Neurotechnologies Applied to Society's Perception of Cyber-Physical Systems (CPS) in Smart Cities

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ABSTRACT

This study aims to quantify the perception of value and acceptance by citizens of the use of cyber-physical systems (CPS) in transportation systems and smart cities using neurotechnologies. The work has been developed in the main cities of the following Latin American countries: Spain, Ecuador, Colombia, and Argentina. Targeting urban, public transport-using graduates, it assesses CPS in smart cities and user experiences. Triangulating qualitative research and neurotechnology, the study extends the taxonomy of emotional domains. The results indicate that users do not always assign equivalent importance to what they truly feel, and it is noteworthy that the most important factor, both quantitatively and emotionally, is the application of CPS to improve efficiency in public transportation. The implications of these analyses are discussed in the final part of the article with the aim of providing recommendations to policymakers on the key aspects to be considered in the design and development of CPS for use in smart cities.

KEYWORDS

Citizen Participation, Cyber-Physical Systems, Neuroqualitative, Neurotechnologies, Smart City

1. INTRODUCTION

Modern cities can be described as intricate systems, characterized by substantial populations of interconnected residents, a wide array of businesses, diverse transportation methods, communication networks, various services, and public utilities. The growth in population and urbanization brings forth a multitude of challenges, encompassing technical, social, economic, and organizational issues, all of which have the potential to undermine the economic and environmental sustainability of these cities (Neirotti et al., 2014). The concept of a Smart City (Hollands, 2008) has gained increasing

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attention and is now presented as a new paradigm for intelligent urban development and sustainable socio-economic growth. A smart city refers to a city that utilizes Information and Communication Technologies (ICT) and other digital means to enhance the quality of life of its citizens, improve the efficiency of urban services, and reduce their environmental impact. Smart cities have become relevant in urban policy as a recognition of the potentially transformative role that advanced information technology will play in city operations as the 21st century progresses (Chin & Guthrie, 2023). Crucial questions that urban literature must systematically address include who decides what makes a city smart and for whom that smart city is intended. Smart cities aim to be more sustainable, efficient, and liveable by integrating data and technology into the management of urban systems. This includes infrastructure such as transportation, energy, waste management, security, health, education, and other public services. Consequently, smart city projects require complex coordination of resources (Gupta et al., 2023). The concept of a smart city is promoted to address local sustainability challenges, and smart city strategies are used to support urban sustainability transitions (Clement et al., 2023).

A smart city leverages information and technology to provide a more innovative, connected, and efficient urban environment for its citizens. There is consensus that smart cities are characterized by the widespread use of Information and Communication Technologies (ICT), which help cities use their resources more efficiently in various urban domains (Albino et al., 2015). However, ICT-based solutions are only part of the resources used for projects and planning approaches aimed at improving a city's economic, social, and environmental sustainability. Cyber-Physical Systems (CPS) are crucial in the context of intelligent transportation and smart cities, as they enable efficient integration of technology and physical infrastructure to enhance mobility, sustainability, and quality of life (Rai & Sahu, 2020). In essence, Cyber-Physical Systems (CPS) aim to establish a novel mode of integrated interaction with humans by leveraging computational and physical capabilities, encompassing intricate, intelligent, and autonomous systems. Artificial Intelligence (AI) stands out as a highly promising technology poised to find applications in a myriad of next-generation integrated systems, spanning CPS, security, and communication within the context of smart cities (Kim & Ben-Othman, 2020).

The advent of these new technologies is ushering in innovative avenues to navigate the current landscape characterized by evolving and unpredictable market requirements. In this dynamic environment, Cyber-Physical Systems (CPS) are emerging as one of the most promising and transformative technological concepts, offering new possibilities for addressing the challenges and demands of the contemporary era (Napoleone et al., 2020). The literature considers CPS to be fundamental components of future smart factories. Cyber-Physical Systems are characterized by their ability to integrate the physical world with the information or cyber world. Their deployment in critical infrastructures has shown the potential to transform the world (Olowononi et al., 2021), and although preventing CPS from suffering adversarial attacks is becoming increasingly challenging, the focus should be on making CPS resilient. It is worth highlighting the robustness of the Cyber-Physical System, consisting of interdependent physical and computational resources (Peng et al., 2020). Numerous infrastructure systems can evolve into Cyber-Physical Systems, such as smart electrical grids, traffic control systems, and wireless sensor and actuator networks, depending on their interdependent networks that provide information or energy to operate.

Some key aspects of using Cyber-Physical Systems (CPS) in the context of transportation and smart cities involve the efficient integration of technology and physical infrastructure to enhance mobility, sustainability, and quality of life. Key aspects of using CPS in these contexts include integrating data and sensors into urban aspects, intelligent traffic management, efficient public transportation, emissions reduction and sustainability, resource management, safety and resilience, citizen engagement, long-term planning, and sustainable financing. The communications of users in smart cities have surged by millions with the increasing demands for applications and technologies. Information exchange based on applications and quality is autonomous, with wearable devices engaging in communication or requesting services. Managing resources in such an environment is tedious due to its distributed, asynchronous, and mobile characteristics, with Cyber-Physical Systems (CPS) being key to improving the reliability of communications in a smart city environment (Chang et al., 2020). Finally, it is worth noting that the growth of the international smart city market over the last decade has been tremendous. Driven by private providers and consultants, the adoption of smart city technology in many cities has been rapid, but this adoption is often not aligned with the overall design of smart cities or the needs and preferences of residents (Spicer et al., 2023).

This work aims to fill the research gap regarding the human-centred design and user experience in the development of CPS for transportation and smart cities. The role of factors such as urban aspects, intelligent traffic management, efficient public transportation, emissions reduction and sustainability, resource management, safety and resilience, long-term planning, or sustainable financing is investigated by analysing the perception and emotional impact on users from different Ibero-American countries. This article can be considered a support for local policymakers and city administrators as it articulates the value proposition of CPS in smart cities through a set of appropriate initiatives and applications.

The structure of the work is as follows: it begins by examining the key elements characterizing Cyber-Physical Systems (CPS) in smart cities in the literature, which are then integrated into an extended taxonomy of domains that have a significant emotional impact on users. Based on this taxonomy, a sample of 4 international cities from Ibero-American countries has been analysed through triangulation interviews, employing qualitative research and neurotechnology. This approach considers the various application domains in which citizens have perceived smart cities. The integration of neurotechnologies in an in-depth interview establishes the concept of neuroqualitative metrics, allowing for a quantitative emotional assessment of users' true perception, highlighting what they genuinely find important or necessary. The implications of these analyses are discussed in the final part of the article with the aim of providing recommendations to policymakers on the key aspects in the design and development of CPS for smart cities. Finally, possible directions for future research are discussed.

2. LITERATURE REVIEW

This section aims to elucidate the potential of Cyber-Physical Systems (CPS) in the context of smart cities by analysing fundamental aspects and their application domains. To achieve this, a categorization of key factors in the application of CPS in smart cities has been proposed, identifying aspects crucial for citizens in the empirical study presented in this article.

There has been a drastic increase in urbanization in recent years, necessitating optimized and energy-efficient solutions for transportation, governance, and quality of life in a smart city for all citizens (Tanwar et al., 2022). A smart city is a concept that refers to a city using information and communication technologies (ICT) and other digital means to enhance the quality of life for its citizens, increase the efficiency of urban services, and reduce environmental impact. Smart cities aim to be more sustainable, efficient, and liveable by integrating data and technology into the management of their urban systems. This includes transportation infrastructure, energy, waste management, security, health, education, and other public services. In summary, a smart city leverages information and technology to provide a more innovative, connected, and effective urban environment for its citizens. Cyber-physical systems (CPS) are crucial in the context of smart cities as they enable efficient integration of technology and physical infrastructure to enhance mobility, sustainability, and quality of life. Table 1 provides an overview of the domains where cyber-physical systems (CPS) play a key role, illustrating various sources of literature relevant to the subject of smart cities. The table below details the eight areas where CPS is applicable.

