Journal of Infrastructure, Policy and Development 2024, 8(3), 3051.
https://doi.org/10.24294/jipd.v8i3.3051

Case Study

Advancing urban mobility in the State of Qatar—Establishing a framework for autonomous vehicles in Doha

Almaha Al-Malki*, Muhammed Madandola, Sarah Al Thani, Goze Bayram, Amina Al-Kandari, Raffaello Furlan

Department of Architecture and Urban Planning (DAUP), Qatar University, Doha PO. Box 2713, State of Qatar
*** Corresponding author:** Almaha Al-Malki, almaha.almalki00@gmail.com

CITATION

Al-Malki A, Madandola M, Al Thani S, et al. (2024). Advancing urban mobility in the State of Qatar—Establishing a framework for autonomous vehicles in Doha. Journal of Infrastructure, Policy and Development. 8(3): 3051. https://doi.org/10.24294/jipd.v8i3.3051

ARTICLE INFO

Received: 17 October 2023
Accepted: 27 November 2023
Available online: 20 February 2024

Abstract: The Government of Qatar is investing considerable resources in the development of integrated transport infrastructure as a solution to traffic congestion and environmental degradation. Autonomous vehicles are expected to be one of the methodologies for enhancing the quality of the built environment and fostering a more sustainable and environmentally conscious urban milieu. While autonomous cars have the potential to address urban difficulties and be utilized for personal, group, and public transit purposes, their implementation in the specific context of Doha has not been thoroughly analyzed. This research explores the potential impacts that autonomous vehicles are expected to have on travel demands, parking needs, and urban planning. It discusses the benefits and challenges associated with autonomous vehicles and predicts their likely implementation and development based on the different precedents. In addition, it explores how it will affect planning decisions such as drop-off and pick-up areas, parking and public transit. The research utilizes a qualitative approach through literature content analysis, field observations, and mobility analysis. Several case studies are analyzed to explore how autonomous vehicles can operate within a limited zone. The study uncovers the issue of ownership and mode of operation as essential factors that can affect the impact of autonomous vehicles (AVs). In addition, implementing AVs may create complex environmental concerns when greener and more sustainable transportation models are not integrated. It is recommended that Doha adopt integrated planning and implementation of AV technologies to ensure that AVs align harmoniously with the environmental stewardship requirement. The research study also presents urban design frameworks for how existing urban spaces can accommodate autonomous vehicles.

Keywords: autonomous vehicles (AVs); urban mobility; urban design; infrastructure; Doha (Qatar)

1. Introduction

The dynamic transportation landscape has been a significant component of the urban planning framework and land use. From the rudimentary forms of horse-drawn carriages to current car-centric cities, urban mobility delineates the human adaptability, innovation, and determination for efficient mobility of individuals and commodities across the intricate landscapes of cities. The current discourse surrounding modern innovations, societal development, and environmental sustainability underpins the narratives of green and autonomous vehicles (AVs) as representative of the present day. The concept of urban mobility in the 21st century encompasses a broader scope than the mere transportation of individuals between different locations. 21st-century mobility not only fulfills the role of mobility but also enhances efficiency by capitalizing on and promoting technological advancements.

It is projected that 21st-century mobility through the rise of AVs will further change contemporary cityscape and planning. Because the AVs are still in their developmental phase, the possible influence of self-driving cars (AVs) on cities and urban mobility is being closely examined (Jones et al., 2023). Several government agencies are initiating regulations in preparation for the safe integration of AVs (U.S. Department of Transportation, 2021). The integration of AVs may necessitate a rethinking of urban design and infrastructure. Traditional roadways and parking structures may need to be adapted to accommodate the unique needs of self-driving cars. In addition, AVs could change how people perceive and use transportation, potentially promoting environmental benefits.

With all these uncertain effects on urban design and infrastructure, AVs are projected to revolutionize the modern built environment, influencing not only transportation systems but also urban design, sustainability, and the overall quality of life in cities. Modern transport solutions are posited as the solution to the widespread use of fossil fuel-powered vehicles and the prevalent challenges in all cities worldwide (Al-Malki et al., 2022; Furlan et al., 2021; Patel et al., 2021). While implementing self-driving cars promises increased road safety and enhanced transportation efficiency, one of the most common solutions to urban issues is public transport, whether in the form of shared or synchronized modes (Al Fadala et al., 2023; Furlan and Sinclair, 2021; Tannous et al., 2020). Vehicle sharing encompasses various modalities, ranging from railroads to the practice of carpooling through car sharing, taxis, buses, trams, or subways. Integrating synchronized transportation modes with recent software technologies can create novel transportation networks that are adaptable to prospective users’ needs. This, in turn, can provide compelling incentives to forsake private car usage, which is a common practice in Qatar and most Middle East countries.

This research aims to develop a set of urban design strategies for integrating AVs in the context of Doha. The study investigates the potential impacts of AVs on Doha’s urban design, including travel demands, parking needs, and planning framework. Through the analyses of several precedents, the study thoroughly analyzes the advantages and challenges associated with AVs and how they improve the urban design, social and environmental aspects while also considering the corresponding political and economic factors.

The introductory section of this research delineates the importance of undertaking this study and outlines its objectives. The subsequent sections of the study are categorized as follows: part 2 presents the literature review conducted for this research. Part 3 encompasses the methodological approach used in this research. The initial segment of part 4 provides a comprehensive examination of precedents in several global cities, serving as a comparative study to establish a benchmark for the recommended framework in Doha. In the subsequent sections of part 4, the study explores the potential economic benefits and the suggested framework for Doha. Finally, the study presents the synthesis and conclusion of the investigation in part 5.

Implications of the study for Doha

Qatar is currently experiencing massive growth and expansion in both the population and the built environment. Doha, the capital city of Qatar, competes with other notable cities in the region, such as Dubai, Riyadh, and Manama, to attract qualified and experienced expatriates (A. Al-Mohannadi et al., 2023; Furlan, Grosvald, et al., 2022). The development patterns underscore the significant prevalence of privately owned fossil fuel-powered vehicles. This research aims to examine the potential impacts of AVs on transportation planning by analyzing relevant case studies worldwide.

Implementing 21st-century mobility perfectly aligns with the requirements of Qatar National Vision (QNV) 2030 and Qatar National Development Framework (QNDF) 2032. The QNV 2030 outlines significant objectives for enhancing the built environment to create an attractive and livable space. Various governmental initiatives have identified the need for contemporary, innovative, and sustainable frameworks for an integrated public transport system (M. Al-Mohannadi et al., 2023; Valdeolmillos et al., 2023). The recently developed Transportation Master Plan for Qatar 2050 (TMPQ) serves as a comprehensive framework for guiding future investments in the transportation sector. One of the primary strategic considerations pertains to anticipating technology changes or problems, such as the advent of AVs (Ministry of Transport (MOT) of Qatar, 2021). Understandably, the city of Doha would be inclined to incorporate solutions in its urban districts that not only accommodate but also promote critical components of 21st-century mobility, such as AVs, connected vehicles (CVs) and electric vehicles (EVs). Therefore, studying how implementing AVs would affect future planning decisions, such as public transit infrastructure, parking, and drop-off/pick-up areas, is essential.

Governmental institutions and urban planners, such as the Ministry of Municipality and Environment and Ashghal Authorities, can use this research as a valuable reference and recommendation guide for the potential use of AVs. Furthermore, the conclusions and findings of this study can be used as a reference for future researchers and professionals to help correlate the real and existing needs for the use of AVs. Consequently, this set of recommendations can provide insight and practical suggestions to professionals on how to use and implement AVs, specifically in Doha, as well as their potential economic and political impacts.

