities in vital areas of research that advance smart cities and the benefits of society. Section IV highlighted some of the contributions of two universities, namely UNIFEI and UofW, in an attempt to show how universities can help advance sustainable smart cities and describe their importance in generating new knowledge related to this area. Thus, these sections justify why universities are relevant in producing expertise and solutions that can benefit society. This section proposes illustrative examples of actions that can be carried out by universities in general, and specifically by the two universities in focus, to advance sustainable smart cities (e.g., social good) further, which can help reinforce university-community ties. These examples constitute opportunities for research related to sustainable smart cities.

Homeless problem: The homeless problem is posing a critical social challenge to governments worldwide. In 2022, around 230,000 people are homeless in Canada and nearly 600,000 in the US. In Brazil, the estimation is that over 220,000 people live under homeless conditions. As for Brazil, however, this number excludes people living in inadequate conditions. Homelessness is simultaneously the source and the sink of several other issues. People become homeless for several reasons, as described in National Alliance to End Homelessness (2007). Domestic violence, mental illness, addiction, and poverty are among the causes. Poverty, in particular, plays a special role since addicted people do not necessarily become homeless, whereas, for poor addicted people, that possibility increases significantly. In this sense, a public policy for affordable houses could benefit this sector of society. Regarding the UofW, University of Waterloo (n.d.) describes a social incubator at the University of Waterloo. Problems are faced under a systemic and intellectual approach to offer solutions to social issues, and homelessness may be one of them. Thus, the university provides a place for discussion and possibilities to embed ideas into business environments, named the Greenhouse project. The following areas could also embrace this project.

- Civil Engineering: One issue regarding homelessness is a low-income housing policy. Alternatives for building affordable and comfortable houses play a role. Besides, heating issues should also be addressed.
- Energy: The Waterloo Institute for Sustainable Energy may help create an environment to provide electricity in a sustainable manner. Sustainable, in this case, also means economically viable. Hence, researchers in Electrical Engineering could help by proposing to incorporate their ideas into regulation.
- Economics and Psychology: One of the problems that the homeless face is the qualification for jobs. For this sake, researchers in the Economy could help by proposing a program to qualify people who want to join the market forces. Psychological help may be necessary for some of them since addiction, mental, and abuse problems may cause severe drawbacks to their ability to learn. Going back to the Greenhouse project, Stankiewicz (2022) describes the problem in addition to the shelter needs of homelessness. In this sense, the work focuses on qualifying young homeless individuals and educating society to reduce prejudice and discrimination. Note that these actions are already ongoing at the UofW, and we are only considering the possibility that different groups could combine their efforts in a unified approach, increasing the synergy among diverse areas.

Regarding UNIFEI, several examples can also be provided in the same areas.

- Civil Engineering: Unlike the conditions described above regarding Waterloo, in developing countries, extreme rainfalls may affect low-income neighborhoods. Palharini et al. (2022) maps this problem for different regions of Brazil. Thus, when considering affordable houses for low-income people, particularly those experiencing homelessness, the location plays a key role since they are economically vulnerable, and any disaster may be a real burden. Hence, Civil Engineering may help by proposing creative alternatives to decrease construction costs while working on preventive measures for flood disasters.
- Energy: Regarding this issue, a fair regulation law requires that low-income people can afford energy costs (dos Santos Benso Maciel et al., 2020). This is related, actually, to a broader discussion about energy as a right or an asset (De Doile et al., 2022). Besides regulation, researchers from UNIFEI are also working on how to make fair use of renewable generation (Costa et al., 2023), which may be helpful for this kind of consumer. In this way, they could, for example, have local renewable-based generation and access to subsidies to help them afford electricity bills.
- Economics and Psychology: UNIFEI does not hold a Psychology program, so interested researchers could seek help from private institutions in the city. However, UNIFEI embraces several programs that help low-income people to have better qualifications, like supporting digital inclusion and offering courses for disabled and hard-of-hearing people, among others.