Table 1. Domains in which cyber physical systems (CPS) are key

Code	Domain	Subdomain	References
D1	Integration of data and sensors in urban aspects	Integration of CPS with Internet of Things (IoT) and big data analytics for transportation and smart city applications CPS-enabled environmental monitoring and air quality management in smart cities CPS-enabled transportation systems for autonomous vehicles and connected vehicles	Hsu et al., 2023; Salih et al., 2023; Gera et al., 2023; Linardatos et al., 2023; Song et al., 2023; Alshbatat, 2023; Holubcik et al., 2023; Goyal et al., 2023; Ismaeel et al., 2023; Moolikagedara et al., 2023
D2	Smart public transportation	CPS-based solutions for public transportation and multimodal transportation systems	Kuo et al., 2023; Subramanian et al., 2023; Ferraris et al., 2020; Visan et al., 2021; Li et al., 2020; Li et al., 2020
D3	Emissions reduction and sustainability	Use of CPS for energy-efficient buildings and infrastructure in smart cities CPS-based approaches for intelligent transportation planning and management CPS-enabled smart grid solutions for transportation electrification and energy management in smart cities	Pandiyan et al., 2023; Yang et al., 2023; Sulaiman et al., 2023; Li & Tan, 2023; Dutta et al., 2023; Balfaqih et al., 2023; Peng et al., 2023; Yu et al., 2023; Wenting Li et al., 2023;
D4	Urban resource management	Urban resource management: lighting, waste management and water supply	Belsare et al., 2023; Mishra et al., 2022; Malik et al., 2023; Gupta et al., 2022
D5	Citizen participation in decision-making	Human-centric design and user experience considerations in the development of CPS for intelligent transportation and smart cities Ethical and societal implications of the deployment of CPS in transportation systems and smart cities.	Giela, 2023; Castilla & Mueller, 2023; Manazir, 2023; Lahat & Nathansohn, 2023; Wang et al., 2023; Dash, 2023; Dash, 2023
D6	Security and resilience	CPS-based solutions for emergency management and disaster response in smart cities	Almeida, 2023; Alshahrani & Prati, 2023; Xia et al., 2023; Aurangzeb et al., 2023; Aurangzeb et al., 2023; Sangaiah et al., 2023; Awotunde et al., 2023; Wenjuan Li et al., 2023; Shao et al., 2023; Kustu & Taskin, 2023
D7	Long-term planning	Smart city design	Ooms et al., 2020; Kumar et al., 2020; Dani et al., 2023; Jang et al., 2023
D8	Sustainable financing	Sustainable financing of smart cities	Ulpiani et al., 2023; He et al., 2020; Vogeley & Ryder, 2023; Panda et al., 2020

Note: D = Domain
Source: Prepared by the authors.

Below is a detailed description of each relevant domain of CPS application in smart cities.

2.1 Integration of Data and Sensors in Urban Aspects

This involves the use of advanced sensors to collect real-time data on traffic, air quality, weather, waste management, and other urban aspects. Integration of this data into CPS systems for making informed decisions. Nowadays, with the continuous integration of big data, artificial intelligence, and cloud computing technologies, there are growing demands and specific requirements for data exchange in sustainable smart cities (Hsu et al., 2023). This includes practical data sharing, which should be implemented non-interactively without a trusted third party involved, preferring dynamic thresholds as participants can join or withdraw at any time. A great deal of data resources and network availability are required for smart city applications to run at the highest level of efficiency. The demand for these objects is increasing data traffic, thereby putting pressure on the network (Salih et al., 2023). 5G-enabled Internet of Things applications address these challenges in smart city applications. However, emerging 6G network technology has arisen to facilitate ultra-reliable and low-latency applications for sustainable smart cities that are unattainable with existing 4G/5G standards. Therefore, advanced technologies such as machine learning (ML), blockchain, and the Internet of Things (IoT) utilizing the 6G network are leveraged to develop cost-effective mechanisms to address communication overload issues in the current state of the art (Gera et al., 2023).

Environmental monitoring and air quality management enabled by cyber-physical systems (CPS) play a crucial role in smart cities, enabling continuous assessment of air quality and data-driven decision-making to address pollution issues and improve residents' quality of life. CPS systems use a network of advanced sensors distributed throughout the city to collect data on air quality, including pollutant levels such as fine particles (PM2.5), nitrogen dioxide (NO2), ozone (O3), carbon monoxide (CO), and others. Carbon dioxide significantly contributes to greenhouse gas emissions, being a major driver of global warming and climate change (Dwivedi, 2022). By gathering sensor-based data and Internet of Things (IoT) technologies, there is the possibility of automating data-driven decision-making regarding the management and reduction of carbon emissions (Linardatos et al., 2023). Data collected by sensors are transmitted through communication networks, such as 5G, IoT, or wireless sensor networks, to a centralized system. Images captured by widely deployed stationary cameras can be quickly transferred via the Internet of Things (IoT) to facilitate environmental pollution estimations at any time and place (Song et al., 2023). Air pollution estimation based on images is typically formulated as a supervised learning problem, relying on a large number of image samples. Monitoring the pollution index in smart cities has sparked interest among researchers to design and develop Unmanned Aerial Vehicles (UAVs) capable of carrying various sensors. Recent advances in drone technology, as well as the rapid expansion of air pollution sensor technologies, have presented valuable alternatives for monitoring and managing air quality in smart cities.

Currently, fixed stations in smart cities are used to measure air pollution and gather accurate data on air quality. However, this data is often insufficient to make decisions that can improve people's lives; monitoring stations require a large and adaptable communication network capable of handling such large amounts of data. Instead of relying on such an expensive and complex network, drones could be considered a cost-effective alternative to current systems (Alshbatat, 2023). Artificial intelligence and machine learning techniques are used to identify patterns, predict air quality, and analyse pollution sources (Holubcik et al., 2023). Information about air quality is made available to citizens through mobile applications, websites, and information panels in public places (Hu et al., 2022). This enables residents to make informed decisions about their daily activities and avoid areas with poor air quality. When pollutant levels reach critical levels, CPS can issue alerts to citizens and authorities (Goyal et al., 2023). They can also provide recommendations, such as avoiding outdoor activities or using public transportation. Regarding intelligent traffic management, the development of traffic control systems that dynamically adjust based on current conditions is crucial, using optimization algorithms and real-time data analysis to enhance traffic efficiency (Ismaeel et al., 2023). A novel approach involves the classification of traffic patterns based on deep recurrent neural networks, which can effectively capture the dynamic and sequential characteristics of traffic patterns (Malik et al., 2023).

Cyber-physical systems (CPS) play a crucial role in the development and operation of autonomous vehicles and connected vehicles, enabling the integration of digital technology and the real-world physical environment. Blockchain video allows connectivity to be established between vehicles in a smart city by utilizing blockchain technology (Moolikagedara et al., 2023). By leveraging intelligent vehicular systems which provide location-based visualization through multiple cameras deployed in vehicles, the scope of video surveillance data collection for observation is expanded, thus enhancing overall situational awareness. The results indicate that this innovative framework provides increased security, privacy, and scalability for distributed networks of smart vehicles in smart cities, paving the way for a connected and efficient urban environment. Data on air quality is integrated with traffic management and public transportation systems. Measures can be taken to reduce traffic congestion and promote the use of cleaner transportation in areas with pollution problems. CPS data enables cities to identify sources of pollutant emissions and take specific action to reduce emissions. These measures may include promoting electric vehicles, improving public transportation, and implementing low-emission zones (Vijayakumar et al., 2022). The information collected by CPS influences urban planning and development, promoting more sustainable practices and the strategic placement of green areas and open spaces.

2.2 Smart Public Transportation

The concept of a smart city is one that employs Internet of Things (IoT) technologies and data analysis to enhance the efficiency of city operations and services, with the goal of providing a high quality of life for its citizens (Ahmed et al., 2022). The idea of a smart city involves the utilization of IoT technologies and data analysis to optimize the efficiency of city operations and services, ultimately aiming to enhance the quality of life for its residents (Kuo et al., 2023). To achieve sufficient coverage and service frequency, an integrated and coordinated multimodal public transportation system is needed, leading to a substantial increase in operational complexity. Environmental concerns and the recent pandemic may also alter work and commuting patterns in the future, with more people working from home and companies adopting flexible work shifts. For smart cities, public transportation must offer ubiquitous access, real-time responsiveness to demand, convenience, high-quality service, and energy-efficient operations. The use of cyber-physical systems (CPS) is fundamental for improving public transportation through scheduling, monitoring, and real-time information for passengers, along with the promotion of multimodality, combining various means of transportation (bus, train, bike, etc.) for more efficient mobility (Subramanian et al., 2023). This enhances the efficiency, safety, and quality of public transportation systems and is driving the adoption of multimodal transportation systems.

CPS enables route planning and schedule programming with dynamic adjustments in public transportation. Real-time monitoring of vehicles and assets allows public transportation operators to know the location and status of the fleet, providing real-time information to passengers through panels at stations, mobile applications, and websites, allowing access to updated schedules, routes, arrival times, and service alerts (Ferraris et al., 2020). CPS systems can collect real-time data on public and private transportation demand, enabling transportation authorities to optimize capacity and resource allocation. Similarly, safety in public transportation is enhanced with the installation of cameras and security sensors in vehicles and stations. In the worldwide landscape of intelligent cooperative public transportation systems (C-ITS) within Smart Cities, there is a pressing need for a comprehensive solution that harmonizes the viewpoints of travellers, public administration, vehicle manufacturers, and transportation operators. This collaborative effort aims to establish standards, facilitate interconnection, and assimilate emerging technologies.

The overarching goal is to address operational, safety, and environmental objectives on a metropolitan, national, or international scale (Visan et al., 2021). CPS systems facilitate the integration of multimodal transportation systems, with multiple modes such as trains, buses, shared bicycles, and ridesharing services, efficiently allocating resources such as vehicles and personnel (Li et al., 2020). They also facilitate multimodal payment, where passengers can use a single card or application to pay for multiple modes of transportation. This way, passengers can plan routes that include various modes of transportation for a more efficient journey, and coordination between modes of transportation is improved through real-time traffic and parking management, adjusting signage and routes to minimize congestion and facilitate transitions between modes. Furthermore, CPS systems and big data analysis enable traffic management and route optimization to reduce congestion and improve public transportation efficiency, using intelligent visual modelling systems for passenger traffic (based on neural networks and machine learning) to optimize passenger traffic in public transport and make informed real-time decisions, such as changing traffic lights or redirecting traffic (Lytvyn et al., 2021).