2. Literature review

Two basic categories of automobiles have the potential to either supplement or replace human drivers' efforts: connected vehicles (CAVs) or autonomous vehicles (AVs) (Kopelias et al., 2020). Autonomous vehicles (AVs), sometimes called self-driving, unmanned, driverless, or robotic automobiles, have consistently been depicted in science fiction literature and prominent scientific media for their capability to partially or fully operate and substitute human drivers (Center for Sustainable Systems, 2023; Cohen and Hopkins, 2019). These emerging technologies are a product of advancements in artificial intelligence, machine learning, and a variety of sensors to make real-time decisions. While the terms CV or AV refer to how a vehicle's course is controlled, the former use various communication technologies to interact with drivers, other vehicles, roadside infrastructure, and the cloud. AVs interpret their environments using GPS signals, normal vision cameras, infrared cameras, sensors and ultrasonic to detect and recognize road users and infrastructure (**Figure 1**). AVs have the potential to enhance safety for all road users by employing advanced image and pattern recognition software, along with engineer-assisted training, to reliably identify individuals, objects, environmental conditions, and various events occurring on the road (NACTO, 2019).

AV technology synthesizes four types of information to safely navigate towards its destination: location, perception, prediction, and planning. For a typical automated driving system (ADS), the dynamic driving task (DDT) encompasses the execution of operational functions based on three central tasks and modules: (1) perception, (2) planning and (3) control (Soteropoulos et al., 2020). This enables AVs to maneuver vehicles, evade potential road hazards, and react to varying traffic circumstances.

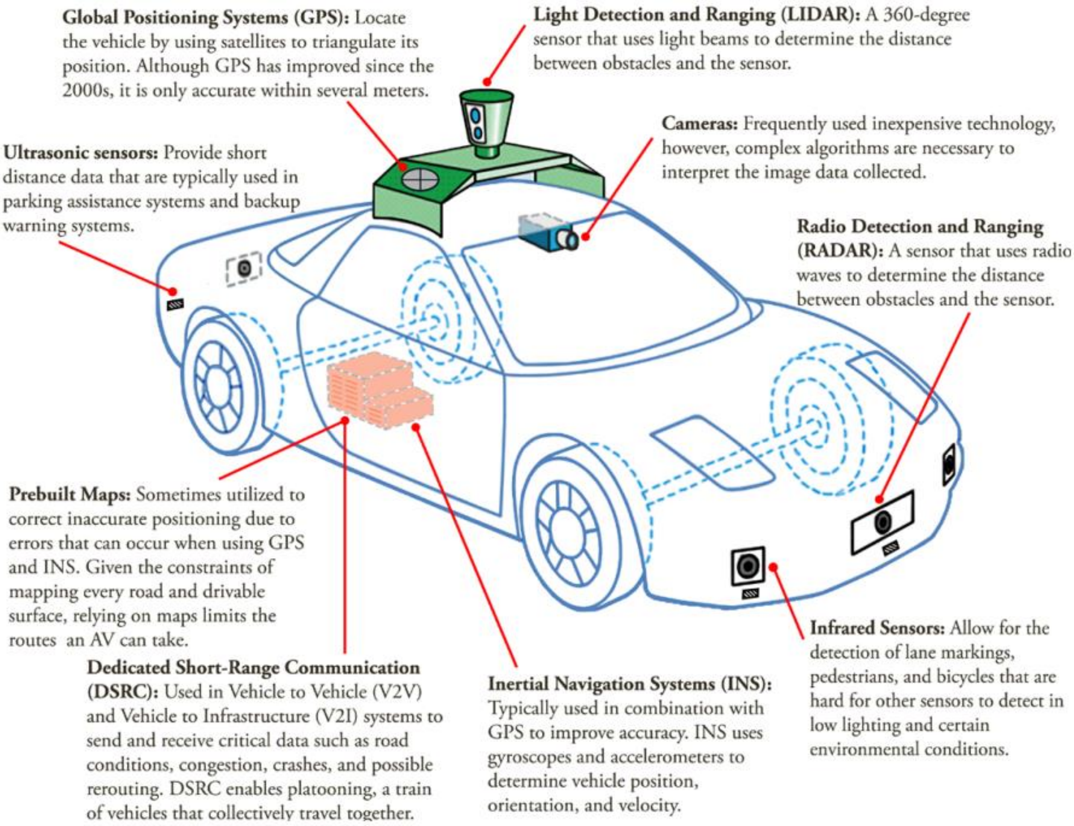

Figure 1. Components of Au that support decision-making processes (Center for Sustainable Systems, 2023).

Different operating models are associated with AVs, each characterized by distinct levels of autonomy. The Society of Automotive Engineers (SAE) introduced the levels of driving automation (SAE J3016) in 2014, which has received formal recognition and adoption by the United States Department of Transportation (Litman, 2023). The National Highway Traffic Safety Administration (NHTSA) in the United States has established a formalized classification system for AVs (SAE International, 2021). This framework delineates six levels of driving automation, ranging from Level 0 (no automation) to level 5 (full automation). Levels 0–2 rely on human monitoring, while 3–5 rely on driving automation systems (U.S. Department of Transportation, 2021). In ascending order of automation, the hierarchy typically consists of assisted driving, automatic driving, and unmanned driving.

- Level 0—No Automation with momentary driver assistance: The vehicle is entirely and solely controlled by the driver. Only assistive features such as warnings and alerts or emergency safety interventions are provided "automatic emergency braking, forward collision warning and lane departure warning" (SAE International, 2021).

- Level 1—Function specific automation: Specific control functions like cruise control, parallel parking automation, and lane guidance are being automated. However, the overall control of the vehicles should be handled by a driver.
- Level 2—Combined function automation: Several control functions are being automated and integrated; for example, cruise control with lane-centering that is adaptive to the surroundings. This level of automation necessitates that the driver assumes responsibility for monitoring the road and is consistently attentive. However, there are specific conditions under which they may be relieved from operating the vehicles.
- Level 3—Conditional driving automation: In certain circumstances, the driver can yield critical functions related to safety (environmental detection capabilities) to the system and trust that the vehicle will assess the conditions that may require the driver to take control. At this level, the driver is not expected to monitor the road continuously. The driver can take over if needed and if the system stops functioning.
- Level 4—High driving automation (self-driving in specific environments): The system assumes complete responsibility for executing driving activities within designated service areas, while occupants assume a passive role as passengers and are not required to participate actively.
- Level 5—Full driving automation: The vehicle can perform the driving functions required for an entire trip without the driver's assistance. Additionally, the vehicle can operate with or without any human occupants.

In recent years, prominent organizations such as Google, Intel and Nvidia, as well as automakers including GM, Ford, Audi, Honda, Toyota, Nissan, Renault, Volvo, Hyundai, BMW, and Tesla, have unveiled their projections to commence the commercialization of such AVs in the forthcoming years (Faggella, 2020; Nunno et al., 2021). Driving assistance technology has been widely observed in vehicles produced on a large scale, often called advanced driver assistant systems (ADAS). Most current AVs are categorized as "level 3," necessitating the presence of human drivers in specific traffic scenarios. Few pilot tests use "level 4" automation, which can independently operate in predetermined routes (Du, 2022). Many studies have highlighted that the deployment of AVs in major urban areas has exceeded the original deadlines for achieving level 4 automation in mixed-traffic scenarios (Jones et al., 2023; Young and Lott, 2022). There is still uncertainty about future applications of full driving automation as the technology is ongoing (Bissell, 2018; Cohen and Hopkins, 2019).

