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Campus 5.0: Monitoring Vehicle Emissions for More Sustainable Mobility

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Abstract. The university campuses are like microcities, providing employees and students with social opportunities and essential services in addition to their core educational activities (teaching, research, and outreach). The smart campus is a growing trend that makes efficient use of infrastructure by integrating smart technologies for decision-making and advancing sustainability goals. The mobility and transport project at the Unicamp University campus is part of the Smart Campus Management Technical Chamber, and the Campus 5.0 concept is aligned with several sustainable development goals outlined in the UN's 2030 Agenda. This proposal aims to develop an inventory of vehicle emissions, establish the connectivity of the information and communication network to analyze the impacts of vehicles on local air quality, and structure support models for decision-making, in addition to presenting practical solutions implemented at Unicamp aiming at greater sustainability of the campus. The information and communication network will allow the collection and analysis of data in real time, providing accurate and updated information on vehicle emissions and air quality in the campus area. Decision support models will be developed, which will allow the definition of policies and actions to promote sustainable mobility on campus, contributing to the creation of a healthier and more sustainable university environment. These results will aid university administrators in improving Green Metrics' key performance indicators.

Keyword:

Mobility, Transportation, Green Metrics, Key Performance Indicators, Campus 5.0

1. Introduction

Campuses are not just the area where university buildings are situated, the built environment can influence human behaviors [1]. Furthermore, they can be considered a small urban model [2]. University campuses are like micro-cities, providing all their employees and students with opportunities for socialization, commerce, accommodation, transport, and leisure. People living in the city where they are located can also enjoy these activities [3]. A campus produces education and research, generating and using information, and around the world, many universities have shown their commitment to implement the concept of Smart Campus and Sustainable Campus.

In recent years, the smart campus has attracted worldwide attention, and most research assumes that smart campuses are technology-driven systems [4]. A smart campus brings several improvements to the management of a traditional campus [5]. Studies related to implementing technologies such as IoT (Internet of Things), cloud computing, augmented reality, and artificial intelligence in smart campuses are found in the literature [4, 6]. The typical structure of a smart campus comprises security operations, people, assets and vehicles that include fleet management and traffic flow monitoring, for example [6].

In pursuing sustainability in university management, Unicamp (Universidade Estadual de Campinas) gathers data, formulates indicators, analyzes, and proposes improvement projects. Since 2018, the university has submitted sustainability indicators to the ranking system for sustainable universities, Universitas Indonesia GreenMetric.

Located in the city of Campinas, in the state of São Paulo (Brazil), Unicamp has a large built area. The campus houses the Unicamp Clinical Hospital, restaurants, squares, institutes, and research laboratories, among others. The university has approximately 40,600 students, including undergraduate, graduate, and technical education students. There are more than 8,500 employees, including professors and staff [7].

In the urban mobility category, the number of vehicles circulating on Unicamp's campuses has been decreasing over the years: while in 2018, over fifty thousand cars were circulating daily on the university grounds, by 2023, this number had dropped to less than thirty thousand. This reduction was driven by factors such as individual awareness and initiative towards shared mobility and internal policies encouraging active mobility. The decrease in vehicles on campuses has directly impacted the university's carbon footprint, which decreased from 16,587 tons of CO2 to 13,977 tons of CO2 between 2018 and 2023. In this regard, electric vehicles have contributed to reducing greenhouse gas emissions, and this reduction is what this article addresses.

This proposal aims to develop an inventory of vehicle emissions, establish the connectivity of the information and communication network to analyze the impacts of vehicles on local air quality, and structure support models for decision-making. This paper's present practical solutions developed at Unicamp as part of the university's efforts to develop a smarter and more sustainable campus. It also seeks to present future perspectives related to the collection and use of data from the academic community that may be useful for researchers, managers, and campus planners in general.

2. Theoretical Approach

The Smart Campus initiative at Unicamp harnesses the power of the Internet of Things (IoT) to enhance control intelligence and facilitate informed decision-making, fostering a more productive campus environment. By gathering and analyzing data, the initiative aims to optimize various aspects of campus life, improving efficiency in service delivery.

Moreover, the insights derived from this data will inform decision-making processes and drive the development of projects aimed at enhancing security, mobility, overall living experience, and quality of life for the university community.

Originating as a project in 2016 as part of the University Prefecture of Unicamp's Strategic Planning, the Smart Campus has evolved into a dynamic working group within the Informatics division of the Campus City Hall since 2021. This transition ensures the continuity of ongoing projects while establishing a central hub for IoT initiatives within the university, serving as a benchmark for future endeavors.