2.3 Emissions Reduction and Sustainability

The implementation of Cyber-Physical Systems (CPS) is essential to promote electric mobility and encourage sustainable transportation practices in smart cities. This involves combining the use of renewable energy and clean technologies in both public and private transport. Real-time monitoring of air quality through IoT sensors and CPS helps identify areas with poor air quality and which are sources of pollution, enabling the implementation of measures to reduce pollution and promote sustainability with this information (Shankar et al., 2021). Cities face challenges in managing their energy consumption and the need for technological advances to overcome these challenges (Pandiyan et al., 2023). Advancements are categorized based on their applications, such as smart grids, smart buildings, and smart transportation, offering benefits such as increased efficiency, reduced costs, and improved sustainability. Successful implementation cases of smart energy management technologies highlight potential areas for research and emerging technologies, including blockchain, edge computing, IoT, big data analytics, energy harvesting technologies, machine learning, and distributed energy resources (DER). As industrial and household loads continue to grow in smart cities, balancing energy supply and usage becomes more challenging (Yang et al., 2023). Increasing energy production on the supply side is one method to alleviate demand peaks, but additional facilities may be required due to the short duration of peak loads. The rapid development of the modern electrical system allows various components of the smart grid to securely connect, enabling a wide range of applications such as distributed energy management, system state forecasting, and cybersecurity (Sulaiman et al., 2023). These components generate large amounts of data that automate and enhance the efficiency of the smart grid.

Challenges in incorporating photovoltaic systems and wind energy sources into smart city electrical grids are addressed using digital twin simulations, providing a virtual representation of the electrical network for more efficient energy management (Li & Tan, 2023). On another note, intelligent transport planning addresses sustainable assessment and the design of freight movements through transportation networks, with appropriate design of urban routes for local carriers within cities or urban areas. Efficient and dynamic traffic management is an integral part of any smart city, determining the overall traffic flow efficiency by finding the shortest route considering real-time congestion and managing traffic signals. Route planning in a dynamic traffic environment remains an open challenge due to essential issues that have not been addressed as yet, especially considering priority vehicles, to provide better traffic flow (Dutta et al., 2023). The logistics industry has encountered issues due to the exponential growth of logistic volumes, process complexity, and lack of transparency. This has led to the proposal of IoT-based blockchain logistic systems for the tracking and efficient management of high-value shipments, ensuring data accuracy and reliability (Balfaqih et al., 2023). This allows optimization of loading and unloading, departures and arrivals, reducing the number of vehicles, and regrouping shipments and deliveries in multimodal environments, as well as reorganizing delivery and pickup areas through knowledge gained from historical data (Peng et al., 2023). Due to the complex topology of urban road networks and the dynamic change of traffic data, establishing a space-time model to accurately predict traffic volume remains a challenging task today (Yu et al., 2023). Route guidance strategies are an important part of advanced traveller information systems, which are a subsystem of Intelligent Transportation Systems (ITS) (Wenting Li et al., 2023). This involves a dynamic lane reversal strategy (DLRS) based on congestion group density throughout the traffic system, showing better adaptability to cope with traffic tide fluctuations.

2.4 Urban Resource Management: Lighting, Waste, and Water Supply

The use of Cyber-Physical Systems (CPS) for the efficient management of urban resources, such as public lighting, waste management, and water supply, allows real-time monitoring to prevent waste and improve energy efficiency. Solid waste management is one of the most critical issues associated with smart cities, impacting the health of our society and the environment. It has been a significant obstacle in the development of smart cities, affecting community living standards. Sustainable growth ensures stability in environmental needs, preserving resources for future generations, making waste management a concern for many authorities (Belsare et al., 2023). This is addressed through the use of IoT for waste monitoring, a network of wireless sensors for data communication, and discrete wave transformations, image processing, and machine learning for image categorization (Cvitić et al., 2021). Additionally, a route based on the classification of container stations is proposed, considering temporal and spatial data on filling times and route locations to minimize collection time through the creation of an efficient garbage collection algorithm (Mishra et al., 2022).

An important challenge for the development of smart cities is effective waste management following proper planning and implementation to connect different regions, including residential buildings, hotels, industrial and commercial establishments, the transportation sector, health institutes, tourist places, public spaces, and many others. Experts in smart cities play a crucial role in evaluating and formulating an efficient waste management plan that can be easily integrated with the overall development plan of the entire city. Machine learning and deep learning are sought-after areas in computer science and are finding extensive applications in the development of smart cities (Malik et al., 2023). Smart cities are an example of intelligent environments where all devices are connected, and computing is done in the cloud. In such a scenario, the system requires an efficient system to handle large requests and deliver data, necessitating the resolution of the resource and cost optimization problem in cloud infrastructure (Gupta et al., 2022) to provide a high service rate and sustainable infrastructure for cloud applications in smart cities.

2.5 Citizen Participation in Decision-Making

The concept of a smart city, influenced by social changes, technology, and geopolitics, is transitioning toward a human-centred model: Smart City 3.0. By emphasizing community involvement, this model ensures that new technologies adapt to the unique needs of each city. The creation of a participatory society is essential for this approach, encouraging public participation in decision-making. Basic mechanisms include public consultations and participatory budgets, as legislated, enhancing co-management between authorities and residents (Giela, 2023). Active community participation in decision-making and feedback on transportation systems and urban infrastructure allows the use of mobile applications and online platforms for data collection to improve the quality of life in the city. In recent years, a "participatory turn" has emerged as a remedy to counteract top-down and technocentric approaches to smart city development (Castilla & Mueller, 2023). The increasing use of digital governance platforms for shared decision-making requires closer analysis of their feasibility, the effectiveness of policies resulting from these platforms, and their challenges and limitations (Manazir, 2023). The goal is to understand the characteristics of electronic participation and, more importantly, the obstacles and limitations that hinder people's participation in shared decision-making (Lahat & Nathansohn, 2023).

Citizen participation in smart city projects is currently a hot topic, but there is a lack of quantitative research exploring this issue. Additionally, little is known about how the sense of responsibility drives participation in smart cities. The quality of information not only contributes to a better understanding of the key factors affecting residents' participation in building smart cities but also contributes to the implementation of improvement strategies and practices for building smart cities (Wang et al., 2023). It is crucial to understand the relationship between the built environment of smart cities, the quality of life of residents and the moderating effect of citizen participation in this relationship (Dash, 2023). Social conflicts may arise during the implementation of transportation infrastructure projects, which can be resolved with a comprehensive approach to public participation in the planning of road infrastructure in smart cities and towns within a sustainable transportation system (Ogryzek et al., 2021).

2.6 Security and Resilience

The implementation of robust cybersecurity systems to protect CPS (Cyber-Physical Systems) from threats and attacks involves combining technologies, enabling better security surveillance in the city. This allows for the identification of unusual events or suspicious behaviour (Almeida, 2023). This includes safeguarding shared data, such as banking transactions, vehicle information, geolocation, etc. With the increasing use of artificial intelligence (AI) and the Internet of Things (IoT), it is crucial to recognize potential security and privacy issues arising from these advanced technologies in smart cities (Alshahrani & Prati, 2023). Various ways exist in which smart city technologies can be vulnerable to cyberattacks and other security threats, posing privacy risks associated with the collection and use of personal data in smart cities. Effective security measures and privacy protection policies are crucial to ensure the security of smart cities (Xia et al., 2023). Collaboration among governments, private companies, and citizens is essential to implement such measures and policies, allowing smart cities to continue developing while ensuring the security and privacy of their citizens (Li et al., 2019). Moreover, the energy systems of smart cities, relying on IoT devices to regulate electrical grids, are susceptible to cyberattacks which may lead to power outages or significant damage to vital infrastructure (Memos et al., 2018). Similarly, smart city water systems, depending on AI-driven sensors to monitor water quality, may be at risk of hacking, potentially resulting in water supply contamination. Another example is intelligent autonomous vehicles (AVs): Networks of Cyber-Physical Systems (CPS) involve wireless communication among various CPS subsystems, such as smart vehicles and devices, to optimize and secure trip planning.

However, the vulnerability of these systems lies in their unreliable wireless communication, making such vehicles susceptible to malware attacks. These attacks pose a threat to vehicle autonomy, lead to heightened communication latency between vehicles, and can result in the depletion of vehicle energy resources (Aurangzeb et al., 2023). Such compromises can lead to traffic congestion, endanger passenger safety, and cause financial losses. Hence, the crucial aspect for ensuring intelligent and secure transportation, as well as the effectiveness of Intelligent Transportation Systems (ITS), lies in the real-time detection of these attacks.

