Immersive Technologies As a Tool For Evaluating Sustainable Mobility Policy Effectiveness

ELDA ROBI[1], MARIAROSARIA PICONE[2,*], ILARIA HENKE[3], ARMANDO CARTENI[4,a]
[1]Department of Architecture and Industrial Design
University of Campania "Luigi Vanvitelli"
Via San Lorenzo - Abazia di San Lorenzo, 81031 Aversa (Caserta),
ITALY

[2]Department of Engineering,
University of Campania "Luigi Vanvitelli",
via Roma 29, 81031 Aversa (Caserta),
ITALY

[3]Department of Engineering and Sciences
Mercatorum University
Piazza Mattei 10, 00186 Rome (Rome)
ITALY

[4]Department of Architecture and Industrial Design,
University of Campania "Luigi Vanvitelli",
Via San Lorenzo - Abazia di San Lorenzo, 81031 Aversa (Caserta),
ITALY

[a]http://orcid.org/0000-0003-4181-6631

**Corresponding Author*

Abstract: Transportation planning is about coming up with and looking at different policies, programs, and projects that affect how people and goods get around in a certain area. In this field, technicians rely on quantitative methods and modeling tools to carefully examine the effects and the real usefulness of the measures proposed to improve the transportation system. To do this, mobility surveys are often used to evaluate the level of acceptance/preference of users for new transport services or improvement of existing ones (e.g., redevelopment of a transport terminal; new bus connections/stops; new services for travelers). Often in these surveys, hypothetical scenarios of services/facilities that do not yet exist are submitted to users through the so-called Stated-Preferences (SP) surveys. Although there is a copious literature on this type of survey and on the models and methods that can be derived from this data, little attention has yet been paid to the quality with which the hypothetical scenarios are presented to travelers (e.g. images, videos or simple text description) and above all to their real ability to identify themselves with these hypothetical contexts (e.g. the choice between a new and non-existing train service competing with the usual bus service used every day). This issue is central for mobility planners, because a low capacity of users' identification corresponds to a low quality of the models and estimates that derive from them, and which can limit/undermine the entire planning process. The recent disruptive development of immersive technologies (es, virtual reality; augmented reality), developed mainly for other sectors (e.g., gaming and entertainment; education and training; retail and e-commerce; architectural design and visualization) today also find a possible application in the transport sector as a usufull tool for evaluating mobility policy effectiveness within, for example, SP survey. This paper aims to look at the main immersive technologies, like Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), and see how they are used in transportation planning. It also tries to point out what works well and what doesn't for each technology. The results show that extended reality technologies (VR, AR, MR) make transport SP surveys feel more realistic and help users relate better to the scenarios, which in turn makes transport models more reliable. VR gives a fully immersive experience but can be expensive and tricky to use, while AR and MR offer a mix of realism and easier access. We also need standard methods and long-term studies to really understand how these technologies affect planning decisions.

Key-Words: immersive technologies, virtual reality, mixed reality, augmented reality, transportation planning, applications of immersive technologies, sustainable mobility, discrete choice experiment.

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1 Introduction

The concept of immersive technology is 50 years old, when in 1964 the first prototype of an immersive human-computer interaction, called "Man-Machine Graphical Communication System", was developed by [1]. Academics have had varied interpretations of immersive technology. For example, [2] refers to immersive technology as the technology that gives a high quality or volume of sensory information to the users. According to him, much importance is placed on the quality and amount of sensory information users receive. [3] describes immersive technology as that which blurs the line between the actual world and the virtual world, giving users a sense of immersion. [4] has also specified that Immersive Reality (IR) encompasses virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies that create immersive experiences by blending physical and digital environments to various extents. Looking at what's already been written in the literature, the first goal of this paper is to go through the different technologies that make up Immersive Reality (IR) and discuss what they do well and where they fall short. Over the past ten years, more and more people have been interested in how these technologies let users experience and interact with digital environments as if they were real. Because hardware and software are getting cheaper and there are so many ways to use them, immersive technologies look promising for business, and companies are trying out new ideas to take advantage of them. Immersive Reality technologies have changed a lot of industries by making user experiences more engaging and giving people new ways to interact with both digital and real-world environments. In each area, VR, AR, and MR are used in different ways to meet specific needs and come up with new solutions. The paper is set up like this. In Section 2, we go over the main types of immersive technologies, like VR, MR and AR, and we try to explain in simple terms what they are and how they work. Then, in Section 3, we look at how these technologies are actually used in different areas, with more attention on transport, for example in planning, in understanding how people behave, and also in testing autonomous vehicles. In the end, Section 4 briefly comes back to the main ideas and shares some thoughts on how all of this could be useful when thinking about more sustainable mobility.