Students have also organized for over 20 years a course for low-income students to help them enter a University. These successful actions may be extended to the local municipality and include homeless people.

Violence in low-income neighborhoods: This is a susceptible topic that deserves special attention from faculty members. Interestingly, when approaching this problem, an academic opportunity is open since monitoring the progress of some social programs may provide signals worth publication. UofW may use the Greenhouse project to reach needy communities and apply their ongoing projects. UNIFEI offers some programs at different elementary and secondary school levels, including digital inclusion and sports. No program, however, is directly applied to deal with this problem. The skills are available to embrace these efforts in this direction, but novel technological solutions may be frequently presented as part of their laboratory activities, which could inspire their curiosity. This could awaken the desire in some of them to become university students. Note that this problem is also related to diversity, since cultural differences may motivate violence. Such a problem may be acknowledged as important, and some actions considered (Sancho-Gil et al., 2023). *Teenage pregnancy*: Teenage pregnancy is a problem that brings severe consequences to young mothers since they are displaced from a typical education path and personal development. These consequences impact the circular economy, considering consequences such as health system increased costs, school evasion, and economic problems caused by poverty traps that (Vasconcelos et al., 2022c) can keep future generations in the same adverse circumstance. Some efforts have been conducted at the UofW to deal with this problem. First, note that the consequences of teenage pregnancy depend on where the pregnant adolescent lives. In this sense, contraceptives can reduce teenage pregnancy compared to the levels reached in the early decades. However, as stressed in Kearney and Levine (2012), the teen birth rates are still very high, and the authors suggest that economic conditions and other problems drive young women to early motherhood. Nabugoomu (2018) describes the nutrition and health of young mothers in Uganda, which showcase some of these problems. We propose that the actions described above for vulnerable communities can also be considered for teenage pregnancy because new perspectives on the future and professional qualifications may change this reality. UNIFEI does not have researchers directly involved in this area. However, local data show teenage (and even child) pregnancy poses a special problem in low-income neighborhoods. Thus, besides educational and informative actions from the local municipality, the actions above to support vulnerable communities are strongly recommended.

Cultural aspects: This is an area that the UofW and UNIFEI have worked very hard in the last decade, and recent information about both Institutions shows a growing trend related to heritage acknowledgment. UNIFEI, for example, has painted several prominent figures in the history of Brazilian science on its main wall. In addition, dance, music, and various cultural activities are offered to its students. UofW, on the other hand, offers several cultural activities to integrate its students. Besides, UofW has been paying special attention to the inheritance received from the original ancestors. In this sense, they are both aware of their environment and the nature of their communities.

It is not unreasonable to think that taking these activities to their communities is possible. Each community would take advantage of knowing how the local culture may lead to the establishment of creative environments in which science and social integration prevail. Besides, such programs may substantially reduce prejudice against people and technology. An extended program that considers a two-way collaborative development that entails visits and student exchange could be a fruitful option. *Modern technologies*: Digital inclusion has been a topic of discussion in the Kitchener-Waterloo area. Positive steps have been taken since then, including free public Wi-Fi. University of Waterloo (2021) invites big tech companies to face the "deep digital divide" problem in Canada, which the COVID-19 pandemic has aggravated. Thus, the university must work as a bridge between companies and local communities, widening the options of digital inclusion and exploring the qualifications programs available to help currently excluded people. The Brazilian reality imposes different challenges. In 2021, Brazil had around 7.3 million homes without internet access, rendering almost 30 million people digitally excluded. Since it was during the COVID-19 pandemic, educators had to struggle to work and witness an increase in the gap between public and private school students powerlessly. Some students at UNIFEI have run a free course for low-income people to have more access to universities, but even this kind of initiative has been harmed by the COVID-19 pandemic. UNIFEI has also promoted inclusion initiatives. However, some neighborhoods still present low school performance, and modern technologies could help to integrate the students and unemployed into society. It is advisable to create programs in local schools and community centers to carry out educational programs based on modern technologies.