Technology has enabled many devices to exchange vast amounts of data and communicate with each other, thanks to rapid technological advances. The use of the Internet of Things (IoT) is highly valued today and widely used in various interesting applications, such as hospitals, industries, and cities (Mishra & Chaurasiya, 2023). Security is considered a major concern in IoT-based applications due to advances in information technology and software (Guebli & Belkhir, 2021). Internet transactions have become significant in the case of smart cities and are often prone to a range of cybersecurity threats. When it comes to personal data, it is crucial to ensure that this is not disclosed, and no confidential information is divulged (Sangaiah et al., 2023). The adoption of information and communication technologies for smart city development has increased the risk of cyber threats, emphasizing the need to review the cybersecurity governance model. In order to safeguard a decentralized setup like smart cities, the Collaborative Intrusion Detection System (CIDS) has become a conventional security mechanism to protect different types of computer networks (Awotunde et al., 2023), especially decentralized computing platforms like the Internet of Things (IoT).

The main benefit of CIDS lies in the information-sharing process among devices, nodes, software, and hardware entities. However, traditional CIDS often requires a trusted third party, for example, a centralized computer server, to help build a reliable communication channel among various entities. Blockchain technology has provided a solution to secure the distributed/collaborative detection system (Wenjuan Li et al., 2023), a blockchain-assisted security management framework for CIDS, summarizing and providing integrated protection offered by blockchain. Moreover, it also addresses the development of contingency and recovery plans in the event of disruptions or natural disasters, allowing authorities to respond quickly to emergencies and natural disasters. Barrier coverage is a fundamental application in wireless sensor networks, widely used in smart cities. In these applications, sensors form a barrier for intruders and protect an area by detecting intrusions (Shao et al., 2023). Cities, becoming more crowded every day, face a range of issues, including increased planning, inadequate infrastructure, heavy traffic, and security concerns. Due to these issues, cities are more susceptible to natural disasters. Although many preparations are made against natural disasters in urban life, it is evident that adequate measures are not taken against secondary disasters. One of the most destructive and frequent secondary disasters is post-earthquake fires. Early fire detection systems exist to minimize losses caused by fires in the potentially chaotic environment that can occur after earthquakes in cities (Kustu & Taskin, 2023). This system consists of a structure that detects fires with a Convolutional Neural Network (CNN), useful for post-earthquake fire detection with low cost, high reliability, and accuracy.

2.7 Long-Term Planning

The development of long-term strategies must consider the changing needs of the city and transport infrastructure, allowing for the incorporation of CPS (Cyber-Physical Systems) in urban development master plans (Dana et al., 2022). The collection of data and big data analysis aid in long-term planning and the development of more efficient and sustainable smart cities. A city is a large and permanent human ecosystem that provides numerous services and opportunities to its citizens. The surge in urbanization and population expansion have exerted considerable stress on city infrastructures and service delivery. Addressing this current urbanization challenge necessitates robust strategies and innovative planning to modernize urban life (Ooms et al., 2020). To cope with these demands, many cities are adopting digitization, intelligent technologies, and smarter approaches to enhance the quality and efficiency of urban services. Policymakers and city authorities are actively seeking solutions to provide new services efficiently, responsively, and sustainably to accommodate the needs of their growing populations. In response to this imperative, the Smart City Transformation Framework (SCTF) has been introduced. This framework is designed to aid policymakers, urban developers, government officials, and service providers in comprehending and gaining deeper insights into the proposed smart solutions for the development of smart cities (Kumar et al., 2020). The framework encompasses four key areas: planning, physical infrastructure, ICT (Information and Communication Technology) infrastructure, and the implementation of smart solutions.

To develop a smart city platform, digital twin technology can be implemented (Dani et al., 2023) to monitor and simulate city conditions. This platform can serve as input for users or the community in planning their daily activities and can support government decisions in city development. The role of information and communication technology in the development of smart city platforms has allowed cities to grow smarter in recent years. The development of various technologies enables cities to collect a large amount of data, gain valuable insights, and, consequently, make city operations more efficient and intelligent. This allows the design of smart city services with a better understanding of data and establishes a comprehensive plan for data-driven smart city development (Jang et al., 2023).

2.8 Sustainable Financing

This implies the search for long-term financing sources, such as public-private partnerships, to sustainably carry out intelligent transportation and smart city projects. Cities are at the forefront of financial innovation, creating projects and business models that are being tested under a hands-on learning approach, bringing about profound and lasting transformative changes and establishing coordination mechanisms with new critical actors (Ulpiani et al., 2023). In this context, current financial management, regulation, and institutional agreements are key barriers to unlocking access to financing and creating a conducive environment for city-level investment. The level of green development reflected in the green finance index and the assessment of the degree of green development in smart cities have significant practical effects on economic transformation (He et al., 2020). The innovation incubation financing system also has a strong effect on the evolution of Smart Urban Development (DUS), with this system identified as private sponsorship, venture capital sponsorship, and sponsorship from higher education entities. Impact investing seeks to generate measurable social and/or environmental impact alongside financial returns (Vogeley & Ryder, 2023). Consequently, the assumed trade-off between financial performance and social benefit is no longer a given.

Panda (Panda et al., 2020) emphasizes that developing countries are embarking on "smart city" programs to position their cities as "growth engines," using intelligent technological solutions and management innovations. However, they are not adopting "smart" ways to finance urban infrastructure based on coherent theories. In particular, they have not leveraged the unearned benefits received by various actors in the urban economy due to agglomeration and network externalities and investments in urban infrastructure. By combining the principles of 'beneficiaries pay', and 'congestors pay', developing economy cities can mobilize broad resources to pay off long-term debt to finance infrastructure needs. In other words, urban infrastructure can be self-financed.

3. MATERIALS AND METHODS

The objective of this research is to determine, through neurotechnology, the cognitive perception of final-year undergraduate and master's students aged between 22 and 25, who use public transport daily to navigate their cities. The focus is on their perception of Cyber-Physical Systems (CPS) applied in transportation systems and smart cities. The selected countries and cities are Spain (Madrid), Ecuador (Quito), Colombia (Bogotá), and Argentina (Buenos Aires). The research uses triangulation, combining in-depth interviews (qualitative study) with neurotechnologies that allow the analysis of emotional intensity experienced through Galvanic Skin Response.

3.1. Objectives

This research aims to answer the question of which aspects are most relevant for citizen-users of specific services provided by CPS in smart cities. The empirical study focuses on the domains where Cyber-Physical Systems (CPS) play a crucial role, illustrating various literature sources relevant to the smart cities theme. The study records the assigned importance ratings to each domain and analyses users' emotional reactions during their responses, capturing the brain activity generated with each choice. The main objective is to analyse the recorded emotional intensity (emotional arousal) when responding to in-depth interviews (qualitative research) using neurotechnology. Specific objectives include:

- Identify the knowledge level of domains where CPS is relevant for smart cities.
- Quantitatively assess the importance attributed by users to each established smart city domain.
- Analyse the emotional intensity generated in users while commenting on each smart city domain they are questioned about.
- Verify differences between responses provided in in-depth interviews and emotional intensity recorded through neurotechnology.
- Determine if there are differences between countries based on quantitative and emotional responses.

3.2. Research Instrument

The problem of obtaining accurate answers to questions posed to consumers exists in traditional market research (Malhotra et al., 2007). The brain constructs reality with partial information and fills memory gaps with seemingly coherent information (Crone & Richard Ridderinkhof, 2011). The combination of neuroscience with traditional research (qualitative or quantitative) has given rise to a relatively new research discipline (Juarez et al., 2020; Morin, 2011). Technological advancements allow this field to go beyond traditional quantitative and qualitative research tools, focusing on consumers' brain reactions to stimuli (Reimann et al., 2010). Neuroqualitative (Juárez-Varón et al., 2021) is a new variant of qualitative research applying knowledge from the latest brain research to in-depth interviews (Madan, 2010). Research with neurotechnologies aims to connect neuronal system activity with consumer behaviour, offering a wide range of applications for brands, products, services, or communication. This can determine purchase intent, preferences, novelty level, knowledge, or generated emotions. Butler (Butler, 2008) proposes a research model connecting marketing researchers, professionals, and stakeholders, emphasizing the need for more research to establish its academic relevance.

Theoretical research with neurotechnologies is grounded in neuroscience, using neuroimaging techniques in this emerging field to test hypotheses, enhance existing knowledge, or examine the effect of marketing stimuli on consumer´s brains (Mengual-Recuerda et al., 2020). Research has established that brain activity patterns are closely related to behaviour and cognition. According to the classical assumption, consumers, in their decision-making process, consider all possible market alternatives and select the one that maximizes "marginal utility." This assumption is no longer valid, as stated by Daniel Kahneman (Kahneman, 2015), a psychologist and Nobel laureate in Economics in 2002. His work focuses on decision-making in uncertain environments and the use of heuristics and mental shortcuts. Therefore, the research technique used in this study is neuroqualitative (qualitative responses monitored with neurotechnology). Its purpose is to measure the cognitive processing of questions in the in-depth interview regarding the importance of key domains of application of Cyber-Physical Systems (CPS) in smart cities. The neurodata used are based on GSR, also known as electrodermal activity (EDA), which records changes in emotional arousal state influencing cognitive perception of stimuli.