2 Types and Characteristics of Immersive Technologies

Immersive technologies are, in simple words, tools that try to make digital experiences feel more real. They can mix the real world with virtual parts, or sometimes replace it. The idea is just to make the user feel a bit "inside" what is happening. Most of the time, people refer to VR, AR and MR when they talk about this. But there are also other things, like 360-degree videos, or systems that give some kind of physical feedback, like touch. Compared to traditional media, they are different mostly because the user is more involved. It's not just watching or reading, but something a bit more active. In essence, these technologies are characterized by a core set of attributes that ensure the enrichment of user engagement, realism, and interaction. Key features of immersive technologies include the following:

Immersion is defined as the feeling of "being there" in a virtual environment. The degree to which a user feels physical and mental involvement in the digital world, often up to the point of losing awareness of the real world.

Interactivity: The term means different ways in which users can interact with the virtual environment or contents in real time. It allows users to give some control over them or influence happenings around them during an experience to present a dynamic and personalized interaction.

Presence: It is defined as a feeling of "being there" in a virtual space. This is in terms of realism and emotional engagement of users with the virtual world, as if it were the real one.

Real-time rendering means that an immersive technology can render and refresh graphics in real time in response to input by the user or the environment. This enables user interaction with the environment that happens in a timely manner.

"Extended Reality" (XR) might be defined as an umbrella term encapsulating Augmented Reality, Virtual Reality, Mixed Reality, and everything in between". [5] The relationship that exists between these technologies can be well explained by Figure 1.

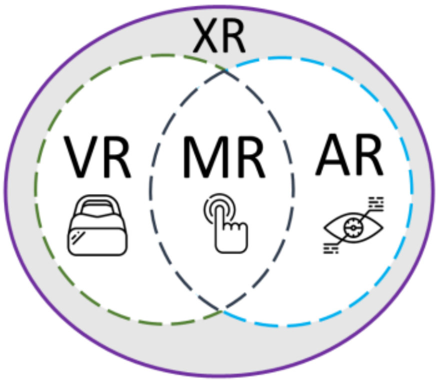

Fig. 1: Extended Reality technologies: Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) [5]

The next paragraph aims to give a clearer idea of virtual, mixed, and augmented realities. It explains what they are, talks about their main features, and gives examples of how they can be used in practice.

2.1 Virtual Reality

Virtual reality is a computer-generated simulation of a three-dimensional image or environment, simulating experience by means of the senses and perception. It represents a multichannel and computer-generated environment with interface tools that provide its user with a view of him inside an environment, moving around, and lastly, interacting with objects and other entities present therein [6]. It provides a detailed look at the external world from different dimensions, and thus users and learners can try things that are not accessible in real life or are not created yet.

Virtual reality is completely immersive. While experiencing VR, there is a complete disconnection with the physical world and full entry into the virtual space of the user. The use of Head-Mounted Displays, HMDs, allows 360-degree views within the virtual environment that VR encompasses. More recently, motion controllers, haptic feedback, and audio have been used in enhancing this "sense of presence" (Figure 2).