Integrating the Internet of Things (IoT) in university campuses offers many advantages for the community and administrators, spanning areas such as mobility, security, energy efficiency, education, and beyond. For instance, IoT facilitates real-time monitoring of campus infrastructure and environmental conditions, empowering the formulation of sustainable policies grounded in comprehensive data analysis.

Figure 1 presents an architecture for integrating Information and Communication Technologies (ICTs) for Smart Cities, according to the Brazilian Handbook for Smart Cities [8]. The diagram illustrates the technological integration of IoT solutions and their incorporation into urban infrastructure and policies. At the bottom layer, different equipment or infrastructure that can incorporate IoT solutions are represented, such as electricity and water distribution systems, roads, and parks.

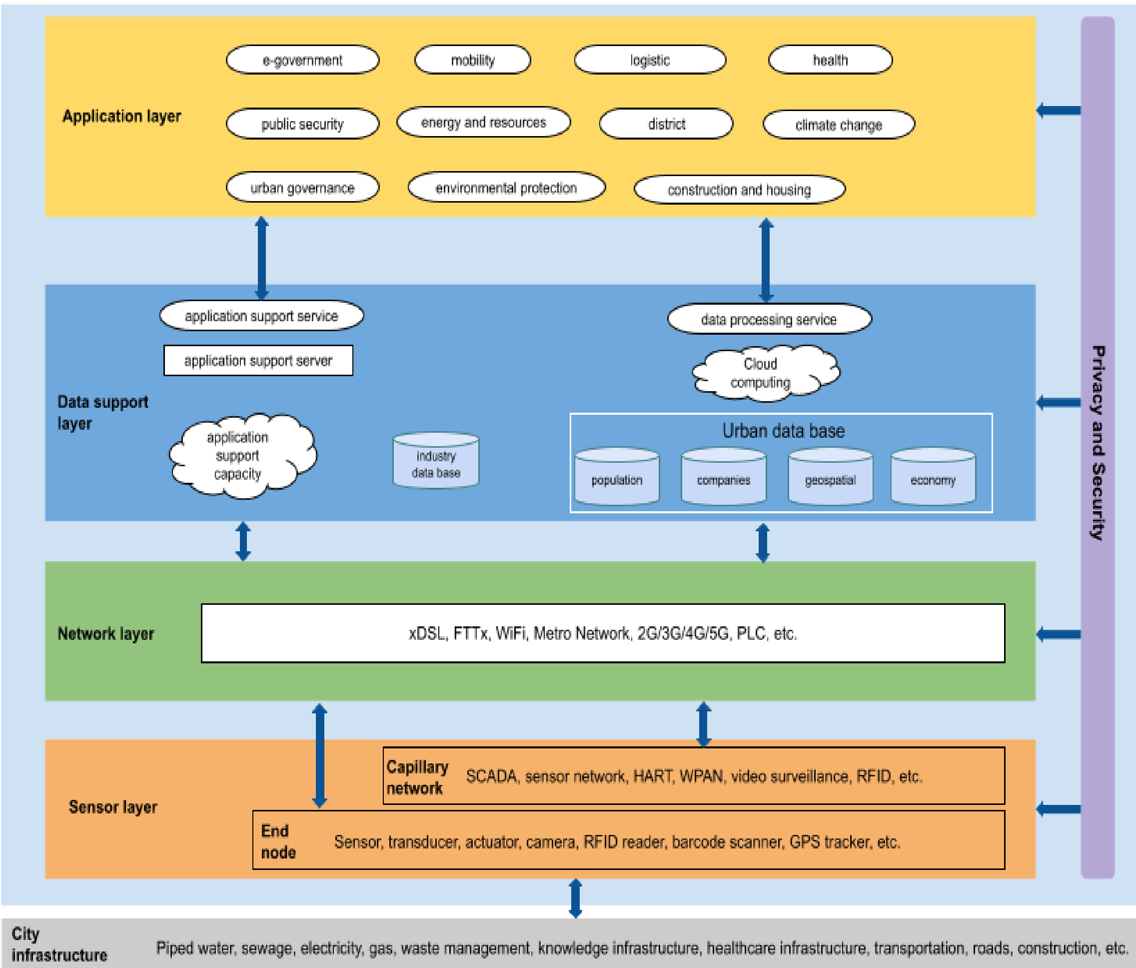

Figure 1. ICT architecture for Smart Cities
Source: Adapted from [8]

The second layer (sensor layer) consists of various IoT devices responsible for sensing, i.e., capturing information from the city's physical infrastructure. An example would be a smart meter aimed at monitoring energy consumption. Once the information is captured, the devices send the data through one of the available communication networks. The network layer typically includes Wi-Fi, Bluetooth, and cellular networks (2G through 5G), among others. These networks transmit the data collected from IoT devices to processing and analysis units. In this layer, data from different devices are aggregated and interpreted.