The qualitative research method used was the in-depth interview. It consisted of a detailed and open conversation between the researcher and the participant, with the aim of obtaining rich and detailed information about the experiences, perceptions, opinions, and knowledge of the interviewee on a specific topic. In this specific approach, detailed conversations with participants were recorded with an audio recorder to explore their experiences and perspectives and later reviewed and analysed. The tool used in the measurement (skin conductance response or GSR) is a neurotechnology that measures the flow of electric current (of low intensity) through the skin, using 2 electrodes connected to the index and ring fingers of the non-dominant hand. When the stimulus (in this case, the question) has an emotional impact on the user, their skin generates sweating and reduces resistance to the passage of current, increasing conductivity (measured in microsiemens). The higher the emotional impact of the question, the greater the electrical conductivity recorded in the skin. The recorded values are normalized to facilitate the comparison of measurements across all users. This allows for a record of arousal or emotional intensity that can range from 0 (no emotional impact) to 1 (maximum emotional intensity). From here, each average value recorded by the user group for each question can be compared with the average value of the other questions, identifying those questions and responses with the greatest emotional impact and contrasting those values and differences with the responses from the quantitative research.

3.3. Sample Characteristics

In the present research, the sample consisted of male and female university students in their final year of undergraduate and master's programs, aged between 22 and 25 years old, who use public transport daily and frequently walk in their city. A total of 120 individuals (50% men and 50% women) participated randomly and voluntarily as study subjects after meeting the criteria of being final-year university students in undergraduate and master's programs, aged between 22 and 25 years old, low to medium purchasing power and high level of education and motivated in terms of environmental respect, who use public transport daily and frequently walk in their city. The selected countries and cities were Spain (Madrid), Ecuador (Quito), Colombia (Bogotá), and Argentina (Buenos Aires). The sample size per city (composed of 30 individuals) was suitable for a neuromarketing study (Cuesta-Cambra et al., 2017). After conducting the empirical study, a total of 4 users were excluded (1 male and 3 females), leaving 116 users.

The chosen demographic group is educated on the topics covered and are daily users of the services that a smart city can manage (topics covered in the study), so their involvement is greater than others social groups. This demographic group contributes favourably to the objectives of the study. Like any potentially selectable group, there are limitations to this approach, but these are among the best-educated, most involved, and commonplace users of smart city services.

3.4. Data Collection and Analysis

To record electrodermal activity, the Shimmer3 GSR+ model was used, along with ConsensysPRO software, v.1.6, for data collection. Subjects underwent an in-depth interview consisting of a total of 30 questions. Each question elicited a rating on a scale from 1 to 5 regarding the importance the user attributed to the presented smart city subdomain. Subsequently, participants were asked for their opinion on the specific aspect and whether they had used or witnessed that feature. Statistical analysis of the data was conducted using R software, v.3.6.3. The independent variable was the participants' gender, with a similar sociocultural profile across all participants, determined by the primary target profile. Dependent variables included the level of emotional arousal and the maximum and minimum levels of emotional excitement recorded in response to the posed questions. Quantitative data analysis was employed to assess users' perception of each proposed CPS application feature in smart cities and identify potential variations based on participants' origins.

The following are the questions posed to the users:

Regarding the semi-structured in-depth interview, the interview protocol was designed to highlight the user experience of smart city domains. The interviews were conducted by the authors, and all of them were face-to-face, with electrodermal activity being recorded. The application of neurotechnologies to qualitative research allows the recording of arousal or the general physiological and psychological activation of the organism (Gould et al., 1992) experienced by the subject during an in-depth interview, thus allowing a neuroqualitative study. All interviews were video recorded, transcribed, and analysed. Concerning the recordings of GSR peaks, which can occur up to 3 seconds after the onset of emotional activation, they were used to determine emotional excitement during the in-depth interview. The qualitative research phase (in-depth interviews) was monitored using the Shimmer3 GSR skin conductance response model. ConsensysPRO v1.6.0 software was used for data collection.

4. RESULTS

The data analysis had two objectives. Firstly, to demonstrate the level of understanding of the concepts of smart cities and cyber-physical systems among young university students. Secondly, to compare the quantitative data provided by the sample with the level of emotional involvement relative to the question developed in the in-depth interview (neuroqualitative). Table 3 displays the respondents' level of knowledge, by country, regarding the concepts of smart cities and cyber-physical systems.

50% of the respondents are familiar with the concept of a smart city in the countries of Spain, Ecuador, and Colombia, while there is 100% unfamiliarity with the concept of a cyber-physical system. However, in Argentina, the level of familiarity with the smart city concept is 100%, and 33% are familiar with the concept of a cyber-physical system and its application (Figure 1). In general terms, the awareness of the smart city concept is 63%, compared to 8% for the concept of a cyber-physical system and its application.

With regard to the level of importance attributed to each application of cyber-physical systems in Smart Cities, the most relevant aspect globally was the application of cyber-physical systems to

Table 2. Questionary parts and questions

Part	Question
Phase 1: First contact with the concept	
P1	*Are you familiar with the concept of Smart City?*
P2	Concept reading
P3	*Are you familiar with the concept of cyber-physical systems or CPS? If so, can you describe it?*
P4	Concept reading
Phase 2 knowledge and influence on the topic. Rate in the country/city	
P5	*Consider integrating data into CPS systems to make real-time decisions about air quality*
P6	Opinion request
P7	*Consider integrating data into CPS systems to make real-time decisions about traffic*
P8	Opinion request
P9	Knowledge of application in city of origin
P10	*CPS systems for efficient public transport*
P11	Opinion request
P12	Knowledge of application in city of origin
P13	*CPS systems for emissions reduction and sustainability*
P14	Opinion request
P15	Knowledge of application in city of origin
P16	*CPS systems for management of urban resources (lighting, waste, water)*
P17	Opinion request
P18	Knowledge of application in city of origin
P19	*Citizen participation in transportation decision making*
P20	Opinion request
P21	Knowledge of application in city of origin
P22	*Security and resilience*
P23	Opinion request
P24	Knowledge of application in city of origin
P25	*Long term planning*
P26	Opinion request
P27	Knowledge of application in city of origin
P28	*Sustainable financing*
P29	Opinion request
P30	Knowledge of application in city of origin

Source: Prepared by the authors.

improve public transportation efficiency, with a value of 4.58 out of 5. This aspect was followed in importance by sustainable financing and proper management of urban resources (Table 4).

Differentiating by feature and country, Air quality and traffic were more highly valued in importance by Ecuador. Similarly, respondents in this country assigned more importance than

Table 3. Level of knowledge of smart city and CPS concepts

Concept	Concept Knowledge	Spain	Ecuador	Colombia	Argentina	Group Average
Smart City	Yes	50%	50%	50%	100%	63%
	No	50%	50%	50%	0%	38%
CPS	Yes	0%	0%	0%	33%	8%
	No	100%	100%	100%	66%	92%

Source: Prepared by the authors.

Figure 1. Level of knowledge of smart city concepts and cyber physical system, by country

Source: Prepared by the authors.

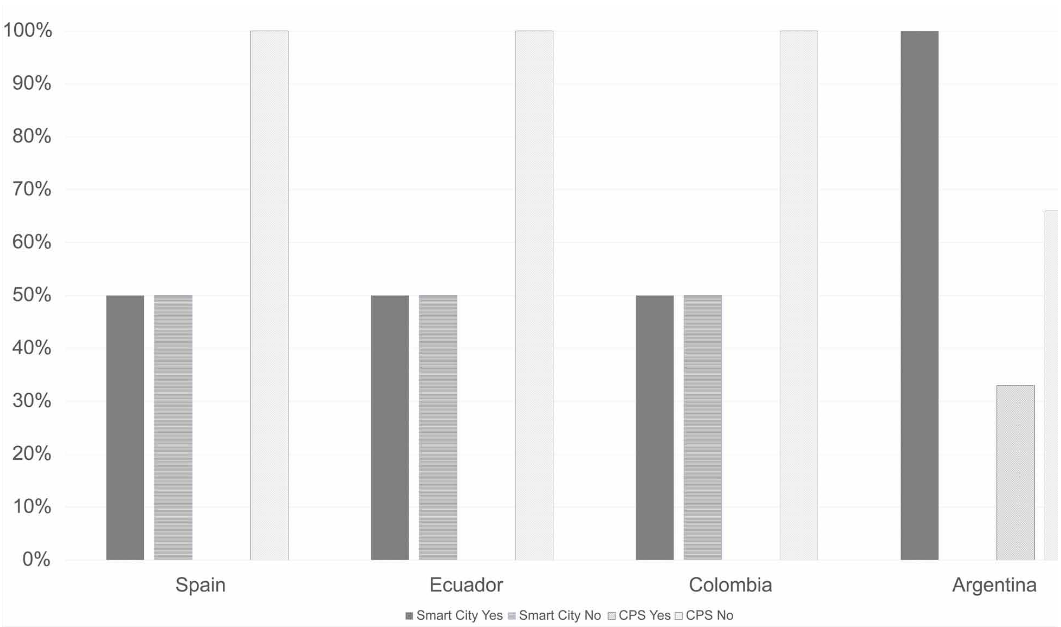


Table 4. Level of importance (scale 1-5) of smart city and CPS concepts

Scope of Application CPS - Smart Cities	Spain	Ecuador	Colombia	Argentina	Group Average
Air quality and traffic	4,00	**4,71**	3,00	3,90	3,90
Efficient public transport	4,50	**4,93**	4,00	4,90	**4,58**
Emissions reduction and sustainability	4,50	**5,00**	3,13	3,40	4,01
Urban resource management	4,50	**4,86**	3,63	4,00	4,25
Citizen participation in transport	3,50	**4,64**	3,13	3,50	3,69
Security and resilience	4,50	**4,77**	2,13	3,70	3,77
Long-term planning	**5,00**	4,86	2,63	3,70	4,05
Sustainable financing	**5,00**	4,93	3,00	4,10	4,26

Source: Prepared by the authors.

the rest to the aspects of Efficient public transport, Emissions reduction and sustainability, Urban resource management, Citizen participation in transport, and Security and resilience. As for Long-term planning and Sustainable financing, they were more highly valued in Spain. Figure 2 provides a per-country representation of the level of importance assigned to each application aspect of CPS in smart cities.