In VR, the virtual world is fully created by a computer. It can be something real, such as a city or a natural environment, but it can also be something completely imaginary, like video game worlds or future cities. These environments are not always static, since they may change depending on user actions or other external factors. To interact with VR systems, users typically rely on controllers such as Oculus Touch or HTC Vive devices. However, interaction is not limited to controllers only. Hand tracking, motion sensors, and eye tracking can also be used. Through these tools, users can move within the virtual environment, interact with objects, and in some cases also communicate with other users in shared virtual spaces. Other systems go further with the use of haptic feedback by means of gloves or suits, which deliver an actual feeling of touching for an altogether new dimension in immersion, such as touching virtual objects, textures, or forces.

Real-time rendering of virtual environments in VR systems depends on user input. The movement of the head, hands, and body of the user directly influences what he or she is able to see and how he or she experiences the virtual space. Real-time response entails a much more natural experience, or rather, the illusion of naturalness.

Unlike the traditional screen, in virtual reality, one is able to get a field of view of 360 degrees and look either left, right, up, or down as they do in reality. As the head changes, so does the dynamical environment around it to create a sense of "being there" rather than observing from one particular fixed perspective.

The headsets are considered the major hardware of virtual reality. They provide a view both visually and auditorily of the virtual world. VR headsets have come a long way, and by now most people have at least heard of the big ones — Oculus Rift/Quest, HTC Vive, PlayStation VR, Valve Index, Meta Quest 2. They all work on roughly the same principle: a screen close enough to your face to fill your field of view, sensors that track where you're looking, and software that updates the image fast enough that your brain buys it. It sounds simple, and in a way it is. Controllers are still how most people interact with virtual environments, and they're fine. You grab things, you point, you press buttons, after a while your hands just know what to do. A handful of newer systems have started tracking bare hands instead, no controllers at all, just cameras watching your fingers. It's impressive when it works. It doesn't always work. Haptic gloves and suits are where it gets weird, in a good way. The whole point is to give you something to feel when you touch a virtual object. A bit of resistance, a vibration, some illusion of weight. The first time it actually works, it's genuinely strange. Your brain knows the object isn't real. Your hand isn't so sure. Positional tracking is less glamorous but just as important. Whether it's external cameras or sensors built into the headset, the system needs to know where you are in the room at all times. In room-scale VR, where you're actually on your feet, moving around, even small tracking errors break everything. The moment the virtual space stops matching your physical movement, the immersion is gone, just like that.

Fig. 2: Example of a Virtual Reality device
(image generated with ChatGPT)

Sound is a key part of the VR experience and helps make it feel more real. Most of the headsets in a VR system have built-in systems for spatial audio, whereby the sound changes depending on the orientation of the user and where he or she appears in the virtual world, with respect to distance from virtual sound sources. Some even support 3D audio to mimic real-world behavior.

At present, there are three categories of virtual simulations that are employed. It is worthwhile to examine each of them individually [7].

2.1.1 Non-immersive

Non-immersive devices are commonly known as desktop virtual reality; it is a VR that functions with any input device. Video games are included in the desktop VR systems. It is a combination of virtual reality and real-world attributes. Computer graphics objects are embedded in scenes of the real world non-interactively in it. Some examples are: **Video games:** Some of these VR games are presented on a screen, where the player does not use a headset.

Simulations: This can be flight simulators or driving games - using a screen - but controlled by standard input devices such as keyboard, mouse, or joystick.

2.1.2 Semi-immersive

Semi-immersive systems, also called hybrid systems. This is one desktop VR development, including other devices like Data Gloves. The input into such kinds of systems is entered and controlled by users; for example, mouse, keyboard, interaction style, glass, and joysticks. Some examples are: **CAVE systems, Cave Automatic Virtual Environment:** Room-sized environments with projections of the virtual world projected onto walls, the floor, and the ceiling. Users can interact with those projections, but may not have full immersion.

Low-end Virtual Reality Headsets: These could be like basic VR headsets, which include Google Cardboard or earlier generations of models, confined to limited immersion sans advanced tracking and high-definition visuals.

2.1.3 Full-immersion

Full immersion requires the user to wear a data glove and an HMD, which tracks the user's head movements, and after that changes the view accordingly. Users who experience full immersion in VR can feel like they're actually part of the virtual world. Some examples are:

- **Oculus Quest / Meta Quest:** A standalone VR headset that lets you move around a room and interact in real time with high-quality graphics.
- **HTC Vive:** A headset that tracks your movements very precisely for a more realistic experience.