In addition to the various elements that influence the overall adoption of AVs, the distinct kinds of ownership and purpose will significantly impact the future of transportation. Drawing from the existing operational and trials of AVs in various cities worldwide, the typology of AVs acknowledges contextual factors and their distinct transportation needs, including passenger transportation, freight and cargo services, as well as precinct and facility-related functions (Jones et al., 2023). AVs have two future ownership models: private ownership and sharing models, such as ride-sharing services(Carrese et al., 2023; Heubeck et al., 2023). While private ownership of AVs offers increased convenience and more productive and relaxing experiences, there is a growing apprehension about the potential impact of AVs on mass transportation (**Figure 2**).

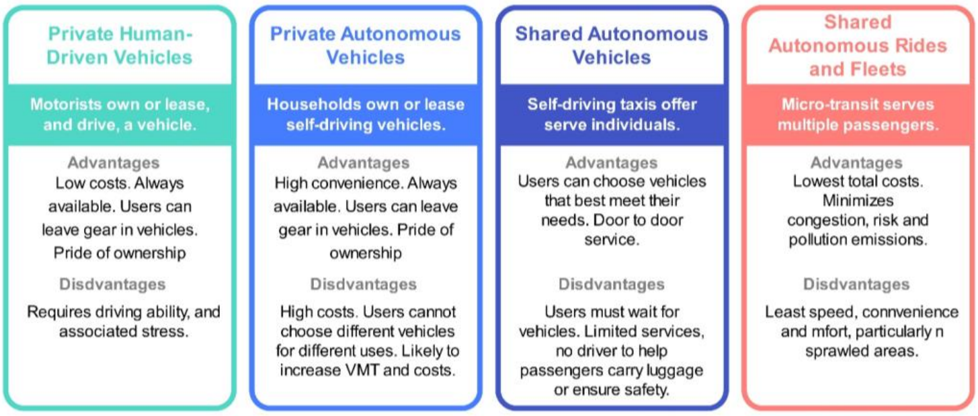

Figure 2. Comparison of autonomous vehicles operating model (source: the authors).

The specific consequences of AVs are determined by factors such as shared autonomous mobility business models and ridership capacity. AVs and shared mobility could significantly transform transportation systems and urban forms based on the benefit of public transportation and advanced technological solutions (Carrese et al., 2023). Shared AVs (SAVs), also known as autonomous taxis, can reduce car ownership and vehicle miles/kilometres travelled (VMT/VKT) by replacing private mobility with mobility-on-demand (MOD) and point-to-point services (Heubeck et al., 2023). SAV fleets can potentially mitigate traffic congestion and alleviate the demand for parking substantially, creating opportunities for other forms of mobility such as public transit, cycling, and pedestrian activities (NACTO, 2019). Significant benefits include enhancing cost-effectiveness and optimizing resource utilization following sustainable transportation solutions.

2.1. Historical background of autonomous vehicles

Since the inception of cars, futurists have contemplated the idea of relieving people from the task of driving. It was during the early 20th century when a significant transformation was achieved in the advancement of AVs. Between 1920 and 1980, several car companies and universities initiated extensive efforts to pioneer AVs. One of the first demonstrations of AVs in Milwaukee was a radio-controlled driverless car in 1925 (Vanderbilt, 2012). However, an additional vehicle was needed to emit radio signals to the transmitting antennae installed in front of the driverless car.

After several decades, researchers studied driverless vehicles that could be activated by electronic devices implanted in the road. Thus, this entailed the development of novel electronically controlled streets, which were initially examined in select regions of the United States and the United Kingdom. Nevertheless, funding was subsequently withdrawn for both instances. Integrating electronic railing necessitated the redesign of roads, which was an expensive endeavor. Hence, the focus shifted from using specialized tracks for AVs to developing fully automated automobiles capable of operating on current road infrastructure (Weber, 2014).

In the 1980s, Ernst Dickmanns from the Bundeswehr University of Munich successfully developed the capability for fully autonomous cars to operate on existing roads without the need for electronic railings. Dickmanns and his colleagues successfully modified a Mercedes Benz van to drive autonomously for more than 20km, reaching a maximum speed of 96km/h on an empty road (**Figure 3**). By 1989, the van had the capability to recognize obstacles; however, it could only detect a restricted number of impediments. In the 1990s, it gained the ability to perform autonomous lane changes (Weber, 2014).

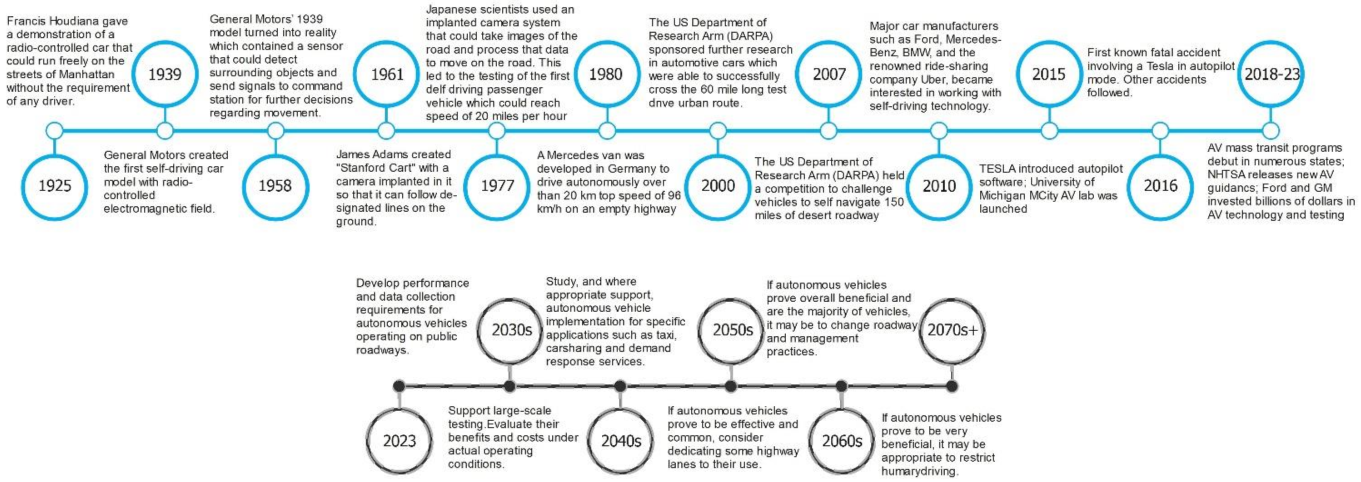

Figure 3. Autonomous vehicles timeline and future implementation projections (Litman, 2023; Nunno et al., 2021).

Many subsequent projects were inspired by the first demonstration of an actual autonomous robotic car operating on existing roads in Munich. For example, the Defense Advanced Research Projects Agency (DARPA) launched the grand challenges to stimulate the advancement of self-driving technology, explore new possibilities, and exceed existing limits in this field. The famous event was held in 2004 in the desert, where many teams competed for a winning prize of $1 million. During its first year, the competition proved unsuccessful for its participants, as the cars could only travel for a few kilometers before crashing (Weber, 2014). None of the contestants could finish the course through the desert with prepositioned obstacles.

However, DARPA organized a more significant challenge in the subsequent year with additional obstacles, turns, and double the prize money. Only five out of the twenty-three entrants completed the course successfully (Vanderbilt, 2012). The third grand challenge occurred in 2007, when AVs were required to drive through a mock urban environment. Out of the eighty-nine participants, only thirty-five teams were selected to compete in the National Qualification Event. Only eleven teams were designated for the final event, with six vehicles completing the course (Schedel, 2008).

Numerous automobile manufacturers and academic institutions have been diligently working on cultivating AVs since the early 2000s. Mostly, the vehicles operated autonomously, with occasional intervention from a human driver, particularly when faced with the difficulty of navigating through intersections. Among the many companies, Google has achieved success in the field of AVs (Hartmans, 2016). However, their vehicles are still undergoing some improvements to achieve complete autonomy while maintaining safety. Similarly, several European countries have funded research projects to conduct tests and demonstrations of AVs nationally (Gavanas, 2019). Some examples of these countries include Finland, the Netherlands, Portugal, Spain, the United Kingdom, Austria, Hungary, France and Latvia.