Following this, each part of the in-depth interview, monitored with galvanic skin response (GSR) to record the emotional intensity of each response, is detailed. The results have been averaged by country and overall. It is possible to contrast the level of importance expressed in the interview with the level of emotional involvement experienced in the response.

4.1 Part 1: Consultation and Explanation of Smart City Concepts and Cyber-Physical Systems

Table 5 displays quantitative responses (Scale 0-100%) and average emotion levels recorded in the response (Scale 0-1), by country and at the group level.

When the respondent is asked about their understanding of the concept and its possible explanation, the level of emotional intensity is higher than the level recorded while the concept is being explained. This occurs both with the smart city concept and the cyber-physical system concept. It is because they feel a higher level of stress due to having to respond, are concerned about the interviewer's perception, and often do not know the answer. In this phase of the interview, Colombian students express the highest level of emotional intensity (0.49), while the lowest value (0.31) is reported by the Spanish respondents. Regarding the question with the highest recorded arousal (0.57) at the group level, it is the first question, a consequence of being the start of the interview and the first question to be answered.

Figure 2. Scope of application CPS – smart cities, by country

Source: Prepared by the authors.

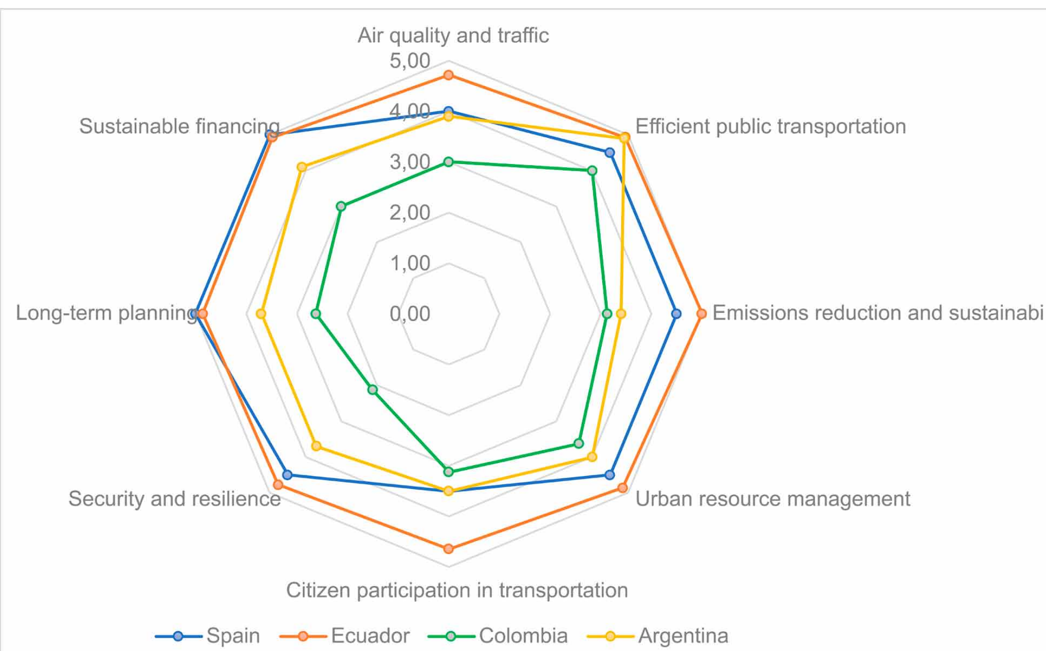


Table 5. Integrate data into CPS to evaluate air quality and traffic. Level of importance (scale 1-5) versus arousal.

1. Introduction	SPAIN		ECUADOR		COLOMBIA		ARGENTINA		GROUP AVERAGE	
	R	A	R	A	R	A	R	A	R	A
Consultation on knowledge of the smart city concept	Yes 50%	0,53	Yes 50%	0,51	Yes - 50%	0,65	Yes 100%	0,60	Yes 62,5%	0,57
Smart city concept explanation		0,16		0,42		0,51		0,44		0,38
Consultation on knowledge of the concept of cyber-physical systems or CPS	No 100%	0,46	No 100%	0,42	No 100%	0,51	Yes 33%	0,46	No 83,2%	0,46
Cyber-physical systems or CPS concept explanation		0,10		0,44		0,28		0,38		0,30
Average arousal in this part of the interview		0,31		0,45		**0,49**		0,47		0,43

Note: R = Response and A = Arousal
Source: Prepared by the authors.

4.2 Part 2: Integrate Data into CPS to Evaluate Air Quality and Traffic.

Table 6 displays the average importance level (Scale 1-5) attributed to 'Integrate data into CPS to evaluate air quality and traffic' and the average emotion levels recorded (Scale 0-1) in the response, by country and at the group level.

With respect to the importance level of this aspect, Ecuadorian students express the highest value, with an average rating of 4.71. In this phase of the interview, Spanish and Argentine students manifest the highest level of emotional intensity (arousal) (0.46 out of 1), while the lowest value reported (0.44 out of 1) corresponds to Ecuadorian students.

In this part, the highest rated importance (quantitative question) does not correspond to a higher arousal (neuroqualitative).

4.3 Part 3: Integrate Data into CPS to Achieve Efficient Public Transport.

Table 7 displays the average importance level (Scale 1-5) attributed to 'Integrate data into CPS to achieve efficient public transport´ and the average emotion levels recorded (Scale 0-1) in the response, by country and at the group level.

With respect to the importance level of this aspect, Ecuadorian students express the highest value, with an average rating of 4.93. In this phase of the interview, Ecuadorian students also manifest the highest level of emotional intensity (arousal) (0.50 out of 1), while the lowest value reported (0.42 out of 1) corresponds to Argentine students.

In this part, the highest rated importance (quantitative question) does correspond to a higher arousal (neuroqualitative).

Table 6. Integrate data into CPS to evaluate air quality and traffic. Level of importance (scale 1-5) versus arousal (scale 0-1).

2. Integrate Data Into CPS to Evaluate Air Quality and Traffic	**SPAIN**		**ECUADOR**		**COLOMBIA**		**ARGENTINA**		**GROUP AVERAGE**	
	I	A	I	A	I	A	I	A	i	A
CPS to evaluate air quality explanation		0,11		0,21		0,13		0,32		0,19
Asking about the importance of this function		0,58		0,50		0,48		0,46		0,50
CPS to evaluate traffic explanation		0,32		0,40		0,34		0,37		0,36
Asking about the importance of this function		0,68		0,48		0,66		0,53		0,59
Knowledge about the application in his/her city		0,62		0,59		0,64		0,63		0,62
Quantitative assessment / Average registered arousal	4,00	**0,46**	**4,71**	0,44	3,00	0,45	3,90	**0,46**	3,90	0,45

Note: I = Importance and A = Arousal
Source: Prepared by the authors.

Table 7. Integrate data into CPS to achieve efficient public transportation. Level of importance (scale 1-5) versus arousal (scale 0-1).

3. Integrate Data Into CPS to Achieve Efficient Public Transport	**SPAIN**		**ECUADOR**		**COLOMBIA**		**ARGENTINA**		**GROUP AVERAGE**	
	I	A	I	A	I	A	I	A	i	A
CPS to achieve efficient public transport explanation		0,22		0,34		0,27		0,28		0,28
Asking about the importance of this function		0,63		0,55		0,56		0,42		0,54
Knowledge about the application in his/her city		0,51		0,62		0,58		0,55		0,57
Quantitative assessment / Average registered arousal	4,50	0,46	**4,93**	**0,50**	4,00	0,47	4,90	0,42	4,58	0,46

Note: I = Importance and A = Arousal
Source: Prepared by the authors.

4.4 Part 4: Integrate Data into CPS to Achieve Emissions Reduction and Sustainability.

Table 8 displays the average importance level (Scale 1-5) attributed to 'Integrate data into CPS to achieve emissions reduction and sustainability' and the average emotion levels recorded (Scale 0-1) in the response, by country and at the group level.

With respect to the importance level of this aspect, Ecuadorian students express the highest value, with an average rating of 5.00. In this phase of the interview, Spanish students manifest the highest level of emotional intensity (arousal) (0.48 out of 1), with an importance rating of 4.50, while the lowest value reported (0.35 out of 1) corresponds to Ecuadorian students, who indicated an importance level of 5.00 out of 5.00.