It finds applications in the industries of gaming, training, and simulation.

PlayStation VR: The virtual system of reality that enables users to play interactive games on the PlayStation Console.

2.2 Mixed Reality

Mixed reality, otherwise hybrid reality, is where the real world with virtual constructs created by it will be mixed with constructs created by a computer—real or possible—to let the user experience new objects or scenarios that actually do not exist [8].

MR ushers in a completely new frontier of VR use—provided the technology can be harnessed for application in the real world on a daily basis. MR is an extremely promising technology in the field of medicine, defense, architecture, urban planning, education, and training.

MR allows virtual objects to be 'contextually' aware and interact with the real world. For example, a virtual object placed on a real surface would interact with the displacements in the real world, such as getting occluded or moved by a real object.

Most MR systems contain advanced sensors, cameras, and depth-sensing technology to attain a real-time understanding of and map out-the real world surroundings in real time. Spatial Mapping: Utilizing spatial awareness and environmental mapping, Mixed Reality systems build a 3D understanding of the real world. This would allow virtual objects to "anchor" in real-world objects and locations for permanence and interaction.

This enables the MR system to comprehend the contours of a room, the detection of walls, furniture, or other objects standing in it, and the positioning of virtual elements within these in such a way that they naturally integrate into the physical setting (Figure 3).

More importantly, virtual objects in MR are not just lying flat on the real world as in AR; they are attached to the real environment, and their position and orientation might be persistent even while navigating around it.

For example, in an MR, a 3D digital chair placed in the room will continue to stay in that exact location even when the user walks out of the rest of that room and back to where the chair had been located.

MR makes it possible for the capability of interaction, bidirectional between the physical and virtual environment. Interaction in mixed reality isn't just about what you do to virtual objects, it goes the other way too. You move something, sure, but the virtual world can also react to what's physically around you. A digital character that walks around your actual table rather than through it. An overlay that shifts when you move a real object out of the way. Small things, but they add up. When it works, you stop thinking about the technology and just accept what you're seeing. Devices like the Microsoft HoloLens or Magic Leap handle this through cameras, sensors, and in some cases depth-mapping tools that are constantly scanning the room. The headset builds a picture of the physical space, furniture, walls, surfaces, and the virtual layer responds to it in real time. It's not always perfect. Anyone who's actually used one of these devices for more than ten minutes has seen a virtual object clip through a table or a character glitch out near a wall. But the moments when it clicks, when a digital thing behaves exactly as a real one would, are still kind of remarkable.

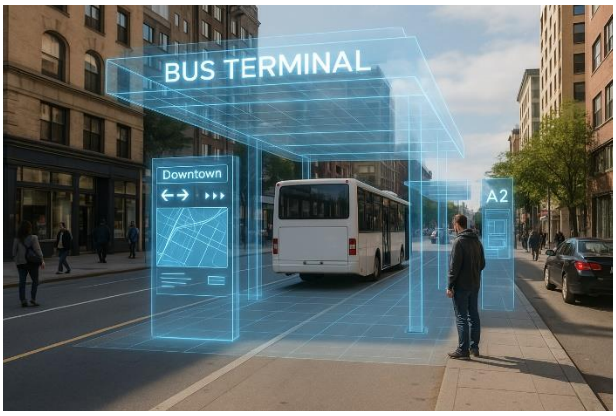

Fig. 3: Example of Mixed Reality
(image generated with ChatGPT)