The future deployment of AVs is unclear, with differing opinions on the readiness of complete driving autonomy. AV developers are more conservative with providing timelines for achieving commercial high and full automation (levels 4 and 5) in mixed-traffic scenarios. Based on the existing implementation and the complex regulatory landscape, research findings indicate that the estimated dates for actualization are anticipated to be later than first planned.

2.2. Legislative background

The majority of state vehicle codes in the United States do not foresee the use of highly automated vehicles, yet they do not explicitly prohibit it (Smith, 2014). As of 2023, 31 U.S. states and D.C. have effectively legislated AV law (Center for Law and the Public's Health, 2023). The Nevada Legislature approved an ordinance to authorize the usage of AVs in June 2011; thus, it became the world's first jurisdiction in which AVs can operate legally on public roadways. The Nevada Department of Motor Vehicles (NDMV) is legally responsible for establishing safety and performance standards and designating areas to test the use of autonomous cars (Dobby, 2011; Millikin, 2011). Google supported the legislation to legally conduct more testing on its Google driverless car (Markoff, 2011). Nevada's law describes AVs as a vehicle that uses global positioning system (GPS) coordinates, artificial intelligence, and sensors to operate without requiring the active involvement of a human operator. In addition, Nevada's law recognized that the operator is not required to remain attentive while the car is autonomously operating. Nevertheless, the regulations require that one person occupies the seat behind the wheel and another person occupies the passenger seat during tests.

In February 2016, an Assembly Bill No. 2866 was introduced in California, which permits the operation of AVs on roadways, even without a driver, brake pedal, steering wheel, or accelerator pedal (Cole et al., 2016). Subsequently, legislation on AVs has stalled in recent years, with many pending federal regulations significantly impacting the growth in the United States (Reilly et al., 2023). The sector has dwindled due to operator closures, smaller startups purchased by more prominent companies, and financial difficulties. In addition, there has been an impasse on increasing the number of AVs on the road and allowing states to set their performance standards. On the other hand, many state governments persisted in advancing legislation on AVs, broadening the scope for their utilisation and progress. Various regulations have been put into effect in several states, including designating a lane specifically for autonomous cars, reducing prohibitions on the sale of AVs, allowing the testing and deployment of fully autonomous vehicles without the need for a human driver, and requiring a human operator in just the lead vehicle of an autonomous trucking platoon

(Reilly et al., 2023).

Determining the legal framework to govern self-driving cars' deployment, testing, and operation poses a significant challenge in some states. Even though they have historically embraced AV technology, the legislative proposals from California and Texas indicate a reluctance to fully support AV technology. The California State Legislature enacted legislation in August 2023 enabling two robotaxi firms, Waymo and Cruise, to expand their commercial passenger services in San Francisco utilising autonomous cars (BBC News, 2023). In October 2023, the California Department of Motor Vehicles (DMV) suspended the deployment and driverless testing permits issued to Cruise LLC, which halted the operation of AVs in the state (California DMV, 2023). These legislative trends indicate complex regulatory operations between different states. With the absence of standardised legislation, the regulatory framework for AV necessitates coordination among governments, companies, and stakeholders to balance innovation and public safety.

In the United Kingdom, the government authorities permitted autonomous car testing on public roads in 2013. Before this permit, all robotic vehicle testing in the U.K. was conducted on private property (BBC, 2013). Adrian Flux, a British company, launched the first personal driverless car insurance policy in the UK in 2016, marking the first of its kind for AVs (Kollewe, 2016). The policy is intended for users with driverless car features, such as self-parking or cars with autopilot features. When Volvo disclosed their plans to unveil such vehicles that are fully autonomous, they revealed that they are not expected to be available for use on public roads until at least 2020.

The French government declared in 2014 that the testing of self-driving vehicles would be permitted on public roads starting in 2015, with a specific 2000 km stretch of road would be designated across the country. In Switzerland, the Federal Department of Environment, Transport, Energy and Communications (UVEK), permitted Swisscom to test a driverless Volkswagen Passat on the streets of Zurich (Berne, 2015). The U.K. enacted the "Automated and electric vehicles act 2018" to explain the liabilities related to insurance for AVs (Beachey, 2020).

2.3. Autonomous vehicle selling factors

Several benefits are associated with the use of AVs. The National Highway Traffic Safety Administration (NHTSA) enumerates mobility, efficiency and convenience, economic and societal benefits, and safety as some of the benefits of AVs (NHTSA, 2022). According to Zhong et al. (2020), (1) it reduces drivers' stress, allowing people to use travel time to rest or work. (2) There is a reduction in the expenses incurred on hiring drivers, namely in the expenditures associated with paid drivers in commercial transportation and taxis.

Additionally, in the context of Qatar, there will be a drop in demand for foreign labor. (3) It can offer mobility for non-drivers, providing them with independent means of transportation. (4) AVs can increase safety since many common accidents caused by human errors can be avoided, thus reducing insurance premiums and related crash costs. (5) It can also increase road capacity and save expenses, enabling vehicles to travel in close proximity. AVs can utilize platooning, which reduces car distance, increasing efficiency and accommodating more cars on existing roads without causing congestion. This can enable narrower lane designs and fewer intersection stops, resulting in less congestion. (6) Implementing AVs will enhance parking efficiency and land use because of different designs. These vehicles have the capability to drop off passengers and locate a parking spot independently or remain in motion. (7) Future AVs are anticipated to predominantly consist of internal combustion engine cars (ICEVs), hybrid engine vehicles (HEVs), or battery electric vehicles (BEVs). Depending on how AVs are powered, such as electric and plug-in hybrid electric, utilizing AVs can reduce environmental pollution and enhance the efficacy of fuel consumption. (8) The adoption can also encourage car sharing and road sharing (Litman, 2018). Other advantages of AVs include enhanced security for on-demand mobility, reevaluation of highly congested urban areas, and infrastructure improvements (Sciaccaluga and Delponte, 2020).

2.3.1. Operating mode

Most AVs nowadays are plug-in electric vehicles and can also be operated by conventional internal combustion engines; however, it is more probable that most will be electric vehicles. Reducing carbon emissions is crucial. Plug-in electric cars need specific technology due to their heightened need for intelligence and improved interaction with route planning and monitoring systems. A suitable example is Tesla Motors, an energy storage and automotive company that sells electric cars, battery products, and electric powertrains. They plan to make all their models fully autonomous in the next decades (Marshall, 2020). It is quite possible that completely autonomous electric vehicles could become a significant element within an integrated smart power grid, where plugged-in vehicles might be used as a temporary storage facility to even out variations in demand and supply (Herzog, 2015; Tan & Taeihagh, 2019). In addition, all the precedents analyzed use an electric plug-in type, making it easier to learn from what they did and what can be the best fit for application in Doha.

2.3.2. Parking requirements

Depending on the ownership and operation model, most AVs do not essentially require parking since it is always on the move. Instead, they operate within what is known as a “shared system” and only need stops to recharge. Nash Islam (2016), CEO and co-founder of U.K.’s first on-demand parking app “Vallie,” envisages that as autonomous technology continues to improve, the character form of parking and cars could be totally redefined in the next five to ten years. Without drivers, robots can operate vehicles in places that do not damage the existing urban landscape and do not need customer stairs, elevators, and pathways for individual car access. Fifteen years from now, some studies predict that SAVs will erase the need for up to 90% of current parking lots (Millard-Ball, 2019; Zhong et al., 2020). In 2015, Audi launched an automated parking garage near Boston for self-driving cars. This innovative facility decreases the parking area required by two square meters per car and anticipates using narrower road lanes (Designboom, 2016).