In this part, the highest rated importance (quantitative question) does not correspond to a higher arousal (neuroqualitative).

4.5 Part 5: Integrate Data into CPS to Achieve Urban Resource Management.

Table 9 displays the average importance level (Scale 1-5) attributed to 'Integrate data into CPS to achieve urban resource management' and the average emotion levels recorded (Scale 0-1) in the response, by country and at the group level.

With respect to the importance level of this aspect, Ecuadorian students express the highest value, with an average rating of 4.86. In this phase of the interview, Argentine students manifest the highest level of emotional intensity (arousal) (0.45 out of 1), with an importance rating of 4.00, while the lowest value reported (0.35 out of 1) corresponds to Spanish students, who indicated an importance level of 4.50 out of 5.00.

In this part, the highest rated importance (quantitative question) does not correspond to a higher arousal (neuroqualitative).

Table 8. Integrate data into CPS to achieve emissions reduction and sustainability. Level of importance (scale 1-5) versus arousal (scale 0-1).

4. Integrate Data Into CPS to Achieve Emissions Reduction and Sustainability	**SPAIN**		**ECUADOR**		**COLOMBIA**		**ARGENTINA**		**GROUP AVERAGE**	
	I	A	I	A	I	A	I	A	i	A
CPS to achieve emissions reduction and sustainability explanation		0,27		0,33		0,17		0,38		0,29
Asking about the importance of this function		0,64		0,48		0,54		0,52		0,54
Knowledge about the application in his/her city		0,51		0,25		0,50		0,51		0,44
Quantitative assessment / Average registered arousal	4,50	**0,48**	**5,00**	0,35	3,13	0,40	3,40	0,47	4,01	0,43

Note: I = Importance and A = Arousal
Source: Prepared by the authors.

Table 9. Integrate data into CPS to achieve urban resource management. Level of importance (scale 1-5) versus arousal (scale 0-1).

5. Integrate Data Into CPS to Achieve Urban Resource Management	SPAIN		ECUADOR		COLOMBIA		ARGENTINA		GROUP AVERAGE	
	I	A	I	A	I	A	I	A	i	A
CPS to achieve urban resource management explanation		0,22		0,27		0,21		0,35		0,26
Asking about the importance of this function		0,36		0,48		0,44		0,49		0,44
Knowledge about the application in his/her city		0,46		0,55		0,42		0,52		0,49
Quantitative assessment / Average registered arousal	4,50	0,35	**4,86**	0,43	3,63	0,36	4,00	**0,45**	4,25	0,40

Note: I = Importance and A = Arousal
Source: Prepared by the authors.

4.6 Part 6: Integrate data into CPS to achieve citizen participation in transportation.

Table 10 displays the average importance level (Scale 1-5) attributed to 'Integrate data into CPS to achieve citizen participation in transportation' and the average emotion levels recorded (Scale 0-1) in the response, by country and at the group level.

Table 10. Integrate data into CPS to achieve citizen participation in transportation. Level of importance (scale 1-5) versus arousal (scale 0-1).

6. Integrate Data Into CPS to Achieve Citizen Participation in Transportation	SPAIN		ECUADOR		COLOMBIA		ARGENTINA		GROUP AVERAGE	
	I	A	I	A	I	A	I	A	i	A
CPS to achieve citizen participation in transport explanation		0,23		0,34		0,18		0,38		0,28
Asking about the importance of this function		0,44		0,42		0,41		0,43		0,42
Knowledge about the application in his/her city		0,34		0,33		0,40		0,46		0,38
Quantitative assessment / Average registered arousal	3,50	0,34	**4,64**	0,36	3,13	0,33	3,50	**0,42**	3,69	0,36

Note: I = Importance and A = Arousal
Source: Prepared by the authors.

Regarding the level of importance of this aspect, Ecuadorian students express the highest value, with an average rating of 4.64. In this phase of the interview, Argentinean students exhibit the highest level of emotional intensity (arousal) at 0.42 out of 1, with an importance rating of 3.50. In contrast, the lowest value expressed (0.33 out of 1) comes from Colombian students, who indicated an importance rating of 3.13 out of 5.00.

In this section, the highest valued importance (quantitative question) does not correspond to a higher arousal (neuroqualitative).

4.7 Part 7. Integrate Security and Resilience Systems to Protect CPS from Attacks.

Table 11 shows the average importance level (on a scale of 1-5) regarding "Integrated security and resilience systems to protect CPS from attacks," and the recorded average emotion levels (on a scale of 0-1) in response, by country and at the group level.

Regarding the level of importance of this aspect, Ecuadorian students express the highest value, with an average rating of 4.77. In this phase of the interview, Argentinean students exhibit the highest level of emotional intensity (arousal) at 0.46 out of 1, with an importance rating of 3.70. In contrast, the lowest value expressed (0.34 out of 1) comes from Spanish students, who indicated an importance rating of 4.50 out of 5.00.

In this section, the highest valued importance (quantitative question) does not correspond to a higher arousal (neuroqualitative).

4.8 Part 8. Incorporation of CPS Systems in Urban Development Master Plans.

Table 12 shows the average importance level (on a scale of 1-5) regarding "Incorporation of CPS systems in urban development master plans," and the recorded average emotion levels (on a scale of 0-1) in response, by country and at the group level.

Regarding the level of importance of this aspect, Spanish students express the highest value, with an average rating of 5.00. In this phase of the interview, Argentinean students exhibit the highest level of emotional intensity (arousal) at 0.43 out of 1, with an importance rating of 3.70. In contrast, the

Table 11. Integrate security and resilience systems to protect CPS from attacks. Level of importance (scale 1-5) versus arousal (scale 0-1).

7. Integrate Security and Resilience Systems to Protect CPS From Attacks	SPAIN		ECUADOR		COLOMBIA		ARGENTINA		GROUP AVERAGE	
	I	A	I	A	I	A	I	A	i	A
Integrate security and resilience systems to protect CPS from attacks explanation		0,18		0,25		0,20		0,31		0,24
Asking about the importance of this function		0,47		0,54		0,51		0,52		0,51
Knowledge about the application in his/her city		0,38		0,37		0,42		0,56		0,43
Quantitative assessment / Average registered arousal	4,50	0,34	**4,77**	0,39	2,13	0,38	3,70	**0,46**	3,77	0,39

Note: I = Importance and A = Arousal
Source: Prepared by the authors.

Table 12. Incorporation of CPS systems in urban development master plans. Level of importance (scale 1-5) versus arousal (scale 0-1).

8. Incorporation of CPS Systems in Urban Development Master Plans	SPAIN		ECUADOR		COLOMBIA		ARGENTINA		GROUP AVERAGE	
	I	A	I	A	I	A	I	A	i	A
Incorporation of CPS systems in urban development master plans explanation		0,20		0,33		0,24		0,43		0,30
Asking about the importance of this function		0,29		0,44		0,49		0,43		0,41
Knowledge about the application in his/her city		0,43		0,33		0,42		0,43		0,40
Quantitative assessment / Average registered arousal	**5,00**	0,31	4,86	0,37	2,63	0,38	3,70	**0,43**	4,05	0,37

Note: I = Importance and A = Arousal
Source: Prepared by the authors.

lowest value expressed (0.31 out of 1) comes from Spanish students, who indicated an importance rating of 5.00 out of 5.00.

In this section, the highest valued importance (quantitative question) does not correspond to a higher arousal (neuroqualitative).

4.9 Part 9. Search for Sustainable Financing Sources to Implement Smart Cities.

Table 13 shows the average importance level (on a scale of 1-5) regarding "Search for sustainable financing sources to implement smart cities," and the recorded average emotion levels (on a scale of 0-1) in response, by country and at the group level.

Regarding the level of importance of this aspect, Spanish students express the highest value, with an average rating of 5.00. In this phase of the interview, the students who also exhibit the highest level of emotional intensity (arousal) are the Spanish students, scoring 0.47 out of 1. In contrast, the lowest value expressed (0.40 out of 1) comes from Ecuadorian students, who indicated an importance rating of 4.93 out of 5.00.

In this section, the highest valued importance (quantitative question) does correspond to a higher arousal (neuroqualitative).

In general, as a group behaviour, only in 2 out of the 9 parts of the questionnaire does the level of importance assigned in the quantitative interview correspond to the associated level of emotional intensity (Figure 3). In the rest of the questionnaire sections, the level of importance assigned in the interview was above the felt emotional intensity when responding. Regarding the group, the highest importance is assigned to Part 3: "Integrate data into CPS to achieve efficient public transport," with a value of 4.58 out of 5, and an arousal of 0.46 out of 1. Similarly, the part with the highest arousal is Part 3, indicating that the group considers the integration of CPS in improving public transport efficiency as the part they value the most, both quantitatively and emotionally.