2.3 Augmented Reality

Augmented Reality - A direct or indirect real-time view of a physical, real-world environment whose elements are 'augmented' or accelerated by virtual computer-generated information, thus enhancing one's experience of reality. AR is therefore interactive and registered in 3D, and it merges real and virtual objects, resulting in a real world with virtual objects. Augmented reality allows one to view the space around one to project a virtual entity into it. If something isn't really there, it can be shown through a device so the user can still see it and play with it (Figure 4). Augmented Reality (AR) puts digital stuff, like images, sounds, videos, or other data, on top of what you see in the real world, and it does it in real time. Unlike VR, which makes a totally virtual world, AR just adds digital bits on top of the real world. The whole point is to give users a more interactive view of what's around them, letting them mess with both real and digital things at the same time. You can use AR on lots of devices, phones, tablets, or AR glasses. The digital stuff lines up with the real world using cameras, motion sensors, GPS, and computer vision, so things show up in the right spot. Most of the time, you can even move or change the virtual objects, like they're really part of the environment.

Fig. 4: Example of Augmented Reality
(image generated with ChatGPT)

Table 1 gives an overview of how Virtual Reality, Mixed Reality, and Augmented Reality differ from each other, looking at their basic definitions, the way users interact with them, some common examples, the typical situations where they're used, the hardware they need, and also how immersive each one actually feels.

Table 1.The main characteristics of AR, MR, and VR reality (source: Authors' elaboration)

Aspect	Virtual Reality (VR)	Mixed Reality (MR)	Augmented Reality (AR)
Definition	A computer-generated environment, either simulated or imaginary, which provides an immersive experience, mimicking physical presence.	Blends physical and virtual worlds into new environments and visualizations to display both physical and digital objects coexisting in space and interacting in real time.	It overlays digital information in the real world to improve reality perception by the user.
Interaction	Typically fully immersive, with limited interaction with the physical world	Allows for interaction with both physical and virtual objects simultaneously	It enhances real objects by allowing them to include digital information, thus allowing the user to interact with both
Examples	Oculus Rift, HTC Vive	Microsoft HoloLens, Magic Leap	Pokemon Go, Snapchat filters
Use Cases	Gaming, training simulations, virtual tours	Design and visualization, remote collaboration, education	Navigation, marketing, healthcare
Hardware	Head-mounted display, controllers	Head-mounted display, sensors, cameras	Smartphones, tablets, smart glasses
Immersion Level	High immersion, complete escape from reality	Variable immersion, blends real and virtual elements	Low to medium immersion, enhances real-world experience
Challenges	Motion sickness, limited physical interaction	Hardware limitations, content creation complexity	Integration with real-world objects, user privacy concerns

3 Example of Immersive Technology Applications

Emerging technologies find a wide range of applications in VR, AR, and MR across numerous sectors. These let users interact with digital environments in a very engaging way, opening up new possibilities for things like training, entertainment, design, communication, and more. Next, we give a quick look at how immersive technologies are being used in different areas: in education (e.g., [9], [10], [11]) medicine and healthcare(e.g., [12], [13], [14], [15]) tourism (e.g., [16], [17], [18], [19], [20], [21]) Marketing (e.g., [22], [23], [24]), architecture and engineering(e.g., [25], [26], [27]), and in the social behavior research(e.g., [28], [29], [30], [31]).

In education, these technologies give students a more immersive way to learn. They can see digital content in simulated environments and use different learning styles, which could help improve how teaching and learning actually work [9], [10]. In the field of medical, education AR and VR are used to visualize complicated anatomical structures and accomplish virtual surgeries to offer higher-quality medical training examplethe training of various surgical and emergency procedures is conducted on doctors and nurses using VR simulations. Virtual reality, especially 360-degree VR videos, further immerses medical trainees' interest in them [14] or using training simulators on an AR/VR-guided procedure for a neurosurgical procedure [12].

In the field of medicine and healthcare, Virtual Reality (VR) is emerging as a valuable tool for treating various conditions. For instance, in rehabilitation, VR programs are being used for both motor and cognitive rehabilitation of individuals who are traumatized or disabled [13]. In pain therapy, VR immersion is expected to reduce pain and alleviate anxiety, at least temporarily [15]. Recent developments show that VR could also help improve thinking and daily functioning in people with dementia. (e.g., [32], [33]). Because of this, VR might soon become an important tool in clinical practice for handling certain psychiatric symptoms [32]. It can also be used in exposure therapy, helping patients face phobias or post-traumatic stress by putting them in controlled, stressful situations.