Shoup (2006) used a compilation of sixteen studies conducted between 1927 and 2001 to show that drivers travel an average of 8.1 min when looking for a parking spot. Thus, up to 30% of all traffic in urban centers can be attributed to drivers searching for parking spots, and in some cities, up to a third of the land is dedicated to parking (Shoup, 2006). A significant benefit of AVs is that they will decrease the demand for nearby parking areas since they would drop-off and pick-up passengers when required. On a similar note, Rodoulis (2014) explains that most vehicles are expected to remain in constant operation and not park at all or return to the depot in less expensive locations where more land is available (Islam, 2016). The need for new parking lots will decrease, and existing parking capacity can be doubled since AVs can park closely together.

In due time, AVs will create revolutionary driving patterns that will change traffic in urban areas and, eventually, city planning. Islam (2016) explains that presently there are two schemes associated with how people will use AVs: (1) as "autovots", where individual passengers will be picked by cars consecutively with a high individual ownership rate; or (2) "taxibots", where several passengers will be sharing a fleet of cars (Islam, 2016). In whichever situation, the effectiveness and readiness of AVs will reduce the need for individual car ownership, decrease the number of cars on the road, and lower the need for city parking. This situation will result in the availability of a significant amount of valuable urban land, potentially leading to greener cities and revitalized suburbs. This implies that the demand for on-street parking will decline, and fewer off-street parking spaces will be required in city centres. Consequently, more road capacity will be available through implementing SAVs, which can be reallocated for other transport modes such as cycling, walking, and mass transit. The magnitude of these effects will differ depending on the current level of car dependency in a given city. Furthermore, government authorities must clearly understand what land is expected to become available and have a strong vision for its use.

2.3.3. Drop-off/pick-up areas

Since AVs require little to no parking in the case of shared mobility, additional space can be assigned for drop-off/pick-up areas. During the testing phase, they will likely have dedicated drop-off and pick-up stations; nevertheless, they are expected to use the same facilities as other cars in the long run. The availability of these areas will be highly dependent on the typologies of the AVs, such as in the cases of Masdar, where educational campuses have their dedicated stations for pick-up and drop-off (Herzog, 2015; Masdar City, 2018). Other countries also showcased different implementation types and pilot studies on AVs within educational campuses. Educational campuses function as a significant "Automated Mobility District (AMD)," which is a designated area where AVs and CAVs are implemented for public transportation (Young and Lott, 2022). Whereas in the case of Singapore, they are more likely to retrofit their existing drop-off areas spaces to fit their autonomous pods, especially since they require less space than regular cars (Ho, 2016; Singapore Ministry of Transport, 2015). Such technologies provide an understanding of how those vehicles can use the same drop-off/pick-up area as regular cars.

2.3.4. Autonomous vehicles challenges and concerns

Several challenges associated with AVs include a decrease in business activities and employment. A decline in drivers' job opportunities is anticipated, which might lead to lower need for car repairs due to reduced collision rates. Misdirected planning emphasis on AVs can deter communities from implementing traditional but cost-effective transportation initiatives, such as transit and pedestrian improvements. Social equity concerns could result in unjust impacts, such as a reduction in other transportation modes' safety and convenience.

While AVs offer the promise of safety by eliminating human error that caused 94% of crashes in the U.S. annual vehicular death rate (NHTSA, 2022), integrating autonomous vehicles into the built environment is not without concerns. Several primary factors of consideration include the safety and security of the general public, as well as the domains of cybersecurity and privacy. The U.S. Department of Transportation (2021) underscores the importance of safeguarding users and communities to achieve the benefits of AVs. Studies have highlighted that current AI struggles to respond to unpredictable pedestrian and bicyclist movements, increasing risk in active transportation (Center for Sustainable Systems, 2023). Deadly accidents and injuries have led to many investigations of AV technologies, necessitating further testing and regulatory approval (Beedham, 2020). Due to safety concerns, the California DMV recently revoked the permits granted to Cruise LLC, a subsidiary of General Motors, to test and operate fully autonomous vehicles without a safety driver (BBC News, 2023; Jolly, 2023). In addition, the optimum performance of AVs remains uncertain in congested urban traffic, unpaved and unmapped roads and regions with poor wireless connectivity. Safety risks are elevated during bad weather, reducing AV sensor accuracy. These emerging issues raise concerns among legislators and community groups.

Despite the emerging advancements in AV technologies, there are added complexities and uncertainty because of the increased vulnerability to cyberattacks, surveillance, and data sharing. AV and other transportation technologies generate and rely on vast amounts of data for navigation and decision-making (NHTSA, 2022). As vehicles become increasingly connected, the risk of unauthorized access and potential misuse of sensitive information adds another layer of complexity to the autonomous vehicle landscape. In addition, AVs are susceptible to cyberattacks, which jeopardise their safety and constitute a localised hazard to individuals and infrastructure in the vicinity of hacked cars (NACTO, 2019). Safeguarding data from cyber threats and ensuring the privacy of individuals present ongoing challenges. Addressing this issue necessitates the implementation of robust cybersecurity standards.

The readiness of existing infrastructure may hinder the proliferation of AVs and CAVs. Numerous studies have indicated the need for a significant overhaul of existing street systems and infrastructure to integrate AVs (Nunno et al., 2021). The special requirements of self-driving cars, such as smart traffic signals, sensors, 5G stations, robust communication networks, signaling controls, charging stations and dedicated lanes, may increase the cost of road infrastructure and maintenance. Municipalities and governments may face the challenge of financing these infrastructure upgrades, potentially diverting resources from other essential public services. In addition, the disparity in infrastructure development across regions poses a significant hurdle, potentially leading to uneven adoption rates between affluent communities and lower-income neighborhoods. Cities may prioritize AVs compared to other sustainable transportation modes, such as walking and cycling, resulting in exacerbating negative impacts on existing transportation, people and the environment (NACTO, 2019).

Although the integration of AVs holds immense promise for the future of transportation, one of the significant drawbacks is the exacerbation of urban sprawl. AVs have the potential to alter urban commute patterns, leading to the adverse impact of urban sprawl and decentralization (U.S. Department of Transportation, 2021). Large cities may see negative effects on urban sprawl, traffic congestion, parking shortages, and public transportation if more people use AVs for personal or shared transportation over public transportation (Nunno et al., 2021). The prospect of a stress-free, tolerable, and productive commute in an AV may entice individuals to relocate to the suburbs, which could have detrimental effects on the environment. The decentralisation process may significantly strain existing infrastructure, as it necessitates the development of new roads, utilities, and services in previously untouched areas. In addition, there will be environmental and sustainability concerns, primarily stemming from increased energy consumption for longer commutes.

While AVs can mitigate the need for parking facilities in urban cores, they may intensify parking difficulties in alternative regions, particularly residential areas. The operation of AVs without occupants during periods of non-use can generate a surge in demand for parking spaces (Soteropoulos et al., 2020). This paradoxical effect could strain local infrastructure and exacerbate parking scarcity, challenging the notion that AVs will inherently resolve urban parking challenges. In addition, VMT and ghost journeys may increase if more people take more trips to work and rest in their cars.