Most of the potential gains from the use of IoT solutions come from combining information from multiple sources. To achieve this, the city may rely on a data support layer involving technologies such as Cloud Computing and Big Data systems. Finally, the knowledge generated from data analysis informs the management and planning of various public policies represented in the application layer. All ICT layers should incorporate security and privacy measures to ensure the integrity and confidentiality of data and uphold user trust.

A university campus shares infrastructure and challenges like those in a city. Thus, Smart Campus Unicamp has organized its ICT infrastructure based on the architecture proposed in Figure 1. One of our plans is to have sustainability indicators available at the application layer, accessible to both management and the internal and external university community.

A dashboard, ‘UNICAMP – Connections by Wi-Fi point, in real-time,’ designed by Smart Campus, is online and shows the geographic distribution and number of devices (such as cell phones and notebooks) connected to the wireless network called eduroam. The number of connections per AP (Access Point, which is the Wi-Fi signal transmitter) is updated every 2 minutes, which allows viewing, in real-time, the number of devices connected to this network and estimating the geographic distribution of people on campus [9].

This initiative opens up several possibilities for new integrations with intelligent systems and devices that generate real-time information that can be viewed on dynamic web maps. Providing georeferenced information on urban transportation and mobility, monitoring systems (wildlife in ecological corridors, reservoir and flood monitoring, security), and others that support the university's management and planning aligns with constructing a truly "smart" campus [9].

3. Results and Discussions

Research on university campuses highlights trends such as reducing the volume of vehicles, sustainable alternatives for displacement, monitoring emissions, parking, public transport, and displacement patterns. Unicamp is addressing these trends. The projects presented in this section have already been implemented by the working group that composes the Smart Campus Management Technical Chamber and are part of the discussion on mobility and sustainable transportation on the university campus of Unicamp in Campinas, São Paulo.

3.1. Circulino – Internal Shuttle Bus

Circulino is a smart device designed to provide real-time location tracking of the internal shuttle bus. The system utilizes GPS coordinates and cellular signals, enabling the device to transmit the bus's location to an online platform accessible to bus users. This functionality allows users to track the bus's arrival in real-time at their location (refer to Figure 2). Furthermore, the device enables Unitransp (the University's Transportation Management Division) to monitor the bus's adherence to scheduled stops and timings. The project has been successfully delivered and is currently operational.

Figure 2: Map of real time of Internal Shuttle Bus [10]

In the future, new features will be added to the IoT device. One is the SMS communication channel, allowing device configurations to be updated remotely. Mechanisms are also expected to be created to identify the bus route automatically. Initially, the computerized monitoring system must analyze the data sent by the devices, comparing them with the unique coordinates of each route. It is also planned to start a repository with the collected data and make it available to interested researchers and companies [11].

3.2. Smart Parking


Figure 3: Intelligent Parking [12]

The smart parking project employs cameras to capture periodic images of parking lots. These images undergo analysis by a neural network, determining the number of available parking spaces. Subsequently, this information is made available to users via a kiosk near the parking lot entrance. Currently, two parking lots within the campus are under surveillance to identify vacant spaces (an example can be seen in Figure 3). As part of future developments, we aim to provide this information through a web or mobile application, enabling users to check availability before arrival. Additionally, the collected data can be leveraged to forecast parking availability for upcoming times and days and analyze vehicle turnover within the parking lots.

3.3. VAMUS - Accessible Vehicle for Sustainable Urban Mobility

The Accessible Vehicle for Sustainable Urban Mobility (Vamus) is designed to serve individuals with disabilities or reduced mobility and their companions. Operating Monday through Friday, from 7 a.m. to 11 p.m., this vehicle can accommodate up to seven passengers, including the driver. Requests for a ride can be conveniently made through the Unicamp Services App. Vamus is an electric vehicle with a range of 40 kilometers (refer to figure 4).