Immersive technology is really shaking up the tourism world. It makes experiences way more engaging. Tourists can check out destinations in new ways, not just when they plan or book a trip, but also while they're actually there, and even afterward. According to [17] and [34], immersive technologies are widely used in the tourism sector by hotels, restaurants, travel companies, and tourist sites. They're changing how these businesses handle customer relations, bookings, and marketing. On top of that, these technologies are opening up new ways to offer experiences and promote destinations [35]. Using AR and VR doesn't just make customer experiences better; it can also give businesses a strategic edge, encouraging new ideas and keeping customers more engaged in tourism and hospitality (e.g., [16], [18], [19]). This shows how immersive technologies can really change things, making tourist destinations more attractive and competitive around the world. In this context, for example [20] and [21] highlight how adopting AR technology in the museum sector promises great benefits as it transforms exhibitions through 2D and 3D visual images and animations affording visitors a new level of virtual presence.

Immersive technologies are widely used in the field of marketing because they offer innovative platforms for digital marketing, providing immersive services that can transform the consumer experience [23]. Virtual reality transports users to digitized worlds, deepening connections with brands, while augmented reality integrates digital components into reality, offering engaging and interactive product interactions [22]. Results showed that immersive new brand experiences, facilitated by AR, increased consumer response [24]. One example is the platform wayGoo, which is a strong marketing tool, offering staff and visitors an immersive tool for indoor navigation, helping users organize their agenda, and discover events with wayGoo event scheduler and recommendation system [36].

Regarding architecture and engineering, Immersive technologies techniques make it a very promising approach for interactive visualization of design, construction, and facility management. A cloud-based multi-user VR headset system named Collaborative Virtual Reality, CoVR, for the purpose of showing interpersonal project communication in an interactive VR environment [25].

The use of immersive technology, such as Virtual Reality (VR) and Augmented Reality (AR), has had a significant impact on social behavior research. A detailed, though not updated, review is provided by [29]. This study provides an extensive introduction to the use of VR in behavioural and social research, outlining the potential of VR as a research tool and its applications in various fields of psychology and social sciences.VR enables researchers to create virtual environments that simulate specific social situations and understand the processes governing dynamically-interacting individuals in human collectives under realistic conditions [31]. This allows for the observation of how individuals react in controlled and repeatable contexts. For example, workplaces, conflicts, or emergency situations can be simulated to see how people react and cooperate. Immersive experiences also make it easier to study hidden biases and how people perceive each other [29], [30], [31].

In the transportation sector, immersive reality is starting to be an important tool for looking at how people might behave in situations that don't exist yet. Using virtual environments, we can simulate these scenarios and see how users would act before anything is actually built (e.g., [37], [38], [39], [40]). For example, VR can be used to see how people react to new transport services [37] or to changes in transport terminals (e.g., [38], [40]). In the studies [38] and [40], an innovative methodology was developed, combining immersive Virtual Reality (VR) and Discrete Choice Experiments (DCEs), to estimate users' willingness to pay (WTP) for bus terminals characterized by high architectural and aesthetic standards, and passenger services (e.g., restaurants, shops, free Wi-Fi). In both cases, VR was employed as an immersive tool to simulate hypothetical upgraded terminal scenarios.

This approach provides valuable data on how such changes might impact user behavior, facilitating more informed planning and optimization of transport services.

It works alongside traditional models and estimation methods to help make better decisions in complicated urban situations. VR is also really useful for testing new technologies, like self-driving cars (e.g., [41], [42]), in controlled and repeatable settings. With virtual scenarios, we can see how these systems work in different situations and if they are ready for real use. Putting VR with self-driving cars is a good idea. It lets developers, researchers and also policymakers test difficult traffic cases without real danger and without high cost. VR can copy real traffic situations, like strange driver behavior, bad weather or lighting, and different city roads. This gives a safe place to test both the technology and how people use it. VR can also show rare situations that are hard to reproduce in real life, and this helps to make self-driving systems safer before they go on real roads. On the user side, VR lets people try trips in self-driving cars in a safe way. This helps researchers to understand trust, acceptance, and how safe people feel.