6 University partnerships

This section describes some key partnerships that helped shape both universities. Thus, besides provoking the universities to play a role in their communities, this paper acknowledges their importance in the economy and human resources formation. Since the list of partnerships may be too long, only a few points are emphasized here.

6.1 University of Waterloo

In engineering, UoW has over 1,000 partners in collaborative research projects in various areas, including advanced manufac-turing, robotics, nanotechnology, data analytics, artificial intelligence, automotive, cybersecurity, blockchain, environmental sustainability and water, wireless communications, and networks and civil infrastructure. Some of these projects involve the redesign and retrofitting of houses to become net-zero and energy efficient. Regarding energy, the Waterloo Institute for Sustainable Energy works with dozens of partners in the private sector, government agencies, research institutions, and other universities at home and abroad to advance sustainable energy. The institute has a track record of successful partnerships worldwide and collaborations with multinational companies such as Toyota, Mitsui, CISCO, and IBM. It is part of a university with satellite campuses or offices in Nanjing, Manhattan, and Rome, enhancing the potential for international collaboration.

Regarding economics and psychology, these departments are heavily involved in multiple partnerships to advance social and economic development projects. There are several partnerships with surrounding communities and cities to address health issues related to addiction, mental health, and psychological conditions.

6.2 UNIFEI

UNIFEI has a long connection with companies, which may go back to 1913, when it was created, and needed to rely on some companies to build its laboratories. A few partnerships may be pointed out. First, recent collaborations are briefly described:

- GIZ (Gesellschaft fu¨r Internationale Zusammenarbeit) the German Agency for International Cooperation. This is meant to construct the Center for Production and Research in Green Hydrogen (CPPHV).
- Start-ups. Currently, there are 16 junior companies at UNIFEI. These companies, mainly composed of students, propose innovative solutions in different areas of knowledge.

Besides these actions (briefly summarized here for convenience), some historical partnerships may be addressed:

- Hydroelectric management. In an agreement with the state utility, UNIFEI was in charge of a real hydroelectric plant in a neighboring area to Itajuba´. With a capacity generation of 1.6 MW, it was a living laboratory for students.
- Courses for Engineering. Since 1973, Electrical Engineers for all regions in Brazil have participated in an extension program that provides updates on several areas of knowledge.

7 Towards a system-oriented perspective

System-oriented approaches advocate that problems such as developing sustainable smart cities should be seen as a system as a whole rather than seeing the problem in parts (Meadows, 2008; Kim, 2000). Considering university contributions from a system-oriented perspective is significant for various reasons. In essence, such a perspective has several benefits, as it helps to know the problem and find solutions from a holistic standpoint, helps to understand the problem in a more structured way, and produce solutions that take into account the interconnections or dependencies among different subsystems, and defines the scope for systems and problems where the influence of internal and external factors can be identified. In contrast, many existing solutions do not take into account, for example, multiple aspects of a problem, such as dependencies among individuals, households, institutions, and government in an integrated way. These interdependencies and the complexity of the context in which cities can be considered sustainably smart indicate the need to adopt a system-oriented perspective. Having roots in a wide range of areas, including biology, mathematics, and philosophy, systems thinking and theories have emerged as highly relevant in analyzing and designing complex problems such as those involving smart cities. System-oriented approaches have unique characteristics that are important to consider in the context of sustainable smart cities. First, systems can be adaptive and emergent. People and situations constantly adapt in highly dynamic environments as social, economic, political, and environmental conditions change in unpredictable ways. Several illustrative questions can be posed: How are people adapting to economic and environmental conditions? What issues and opportunities need to be considered as these adaptations occur? Second, complex systems cannot be understood by examining their parts in isolation. Instead, they must be understood as a whole, including how they are interconnected and interactive. For example, how do social and economic conditions interact to create social problems such as neighborhood violence, housing, or energy exclusion? Third, each part of a system will have its viewpoint and can only hold a partial perspective. These viewpoints vary with previous experiences and cultural features. How to provide solutions that can consider multiple views (e.g., cultural, economic)? Ideally, solutions need to be proposed by individuals and stakeholders with different backgrounds and viewpoints. Finally, system-oriented aspects such as nonlinear feedback loops and time delays must be considered, among others. First, a sustainable smart city constitutes a web of nonlinear feedback loops in which additional feedback loops connect the stakeholders. The feedback loops within a system may reinforce a change or compensate for seeking equilibrium, and reinforcement cycles can be positive or negative. It is often essential to inquire in what direction is the momentum of a change moving or whether people are gaining or losing confidence in specific initiatives. In terms of time delays, the impact of policies or solutions takes time, and some will play out over the years, and this requires the adoption of long-term methods to assess and demonstrate the scope of their impact. Our previous work has demonstrated that system-oriented approaches can provide a foundation for analyzing multi-faceted problems such as those in developing sustainable cities. In Zambroni de Souza and Alencar (2022), we discuss smart grids in sustainable cities from the holistic, system-oriented perspective and argue that a holistic and