Automotive manufacturers are developing electric and hybrid AVs, yet commercially available AVs may be all EVs (Kopelias et al., 2020). The literature emphasizes the benefits of AVs being powered by electricity because they are emission-free and less noisy, and the batteries are a dependable source of energy for the operation of sensors and computers than combustion engines (Nunno et al., 2021). In addition, integrating electric power enables enhanced responsiveness for artificial intelligence systems, thereby augmenting the overall performance of AVs. However, electric AVs have potential long-term consequences from the impact of battery waste and the sources of electricity that power these cutting-edge vehicles (Patella et al., 2019). Even with their praise for reducing reliance on fossil fuels, the actual ecological impact depends on the sources of electricity used to charge their batteries (Liu et al., 2023). AVs have less environmental benefit if fossil fuels power the energy infrastructure. A shift towards renewable energy is crucial, with governments, industries, and individuals playing key roles.

Furthermore, the battery supply chain adds another layer of environmental impact. The escalating concern lies in the resource-intensive nature of battery production, maintenance, and disposal. The extraction of minerals such as lithium, cobalt, and nickel, which are essential components in battery production, has been found to have significant environmental and social implications (Rana et al., 2023). According to the National Renewable Energy Laboratory, prioritizing ethical and sustainable sourcing practices is crucial to prevent ecological degradation in the push for greener transportation (Young and Lott, 2022). In addition, there will be a need to manage the large volume of battery and electronic waste (e-waste) from AVs. Developing efficient and sustainable methods for battery disposal and recycling is an imperative step toward mitigating the environmental impact of AVs.

Additional elements influencing the environmental consequences of AVs and CVs encompass using alternative fuel, vehicle right-sizing or design, platooning, eco-driving, and decreased congestion. Kopelias et al. (2020) discuss several other factors, including route choice, VMT, on-demand mobility or ride-sharing, automation Level, use by underserved populations, and consumer's travel mode or willingness to pay.

3. The research design

The research focuses on two main topics: AVs and urban mobility. This exploratory research utilizes a qualitative approach and analyzes data from the literature through content analysis. In addition, this research necessitates field observations, which are investigated through site and mobility analysis. The study creates an adaptable context and illustrations for Doha.

The researcher employed the following methodologies to gather data about AVs. The research framework is planned as illustrated in **Figure 4**.

- A systematic review of literature on the topics of AVs and urban planning policies (Gavanas, 2019).
- Case study explorations to assess the possible implementation of AVs and their related impacts on the planning framework and built environment (Abuhijleh, 2020; Al Wahedi and Bicer, 2020; Tan and Taeihagh, 2019).

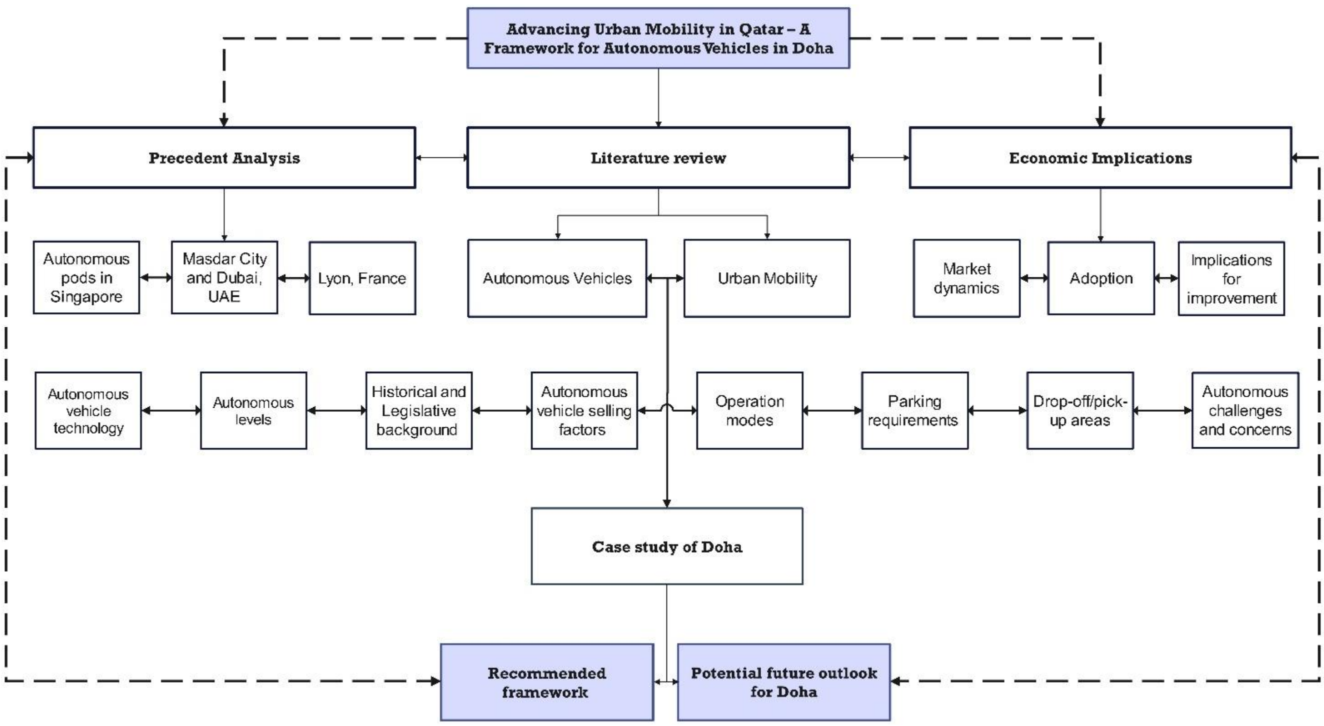

Figure 4. Research design (source: authors).

Accordingly, the data collection methods for this research can be summarized as follows:

- Literature review using both primary and secondary resources on AVs and urban mobility.
- Precedents analysis on how other cities have used and integrated AVs in their urban setting. This approach is significant to extract and develop the proper planning framework that is possible for Doha. The selected examples are based on their location within the local, regional, or international contexts.
- Using Doha as a case study to develop possible frameworks on the potential use

of autonomous vehicles and how it can be improved.

3.1. The case study setting

Doha was selected as a study location to explore how AVs can be integrated into existing roads. The approach aims to identify the most effective strategies and the best lessons from previous attempts to implement autonomous vehicles around the world. In addition, the study examines how such technology can impact the metropolitan city of Doha. Doha has experienced rapid growth in the past three decades, especially with the different megaprojects and megaevents that have taken place, with more expected in the near future (Furlan et al., 2022; Tannous et al., 2021). Thus, urban mobility can pose a challenge in terms of decreasing travel time as much as possible. Using the appropriate strategy for AV implementation could potentially serve as one of the solutions to address this difficulty.

3.2. A review of various implementations of AVs

This section analyzes precedents around the world on the implementation and use of AVs. It also assesses the current situation in Doha and the recommended framework for integrating AVs into the city's built environment.

3.2.1. Analysis of precedents

Several notable regional and international case studies have been selected to highlight some AV operations. These include Masdar City in Abu Dhabi, the implementation of driverless automobiles in Dubai, Singapore, and Lyon in France.

3.2.2. Masdar City, Abu Dhabi, UAE

Masdar City in Abu Dhabi promotes a pedestrian-friendly environment through a rich network of public and transportation alternatives that facilitate easy movement. Walking is aimed to be the most convenient type of transportation inside the city. Promoting walking is highly encouraged within the city as it reduces energy use (Masdar City, 2018). In addition, stairs are prioritized and made more conspicuous in the architectural design, while elevators are hidden. Masdar City started testing and implementing several hubs for AV integration in the early 2010s. Notably, personal rapid transit (PRT) was implemented in 2011 and was followed by a collaboration with Navya in 2018. Despite its name suggesting personal usage, the PRT system eliminates the need for personal automobiles, resulting in a net carbon effect of zero (Masdar City, 2023). They can be classified as SAVs.