Just like studies that look at how people feel about traditional transport infrastructure, like train stations (e.g.,[43]), immersive technologies give us new ways to see how users react, both emotionally and mentally, to new mobility systems in a virtual setting.

In the end, this mix helps us better understand how autonomous systems work, how people use them, and how cities can get ready to include them in future transportation.

Recent studies show that VR simulation platforms give a safe and flexible way to train and test self-driving systems. They can recreate all sorts of complex scenarios over and over without any real-world risk. For example, [41] suggested using a VR-based setup to test autonomous vehicle algorithms in busy city environments, letting researchers push the systems hard without any real danger. Similarly,[42] showed that immersive VR can help check the safety of self-driving cars by including people in the simulation, so pedestrian behavior and unexpected events can be tested safely. These systems don't just let us test how the car "sees" and makes decisions; they also let us look at human factors, like how passengers or nearby drivers react to what the autonomous vehicle does. On top of that, combining VR with simulated sensors, like LiDAR, radar, or camera feeds, and real-time data analysis makes the simulations more realistic and speeds up development. This is becoming really important as city traffic gets more complicated and there's more pressure to roll out autonomous vehicles safely and responsibly.

Immersive simulations mark the next phase of VR and AR applications in driving simulators. For instance, VR can simulate several conditions that other driving simulators cannot, such as varied terrain, road, and urban conditions. Enhanced Visual Systems: This might be an add-on functionality where real-time information, such as speed limits, road signs, or hazard alerts, is shown in augmented reality in the view of the driver in the simulator, with the aim of studying the interaction of this technology with drivers' situational awareness and safety.

Computational modeling and simulation techniques are considered very critical in the field of traffic engineering, as they bear immense relevance to transportation planning and analysis of road safety. In this way, driver behavior simulation can give more understanding to researchers and policy analysts about how individual and group driving decisions affect traffic flow, safety, and efficiency. Driving simulation research is very useful for improving transport safety, smooth traffic, and efficiency. It gives a safe and controlled environment to study driver behavior, vehicle performance, traffic flow, and road design. As self-driving technologies and other vehicle systems continue to develop, simulations will become even more important. They will open more opportunities for research, testing, and possible real-world applications. At the same time, AR is also starting to be used in driving simulators. Initial applications of AR enhanced driving simulations by overlaying useful information within the driver's field of view, such as road signs and hazard warnings. Companies like Toyota and Mercedes-Benz have built simulators using AR, mainly to make driving feel more real and also to test new car interfaces. AR is also used in driver training and for driver-assist systems, so people can get used to them more easily. In general, this can help make driving safer and also a bit easier to understand. Simulating driver behavior is quite an important tool in transport planning, traffic management, and also vehicle design. By adding real driver behavior into traffic models, simulations can give a better idea of how traffic flow, safety, and efficiency can change in different situations. This helps plan smarter roads, safer streets, and better transport policies. It has also helped engineers develop safer roads, increase the flow of traffic, or even prepare for autonomous vehicles. Driver behavior simulations are key to improving the transportation system as a whole. The Driver Behavior Simulations develop models of how vehicles will interact within the flow of the entire system and provide critical information on congestion phenomena. By simulating how drivers behave in different situations, planners can get a better idea about traffic and try different things, like changing traffic signals, using lanes in a different way, or just improving road layouts. Also, real-time data systems like Automatic Vehicle Location (AVL) are now often used together with simulations, so traffic prediction in cities can become more close to reality. For example, when a city wants to build a new road or change an intersection, simulations can be used to see what might happen with traffic, including driver behavior, and to test different signal timings in order to reduce delays. Driver behavior simulations are one of the major inputs sought in the determination of safety risks on roadways. They can simulate dangerous scenarios, such as sudden lane changes, speeding, tailgating, or distracted driving, that look at the likelihood of accidents and develop strategies for accident pre. Simulation of driver behavior is very critical in the design process that involves AV and V2V systems. From knowledge of how human drivers react in various scenarios, improvements can be made in decision-making algorithms for autonomous systems such that the responses are safe and predictable in mixed traffic environments where AVs interact with human drivers.vention.