practical view of electricity as a common good must consider the different circumstances of the local communities. Further, in Vasconcelos et al. (2022b), we proposed a multi-aspect dynamic system model to assess poverty traps. We argue in this article that a holistic analysis is paramount to ensure sound and sustainable living standards. The study relies on the interdependencies among individuals, households, institutions, and nations, and this integrated perspective may help promote a more favorable trajectory out of poverty and sound and sustainable social welfare. This is in accordance with Virani (2020), which shows the power of small initiatives and their local effects in their communities. By adopting a holistic view, providing solutions based on system-oriented approaches that can advance the design and development of sustainable smart cities becomes increasingly desirable.

The foregoing paragraphs enable one to address the different axes of a smart city, in general identified: smart economy; smart mobility; smart environment; smart people; smart living; and, finally, smart governance. Note that the previous projects described for both universities address these axes. We follow, however, the approach proposed in Ghosh and Arora (2022), that criticizes the undemocratic role a smart city may have in increasing the inequalities in a society. Table 2 shows the implications proposed by the authors of Ghosh and Arora (2022) in such a way that Unifei and the UofW may offer the most from their abilities.

8 Discussion

The previous sections showed that different realities may shape the way universities may embrace their communities. On the other hand, many common problems are observed, and cooperation may enable researchers to find local solutions. Section III described the influence of universities in the timeline of human development. Indeed, it shows that universities played a major role in the disruptive changes in the last centuries.

Section III is followed by the discussion of universities in different realities. In this sense, common problems must embrace a holistic approach, acknowledging the cultural characteristics of the place studied. The problem of social inclusion is then faced by considering homeless and low income people, when housing, energy and psychological problems are discussed.

This paper describes the contributions of the two selected universities in terms of the six dimensions listed in Table 2. Before addressing the six dimensions Section III answers the research question RQ1 by describing the contributions and impact of universities to help address smart city challenges in general. The research questions RQ2, RQ3, RQ4, and RQ5 are answered in Sections III, IV, V, and VI, respectively. In terms of the six dimensions listed in Table 2, regarding smart economy, UNIFEI has provided contributions involving economic stability and the circular economy (Section IV) and developed collaborative research projects using new technologies (e.g., green hydrogen) (Section VI). UofW has made contributions also related to economic stability and circular economy (Section IV) and developed collaborative research projects using new technologies (e.g., AI, robotics, nanotechnology) (Section VI). Regarding smart governance, both UNIFEI and UofW have developed digital services using new technologies. Regarding smart living, UNIFEI has developed projects to provide affordable housing and meals to low-income students and alternatives to decrease construction costs (Section IV), projects related to subsidies of energy costs and solutions to deal with violence in low-income neighborhoods (Section V), and cultural and heritage-oriented projects and digital inclusion projects involving emerging technologies (Section VI). UofW has developed alternatives for building affordable houses and smart buildings, projects involving psychological support (e.g., addiction, mental health), solutions to deal with violence in low-income neighborhoods, cultural and heritage-oriented projects, and digital inclusion projects involving emerging technologies (Section V). In terms of smart mobility, UNIFEI has developed navigation systems for driverless vehicles (Section IV) and UofW has developed driverless vehicles (Section IV). In terms of smart people, UNIFEI has developed courses to improve job qualifications of low-income population (Section IV) and UofW has provided youth-related education and talent development projects. Finally, regarding smart environment, UNIFEI has developed energy efficiency and transition projects (Section IV) and UofW has advanced energy transition and efficiency projects.