Vehicles that use fossil fuels are not permitted inside Masdar City; any travel inside the city is through electric-powered PRT vehicles. In the PRT passageways, magnets have been installed every four meters on the solid floor to enable the PRTs to navigate. Additionally, all the PRT vehicles are connected to a central computer system. The vehicles can travel 40 kilometers per hour and a reduced 25 kilometers on curves. They are electrically powered by a battery that recharges whenever the vehicles are parked in their stations (Duvarci and Akpinar, 2012).

During Abu Dhabi Sustainability Week in 2018, Navya won the global competition responsible, therefore assuming the responsibility for expanding the next phase of Masdar's mobility strategy (Masdar City, 2018). Navya is a French-based company responsible for the manufacturing of AVs. Their AVs are designed to perform all critical safety decisions and monitor road conditions. The SAV fleet is projected to extend 1 kilometer outside of Masdar City. Currently, Masdar City is conducting pilot studies to test how those vehicles will perform during Abu Dhabi's summer environment.

In October 2023, the Smart and Autonomous Vehicle Industries (SAVI) cluster was inaugurated in Masdar City, which aims to transform AVs across air, land, and sea mobility (Emirates News Agency-WAM, 2023). The cluster encompasses several components: academia, testing zones, research and development laboratories, certification facilities, and other entities. The primary objective of this initiative is to expedite the adoption and implementation of green transport services, thereby propelling both the United Arab Emirates and the global community towards a zero-emissions future.

3.2.3. Driverless cars in Dubai, UAE

In early 2015, the Dubai Road and Transport Authority (RTA) inaugurated a study on AV technology for potential use during the 2020 World Expo event. According to the RTA, the project was a strategic intention to use the latest technologies to enhance smart mobility. The RTA appointed a team to travel to several European countries to benchmark the latest solutions for smart mobility. As part of the government agenda, Dubai aims to achieve a 25% utilization rate of AVs for all trips by 2030.

A driverless car named EZ10, manufactured by Easy Mile Company, started some pilot tests in specific locations within Dubai in 2016. The initiative provided the opportunity to test the vehicle's endurance to Dubai's weather and battery performance (Gambrell, 2016). Similarly, the RTA piloted an autonomous taxi project on dedicated roads within Dubai. The autonomous taxi vehicle, manufactured by Mercedes Benz, has sensors and cameras installed to detect road congestion and conditions. Likewise, it can autonomously control the vehicle to avoid collisions with other cars (Bridge, 2020).

In 2019, Dubai announced the first draft of standards and regulations relating to the use of AVs, which will facilitate their widespread implementation in the city. However, high and full AVs were still prohibited on public roads (Shambler, 2019). On October 27, 2021, the Dubai RTA announced its intention to establish legislation governing the operation of commercial AVs. Cruise, a leading manufacturer of AV technologies, was commissioned to produce driverless taxi cars with a target to implement around 4,000 AVs by 2030 (Library of Congress, 2021). The inaugural deployment of AVs is anticipated in 2023.

In April 2023, the Dubai government issued Law No. (9) of 2023 to regulate AVs in the city. The law aims to foster smart mobility, improve investments, and facilitate the use of AI in transportation (Government of Dubai, 2023). The RTA is responsible for developing strategic plans, identifying categories of autonomous vehicles, setting technical, operational, and safety benchmarks, demarcating roads, and developing infrastructure for AV operations. The law mandates licenses for AVs, requiring technical tests and road sign reading capabilities. As part of this initiative, the United Arabs Emirates (UAE) Cabinet granted the first preliminary national license for self-driving cars to a Chinese company, WeRide (Gulf News, 2023). WeRide provides level 4 AVs and plans to test all types of autonomous vehicles on UAE roads, marking the first national-level implementation in the Middle East.

3.2.4. Autonomous pods in Singapore

Singapore is one of the most prepared countries to incorporate AVs into its built environment. In a study examining the countries' AV policies and legislations, consumer acceptance, infrastructure, and technology and innovation, Singapore scored second among 25 countries in terms of overall readiness (Ho et al., 2020). The Singapore government has been actively incorporating driverless cars into the country's transport plans, with various forms of AV applications being developed and tested (Chng and Cheah, 2020). The Smart Nation plan, launched by the government in 2014, features using AVs to resolve Singapore's transportation problems.

The Singapore Autonomous Vehicle Initiative was established in 2014 to manage the development and experimentation of AVs in Singapore. In 2017, the Ministry of Transport introduced a series of legislation in preparation for the extensive use of AVs. Beginning in 2022, Singapore has three areas incorporating AVs as a daily transit option (Ho et al., 2020). Furthermore, SAV services hold great promise due to the high cost associated with car ownership in Singapore (Batarags, 2019).

One of the Avs launched in Singapore is the Group Rapid Transit (GRT), which was introduced in 2017. Predominantly, they function as minibuses, similar to automated shuttles that can transport people across the city (Land Transport Guru, 2018). GRTs are fully electric, have a maximum speed of 40 km per hour, and are completely automated. They operate using a magnet-based navigation and obstacle detection system.

3.2.5. Lyon, France

In Lyon, the government launched driverless bus services in late 2016. These bus services transport passengers within a radius of 1350 m around the city center. The battery-powered minibuses have a capacity of 15 passengers and operate on a ten-minute fleet with five stops in the city center. Every minibus has advanced navigation technologies to analyze and detect nearby movements (Dimitrove, 2019). Commuters and residents of Lyon can use the service free of charge.

The minibuses, which are designed by Navya, are fully autonomous with no pedals or a steering wheel. However, a human operator is always present in the minibus. The minibuses operate at a maximum speed of 45 km per hour during full operation and 25 km per hour during tests (Intelligent Transport, 2019). After compliance with public safety standards, the vehicles were approved for use on public roads.

3.2.6. The current situation in Doha

A Doha-based smart transportation company partnered with Navya to launch electric AVs for commercial use in 2017. Both companies will supply and distribute AVs in Qatar (Pathak, 2017). The autonomous vehicle, Navya Arma, can transport up to 15 passengers simultaneously at 45 km per hour. According to a spokesperson from the Ministry of Transportation and Communication, these vehicles will be available in Hamad Port, Qatar University, and West Bay during the summer of 2018. In addition, If the launch proves successful, the vehicles will be introduced on main roads.

However, news has since subsided without any further activity observed beyond the pronouncements in 2018.

In 2019, the Qatar Investment Authority (QIA) initiated the "Project qatar mobility" in partnership with Volkswagen. The project aims to deliver driverless shuttles for public use by 2022, which will operate at a level 4 autonomous scale (Myles, 2019). QIA and Volkswagen are investing in developing the fleet of self-driving shuttles and the digital infrastructure required for these vehicles. The fleet for self-driving shuttles is planned to be integrated into the existing transportation network.

Airlift, a local startup company, has recently commenced testing AVs designed explicitly for delivery purposes, with a maximum weight of 120 kg (Bijukumar, 2020). Nevertheless, the company have not yet disclosed the timing for implementation and how it plans to launch the vehicles.

3.2.7. Economic implications of developing and implementing autonomous vehicles in Doha

Comprehending the economic implications of implementing AVs is essential since it plays an important factor in driving or deterring the use and supply in the market. In the case of Qatar, it is important to analyze such implications without any exceptions.

The market dynamics examine the economic, social, and environmental aspects that support the use of AVs. Studies have highlighted that the principal concerns for buyers today are cost, security, and safety (Litman, 2023). In order to make AVs more readily available for consumers, the cost must decrease. This strategy will only happen when several manufacturers sell these vehicles, and the technologies are more common (Silberg and Wallace, 2012). Likewise, individuals are worried about the safety of these vehicles. While autonomous vehicles are expected to be much more secure than human drivers, individuals will be significantly less lenient of machine errors than human mistakes. This may prompt some decline in performance, as the early vehicles' editions will presumably operate at lower speeds. Given that, the autonomous vehicles market is expected to grow, reaching a value of $1.9 trillion in economic global impact by 2025 (Fagnant and Kockelman, 2015).