4 Conclusion

Immersive technologies are changing entire industries, from new ways to visualize, learn, collaborate, and create, offering a better quality of service, improved decision-making, and new ways to engage customers and interact. These technologies are getting better all the time. That means they'll have an even bigger effect and help solve problems in new ways. Immersive tech is making transport safer and smoother. It can even make it more fun. VR, AR, and MR are changing things a lot, helping design better cars, improve training, make maintenance easier, and give passengers a better experience. One of the most interesting ideas is using VR together with self-driving cars. People are starting to use this more now. It is a safe way to test and train, and also to see how systems work in a controlled space. With these immersive simulations, developers can copy busy city traffic, try rare or risky situations, and also change vehicle algorithms before they are used in the real world. This can make things safer, help development go faster, and also increase trust from users. VR can also help researchers see how people might behave around self-driving cars in the future. It gives some idea about acceptance, comfort, and behavior changes, which are important if autonomous vehicles will be used widely. Even if these technologies are still quite new, they could become part of everyday transport in the future. They may change how people travel, how transport systems are used, and how people experience moving in cities. Recently, immersive technologies like Virtual Reality, Augmented Reality, Mixed Reality and Extended Reality are also used more to study transport policies and improve them using real data. They help policy-makers, city planners, transport agencies and researchers to simulate and study transport systems and city movements, often in a more flexible way than before. In this way, immersive technologies can build interactive models that show complex situations, give possible scenarios, and test different policy options. It helps make smarter decisions, get people more involved, and actually put policies into practice better. These tools can be used together with traditional methods, like cost–benefit analysis and multi-criteria approaches. Those methods are usually used to see if transport projects are practical and sustainable (e.g., [44], [44]).

Using immersive technologies for mobility policy is really changing things for cities, transport agencies, and governments. These tools make it easier to see what different actions might do. They help predict outcomes and involve stakeholders better, using data to guide decisions. This means immersive technologies will probably play an even bigger role in the future as we try to make transport systems stronger, fairer, and more sustainable. Overall, these tools can help plan urban transport that's ready for the future, deal with big issues like congestion and climate change, and make sure policies work for everyone. Policymakers can use them to test, see, and adjust mobility policies in realistic virtual setups. In the end, these technologies don't just make policies work better; they also help build urban transport systems that are inclusive, sustainable, and flexible.

Immerse-the introduction of immersive technologies in mobility policy evaluation-changes the paradigm of how cities, transportation agencies, and governments evaluate and adopt transportation policies. These tools go a step further and deeper to realize impacts more accurately, making it easier to predict outcomes, engage stakeholders, and make data-driven decisions. Immersive technologies will become all the more important in the creation of resilient, equitable, and sustainable transport systems in the future. Immerse tools will allow them to try out, visualize, and refine their mobility policies in a realistic virtual environment, which in turn, provides ways to future-proof the urban transport systems to respond to some of the critical challenges: congestion and climate change. Finally, they help make sure policies work for all kinds of communities. Over time, these technologies will not just improve mobility policies, they'll also help move us toward urban transport systems that are fairer, more sustainable, and ready for the future.

A final consideration concerns the limitations of the present work. Although the paper provides a comprehensive overview of immersive technologies and their potential role in transport planning, this study has primarily adopted a qualitative and conceptual perspective. Future developments should therefore include the application of a more quantitative analysis and empirical validation conducted on the same case study, to rigorously assess the effectiveness of immersive technologies on user behavior and model reliability. This seems like a really promising path for future research and for making immersive-based transport planning methods stronger. Using immersive technologies alongside participatory and cognitive decision-making approaches, like the ones suggested in recent transport planning studies (e.g., [46]**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**), can help planners deal with uncertainty and include a wider range of people in mobility decisions.

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