Smart cities need universities to come up with technological and social solutions, and universities need partners to make their ideas available in large scale. This may a barrier for the implementation of smart cities, since some industrial players face smart cities as a business opportunity only. Universities should go after partners that can buy their inclusive idea of smart cities, which may, indeed, benefit companies and the industrial area as a whole, since the inclusion of people empower them as costumers, generating more opportunities. This is better achieved if a system oriented approach is employed. Thus, future works should consider a system oriented approach to come up with a single platform that incorporates all the financial, ecological, market and social constraints into a unified formulation. This could, for example, assess the general impact of society if school evasion is diminished, for example. Likewise, public policies could benefit from this approach.

Note that this paper focuses on theoretical aspects of this discussion. A formal approach should consider the mathematical formulation of the problem, and some methods, like the Wonderland model (Vasconcelos et al., 2021), may help to assess the several possible interconnections. It is important to mention that we proposed some research questions to guide the research path developed here. The answer for each one has been found by considering the literature associated, and paying attention to the different realities of each university analyzed. We found that, even with different realities, universities share common problems and goals, and surprisingly, even different societies may present similar social problems. In this sense, this paper fills a gap in the literature, paving a research path that may provide relevant information for social and universities policies.

9 Conclusion and future work

This paper discusses the key role of postsecondary institutions in developing sustainable smart cities. The presentation examines this role in terms of historical contributions, examples of contributions from the standpoint of two universities, one in a growing and another in a developed country, and potential future contributions. The treatment of these aspects from a system-oriented perspective is also discussed. Several activities are identified and acknowledged in general and from the standpoint of the two selected universities, showing the local positive impacts on the economy and neighborhood.

TABLE 3 Main drivers of smart cities.

Other Aspects	UNIFEI (Itajuba)	UofW (Waterloo)
Distributive	Projects focus on poor people from poor communities	Low-income oriented projects
Participatory	Faculty, students and community members	Faculty, students and local companies
Responsive	Planners should consider difficulties encountered in food access and school performance of children	Community members should be heard

After acknowledging the unique expertise and the ongoing programs, this paper proposed actions that can extend some of these programs.

The system-oriented approach helps to understand the complexity and points out some solutions. Thus, since all stakeholders play a role in the process, universities and communities may benefit from joint activities. In the end, communication among the various stakeholders and the application of high-quality research knowledge on approaches to building sustainable smart cities may yield a better integration between universities and the needs of local communities and their residents.

Future work could tackle multiple lines of investigation. First, we could consider exploring how the different aspects of the dimensions of smart cities described in Table 2 are covered by universities in general. Second, we could explore how the application of specific system-oriented approaches could help to provide more holistic solutions to problems that are being tackled by universities. Third, other alternative dimensions could be considered in assessing the contributions of universities to the development of smart cities, such as those shown in Table 3.

Finally, we could consider how the collaboration among universities in different localities and facing different realities could improve smart city solutions, and enable the collaborating partners to better understand the complexity of the problems and share solutions.

Considering different realities may help to understand the political and economical motivation of some stakeholders in the smart city conception. Thus, fighting inequalities by placing technological solutions is a crucial role that universities may play. Both universities focused in this paper may propose approaches reproducible by other colleges and universities as they continue to advance their contributions to advancing sustainable smart cities.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

AS: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. PA: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. DC: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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