Figure 4. VAMUS (Accessible Vehicle for Sustainable Urban Mobility) [13]

3.4. Pilot Project - Mobility and Transportation

This pilot project aims to establish a Smart City Living Lab on the Unicamp Campus to deepen the understanding of smart cities by exploring solutions and experimental scenarios. The ICT infrastructure is designed to be open, scalable, modular, and compatible with the Campus 5.0 ecosystem, facilitating integration with other campus initiatives and seamless portability to and from other systems and technologies. It will feature a control tower and adhere to the Hub Spoke model for socio-technical informational networks (refer to Figure 5).

In the initial phase, the pilot project will concentrate on mobility and transportation. The primary objective is to develop an integrated tool within the framework of the smart campus, leveraging new technologies to integrate transportation, mobility, and environmental impact data on the university campus. This tool will encompass vehicle emissions inventory, hourly vehicle traffic patterns, vehicle flow density, emissions categorized by week and vehicle type, and modeling scenarios involving fleet reduction. The conceptual framework entails deploying a technical sensor network for vehicle counting, followed by establishing an informational network housing a database containing vehicle emission factors and the corresponding data of vehicles traversing the campus. Subsequently, decision support models and intelligent action systems will be implemented, featuring a platform for visualizing vehicle emissions, and facilitating decision-making (refer to Figure 6).

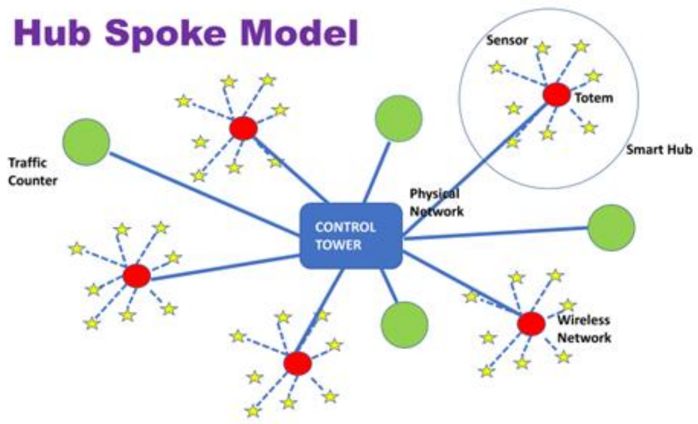

Figure 5: Hub Spoke Model - Campus 5.0 Project
Source: Authors

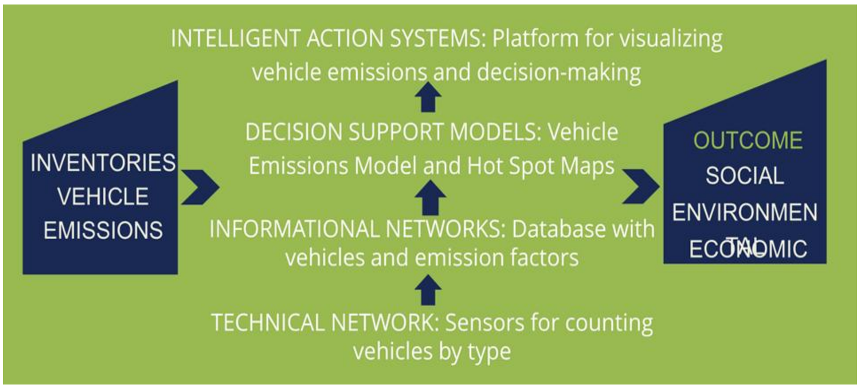

Figure 6: Campus 5.0 Project - Pilot Project in Mobility and Transportation
Source: Authors

3.4.1. Baseline scenario

One of the steps for implementing the pilot project is analyzing the available transportation resources on the university campus and how these resources have impacted pollutant emissions. An analysis of the current scenario of shuttle bus flows circulating internally on campus and buses traveling between the campus and student housing was conducted. As previously mentioned, the analysis was carried out based on the key parameters used for calculating emissions. Table 1 shows the number of vehicles, the number of trips per vehicle, the distance traveled in kilometers, and the Age of the vehicles.

Table 1. Information about shuttle buses

Type of Bus	Quantity of bus (unit)	Quantity of Trips (unit)	Travelled Distance (km/day)	Average Age (years)
Urban (Combustion)	5	99	1.692,50	8

Source: Authors

Table 2 shows the route taken by each bus, the day of the week, the number of trips per day, the total kilometers traveled per day, and the total kilometers traveled in 2023.

Table 2. Information about route and kilometers traveled.