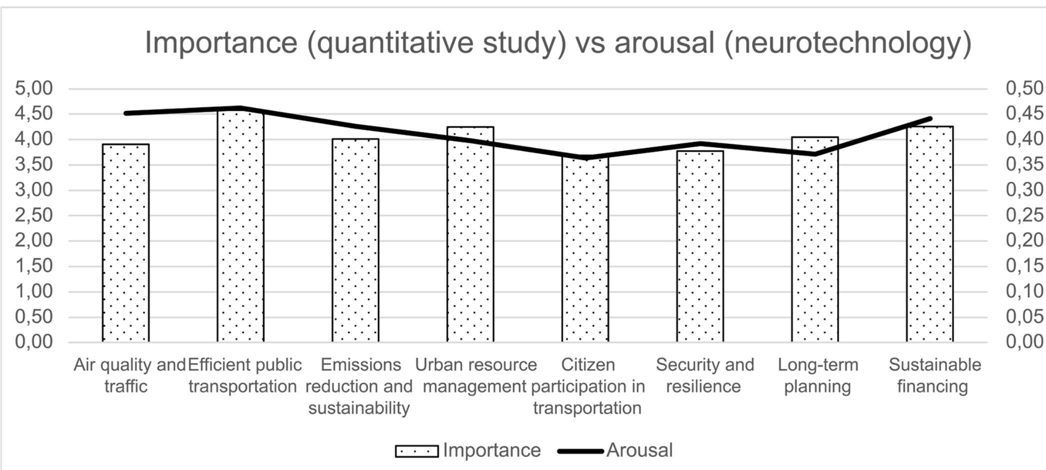
The importance declared by users does not always align with the emotional response. Theme 1 (Air quality and traffic) has a stated importance below the emotional response. Theme 2 (Efficient public transportation) has equivalence of stated importance and emotional response. The third theme

Table 13. Search for sustainable financing sources to implement smart cities. Level of importance (scale 1-5) versus arousal (scale 0-1).

9. Search for Sustainable Financing Sources to Implement Smart Cities	SPAIN		ECUADOR		COLOMBIA		ARGENTINA		GROUP AVERAGE	
	I	A	I	A	I	A	I	A	i	A
Search for sustainable financing sources to implement smart cities explanation		0,44		0,33		0,44		0,47		0,42
Asking about the importance of this function		0,43		0,53		0,57		0,43		0,49
Knowledge about the application in his/her city		0,53		0,35		0,31		0,47		0,41
Quantitative assessment / Average registered arousal	**5,00**	**0,47**	4,93	0,40	3,00	0,44	4,10	0,46	4,26	0,44

Note: I = Importance and A = Arousal
Source: Prepared by the authors.

Figure 3. Importance versus arousal in the application of CPS in smart cities
Source: Prepared by the authors.



(Emissions reduction and sustainability) has a stated importance below the emotional response. Urban resource management (topic 4) has been valued with greater declared importance than the emotional impact it has had. Theme 5 (Citizen participation in transportation) has equivalent values of stated importance and emotional response. Security and resilience (theme 6) have slightly greater emotional response than stated importance. Topic 7 (Long-term planning) has shown a declared importance greater than the true emotional impact, standing out for talking about the long term. Finally, the financing has implied an emotional response value slightly above the declared importance.

Consequently, the emotional response is greater than the declared importance when it comes to perceptible issues in daily life and changes the orientation of both registers when it comes to managing resources or long-term planning, not being directly reflected in their daily lives.

5. DISCUSSION

The concept of a smart city represents the solution for intelligent urban development and sustainable socio-economic progress. The use of advanced information technologies in city transformation aims to make them more sustainable, efficient, and closely coordinated with resource management. Cyber-physical systems (CPS) serve as transformative technological elements, enabling the integration of the physical and cyber worlds. In terms of its empirical contribution, this study primarily emphasizes the perception of value and acceptance within the Ibero-American society regarding the use of CPS in smart transportation systems and cities, employing neurotechnologies. This analysis has focused on quantifying the assessment and perception of the use of CPS in the planning and management of intelligent transport, autonomous and connected vehicles, public transportation, air quality, IoT in transport, emergency management, and user experience. The study is framed within considerations of human-centred design and user experience in the development of CPS for intelligent transport and smart cities, as well as the ethical and social implications of deploying CPS in transport systems and smart cities. To avoid issues associated with traditional market research, the proposal has been to combine neuroscience with traditional research (qualitative or quantitative), utilizing a relatively new research discipline based on technological advances. This approach allows the field to go beyond traditional quantitative and qualitative research tools and focuses on consumers' brain reactions to stimuli, applying the latest brain research knowledge to in-depth interviews.

The research technique used in this study is neuroqualitative (qualitative monitored with neurotechnology). Its purpose is to measure the cognitive processing of issues discussed in the in-depth interview regarding the importance of key application domains of cyber-physical systems (CPS) in smart cities. The neurodata used are based on GSR, also known as electrodermal activity (EDA), which records changes in emotional arousal that influence cognitive perception of stimuli. The overall recorded results, as group behaviour, reveal that the importance levels assigned in the quantitative interview by participants do not correspond to the associated level of emotional intensity. Consequently, responses are not aligned with emotional activation but rather appear as isolated, non-relativized, and socially accepted answers. The highest quantitative rating is assigned to the importance of integrating CPS in improving public transport, and it is the only response that reflects emotional impact. Therefore, the group considers this application the most relevant in the study, as it is part of their daily routine and represents the most significant issue to address in their city.

These findings, where a mismatch is perceived between the declared importance and the emotional response, have direct implications for policy makers when designing and implementing CPS in smart cities, and the results can be reversed with greater communication about the real impact of topics that generate less emotional impact than declared importance, since they do not really affect users emotionally and, consequently, do not generate motivation towards change.

6. CONCLUSION

This work can be considered a contribution to the development of empirical research aimed at gaining a better understanding of human-centred design and user experience in the development of Cyber-Physical Systems (CPS) for smart cities. To this end, seven main domains and associated subdomains of CPS development for smart cities have been created (air quality and traffic, efficient public transport, emissions reduction and sustainability, urban resource management, citizen participation in transportation, security and resilience, long-term planning and sustainable financing). This work contributes to the expansion and enrichment of the existing classification or categorization of emotional experiences in the field of CPS usage in smart cities. It identifies emotions linked to the analysed domains, providing a more precise and detailed understanding of the actual importance of each domain. It adds to the body of knowledge by offering a new perspective on emotional experiences applied to specific fields such as smart cities. This research enhances the accuracy of investigations by combining two relevant market research methods and may influence the design of future academic methodologies for market research.

The assessment of cognitive perception by senior undergraduate and master's students, aged between 22 and 25 years, who use public transport daily and navigate their city, has been collected through neurotechnology. This evaluation focused on the application of Cyber-Physical Systems (CPS) in smart cities. A triangulation research approach was used, combining in-depth interviews (qualitative study) with neurotechnologies that allowed the analysis of emotional intensity experienced (Galvanic Skin Response). The aim was to answer the question of which aspects are most relevant to citizens using specific services provided by CPS in smart cities. Importance ratings were recorded for each domain, and users' emotional reactions were analysed during their responses, capturing the brain activity generated for each choice. The results of this study revealed that the three most important aspects for this user group are, in order of importance:

1. Integration of data into CPS to evaluate air quality and traffic
2. Search for sustainable financing sources to implement smart cities
3. Integration of data into CPS to achieve urban resource management

On the other hand, the three aspects with the highest emotional involvement are, in order of importance:

1. Integration of data into CPS to achieve efficient public transportation
2. Integration of data into CPS to evaluate air quality and traffic
3. Search for sustainable financing sources to implement smart cities

In most responses, the quantification of importance does not align with emotional involvement when answering the question. Emotional involvement serves as a signal of the influence on the cognitive perception of the presented stimuli. As a result, specific research objectives have been addressed, concluding that the level of knowledge about the domains in which Cyber-Physical Systems (CPS) are relevant for smart cities is low (8%). Quantitative assessment highlights the overall importance of evaluating air quality and its connection to traffic. Emotional involvement emphasizes a greater concern for the integration of data into CPS to achieve efficient public transportation. Differences between responses from in-depth interviews and emotional intensity recorded through neurotechnology are evident. Additionally, variations exist between countries in both quantitative and emotional responses, reflecting concerns about specific situations.

This new knowledge provided by the study, the result of understanding the real motivations of users in the implementation of CPS in smart cities, can inform in a practical way, and help with our understanding of the motivations of citizens and guiding the development efforts of CPS in smart cities. Possible challenges or barriers in the implementation of these recommendations can be reduced with correct communication, improved understanding of the real impact and emotional activation that leads to greater motivation towards change. These findings, where a mismatch is perceived between the declared importance and the emotional response, have direct implications for policy makers when designing and implementing CPS in smart cities, and the results can be reversed with greater communication about the real impact of topics that generate less emotional impact than declared importance, since they do not really affect users emotionally and, consequently, do not generate motivation towards change.

Our research lays the foundations for future improvements in the efficiency of CPS development in its application to transport and smart cities, considering the perception and assessment of citizens. Similarly, it establishes a comparative model of two market research methodologies: quantitative and neuromarketing. This line of research allows the proposed model to be defined and used for future market research, where a panel of experts is used.

COMPETING INTERESTS

The authors of this publication declare there are no competing interests.

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