Bus Flow	Quantity (unit)	Trips/day (unit/day)	Travelled Distance (km/day)	Weekdays and Weekends in 2023	Total kilometers traveled in 2023
Shuttle Bus 1 - Weekday	3	52	545,8	248	135.358,4
Shuttle Bus 2 - Weekday	2	46	472	248	117.056,0
Shuttle Bus/Student House - Weekday	3	146	625	248	155.000,0
Shuttle Bus/Student House - Weekend	1	9	49,7	105	5.218,5

Source: Authors

Some assumptions were made to calculate vehicular emissions. It was considered that urban buses powered by combustion use diesel as fuel, and the fleet age is 8 years. To calculate exhaust emissions, data on emission factors, intensity of use, and number of vehicles are required by fuel, year, and vehicle category. The general equation for calculating exhaust emissions is given by equation 1 (Exhaust Emission) and Table 3 [14]:

$$E = Iu \times FE \times Fr \qquad (1)$$

E = Mass of pollutant emitted in the period considered (g/year); Iu = Average annual usage intensity traveled by the vehicle (km/year); Fe = Emission factor for the type of vehicle, pollutant and fuel used (g/km); Fr = Circulating fleet, by type of vehicle and by year (number of vehicles)

Table 3. Emission factors considered in the calculation.

Emissions Factor	CO (g/km)	HC (g/km)	CH4 (g/km)	NOx (g/km)	PM (g/km)	N2O (g/km)	Autonomy (km/L)
	0,53	0,021	0,06	2,71	0,024	0,03	2,1

Source: [14]

Table 4 shows the results of vehicular emissions for some pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), and methane (CH_4), one of the greenhouse gases.

Table 4. Results of shuttle bus pollutant emissions at Unicamp.

E = Iu x FE x Fr	CO (g/km)	HC (g/km)	CH4 (g/km)	NOx (g/km)	PM (g/km)	N_2O (g/km)
Shuttle Bus 1 - Weekday	71.740	2.843	8.122	366.821	3.249	4.061
Shuttle Bus 2 - Weekday	62.040	2.458	7.023	317.222	2.809	3.512
Shuttle Bus/Student House - Weekday	82.150	3.255	9.300	420.050	3.720	4.650
Shuttle Bus/Student House - Weekend	2.766	110	313	14.142	125	157
Total in g/year	218.695	8.665	24.758	1.118.235	9.903	12.379
Total in kg/year	219	9	25	1.118	10	12

Source: Authors

Table 4 presents the calculation of emissions from shuttle buses circulating internally on the Unicamp campus and those traveling between the university and student house. It is observed that the most emitted pollutant by buses is NOx, followed by CO, CH4, N2O, PM, and HC. It is worth noting that nitrogen oxides (NOx) contribute to the formation of photochemical smog, whose main pollutant is ozone, and contribute to the formation of acid rain and particulate matter. It constitutes one of the most concerning pollutants.

Carbon monoxide (CO) is a gas resulting from incomplete fuel combustion and, when inhaled, reduces the blood's ability to transport oxygen, causing health damage. The analysis of the data can be used to assess the environmental impact of buses on the university in terms of air pollution and to assist in discussions on more sustainable transportation policies. Considering this scenario, the university is implementing solutions to reduce pollutant emissions from transportation. In 2020, the electric bus was implemented. The bus is a 100% electric vehicle, part of the Shuttle Bus (a free internal transportation system), intended for all individuals moving around the campus. It is part of the Sustainable Campus Project and features a sustainable charging station, including its photovoltaic generation and energy storage system (Figure 8). The launch of the electric bus occurs as part of the execution of the Electric Mobility Living Lab project, which is one of the initiatives of the Sustainable Campus Project.

Figure 8: Electrical Internal Shuttle Bus [15]

4. Conclusions

The study presented various initiatives carried out by Unicamp through the Smart Campus Management Technical Chamber in partnership with the Sustainable Campus Project. Additionally, the study showed the pilot initiative and analyzed the importance of transport and mobility for a sustainable campus while technological innovations allow for efficient data collection, manipulation, and analysis. The project's next steps involve integrating mobility data related to active transportation (walking and cycling) with real-time analyses of vehicle flows on campus.

According to [16], the Smart Campus integrates intelligent physical and digital spaces to provide responsive, intelligent, and improved services, creating a productive, creative, and sustainable environment. Using available technologies, the integrated study of mobility and transport and the relationship of these activities with environmental pollution can help in decision-making and strategic planning of the campus, improving the quality of life of all users. The various ways of getting around the campus, the types of vehicles, the patterns of travel, and the services offered, such as public transport and parking, are examples of activities to consider.

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