The adoption of AVs relates to the regularization of cutting-edge automated driving solutions, which will happen in stages initially and eventually culminate in full automation. The implication of this investment is not only limited to the manufacturing industry but also encompasses the economic, social, and political aspects of using autonomous vehicles (Silberg and Wallace, 2012). Karwa, Qatar's local taxi company, could benefit from Singapore's successful implementation of SAVs as citywide 'taxivots' in the case study analysis. Implementing such measures can have significant long-term benefits for Doha since it will effectively reduce traffic and limit the influx of transient low-income workers employed as taxi drivers.

3.3. Recommended framework

Because level 4 and 5 driving automation is ongoing, it is critical to understand that AVs will not imminently replace any other transportation mode but will complement the available ones (Litman, 2023). Studies suggested that even if all newly acquired vehicles were completely automated tomorrow, AVs would still take at least two decades to account for 90% of all vehicles on the road (NACTO, 2019; Nunno et al., 2021). In the autonomous age, cities should prioritize electric AVs rather than fossil-fueled ones because of the negative environmental consequences. It is essential to refine the supply chain and lifecycle of batteries, from raw material extraction to manufacturing, usage, and eventual disposal. In addition, cities should also integrate efficient modes of transportation like public transportation, biking, and walking by supporting user-centric redesigns, and implementing smart pricing and curbside management.

Based on the analyzed precedents and the current situation in Doha, some recommendation frameworks have been developed to effectively initiate the implementation of AVs in Qatar (**Table 1**). The precedents highlight the importance of ownership and use patterns toward implementing AVs. Private ownership and individual AV trips should be discouraged because of the prospect of complex challenges such as increased traffic/VMT, parking problems, urban sprawl and infrastructure costs. As The National Association of City Transportation Officials (NACTO) recommended, AVs' goal should be moving people, not cars. Rather than making long trips more pleasant, AV technology should be used to decrease car usage. The government and other regulators should enact stricter policies to limit private AV ownership and use. In addition, there is a need for initiatives to incentivize the use of SAVs through public/private partnerships. SAVs have the potential to mitigate traffic congestion and parking challenges. A significant paradigm shift is required to prioritize semi-private fleets and shuttle services. Addressing these issues demands a concerted effort from policymakers, technology developers, and society.

Educational campuses or megaprojects such as Lusail City, Education City, or Aspire Zone are recommended for pilot tests of AVs. These locations can be categorized as part of Qatar's AMD, where AV technologies can be safely implemented (Young and Lott, 2022). The primary objective of such districts is to provide publicly accessible mobility services that fully utilize the potential benefits of automated mobility services. Numerous deployment sites of Avs in the United States and Europe are situated within educational campuses and planned residential communities.

As for the level of autonomy, it is advisable to start with level 3 and progress to level 4 within the next five years once specific insurance policies have been established. The safety risks seen in level 4 AVs in the United States have raised significant worry, prompting the need for more testing and advancements. While the current vehicle types tested in Doha are Navya and Volkswagen, Navya and EZ10 vehicles are widely used in several countries as their primary choice for initial deployment. Therefore, it is recommended to continue testing these vehicles' endurance within Doha's urban context alongside renowned automobile brands such as Mercedes Benz and Tesla.

For parking spaces, it is advisable to park the vehicles in their designated charging station, which should be incorporated into existing parking spaces. The government should facilitate land use policy to integrate the AV infrastructure into the existing urban framework. As part of the Leadership in Energy and Environmental Design (LEED) requirement, an international standard for sustainability, the charging points/parking spaces must be close to on-site parking and vertical circulations (U.S.

Green Building Council, 2023). While there are two types of charging stations, plug-in and wireless—inductive charging (U.S. Department of Energy, 2023), the policy should prioritize the former in peripheral locations when AVs are inactive. Wireless charging is challenging since it should be integrated into the building foundation. Hence, it is recommended to use strategies that retrofit existing parking spaces and other infrastructure to enhance convenience and reduce cost.

Table 1. Recommendations that are applicable based on precedents analysis.

	Regional case study		**International case study**		**Local case study**
	Masdar City, Abu Dhabi	**Dubai, UAE**	**Singapore pods, Singapore**	**Lyon, France**	**Doha, Qatar**
Vicinity character	Educational Campus	City Wide	The scale of driverless cars usage is City wide	City Wide	It is recommended to start with educational campuses and other AMDs.
Typology	Semi-private	Semi-public	Connected Driverless Shuttles as taxivots	Semi-private	Semi-private
Level of autonomy	Level 4—High Driving Automation	Level 3—Conditional Driving Automation Level 4—High Driving Automation	Level 4—High Driving Automation	Level 4—High Driving Automation	Recommendation: Level 3 → Conditional Driving Automation Level 4 → High Driving Automation in a controlled fleet with lanes dedicated to driverless vehicles
Vehicle type	Electric-powered Personal Rapid Transit (PRT) vehicles, Navya	EZ10, Mercedes Benz	Electric-powered Group Rapid Transit (GRT) vehicles	Navya	Recommendation: Electric-powered Personal Rapid Transit (PRT) vehicles
Pick up/drop off areas	They pick up/drop off passenger at the different PRT stations available	They pick up/drop off passenger at the different stations available	They pick up/drop off passenger at the different GRT stations available	They pick up/drop off passenger at the different stations available	Recommendation: Designated drop off/pick areas in certain location within megaprojects in Doha
Operating mode	Battery powered and recharges at the stations between trips.	Electric-powered vehicles	Battery powered and recharges at the stations between trips.	Electric-powered vehicles	Recommendation: Electricity Plug ins
Parking	A separate station within Masdar City	Designated charging points	They will be parked on the existing car parks after slight modification.	Designated charging points	Recommendation: Integrated to existing parking lots
Completion date	2011 for RPT, Navya understudy	2020 → For Expo 2030 → 25% use city wide	December 2016 → 12 vehicles are launched 2018 → fully self-driving taxi fleet	Launched in September, 2016	Recommendation: It is possible within the 5–10 years

3.4. Potential future outlook for Doha

A significant consideration in Doha's urban planning and management is the incorporation of integrated, sustainable, and green mobility. As established in the government's vision and support, the Qatar National Development Framework aims to consolidate Doha's unique identity and welcome new innovative ideas and pilot projects. Moreover, there is a strong emphasis on urban design, in which innovative actions can be reflected and have local and global impact. The optimal strategy for implementing AVs in Doha entails carefully considering its urban framework, creating localized testing beds, and legalising AVs. It is also important to introduce insurance policies related to the use of such vehicles.

AVs can potentially address mobility challenges, provided that due attention is given to the local context and sustainability frameworks. From an environmental perspective, it will reduce pollution and increase dependence on more renewable energy sources since most autonomous vehicles are expected to operate on electricity. As for the government's role, it is recommended that they establish a regulatory system for AVs to ensure the safety of the users and the community. **Figure 5** outlines a proposal that presents short, intermediate, and long-term goals for AV implementations in educational campuses and Doha.

The short-term goal will be to test and pilot AVs within designated AMD locations, as shown by the instances of the precedents. Simultaneously, the use of AVs will provide results in terms of performance and data collecting, which will contribute to outcomes such as increased public awareness, the establishment of insurance policies, and the fulfilment of other necessary prerequisites for the widespread adoption and deployment of AV technology. After effective cost and benefit analysis, it is anticipated that extensive testing in Doha may be possible throughout the 2030s. The potential for widespread use of AVs in the taxi industry and other emergency response services is anticipated to materialise nationally throughout the 2040s. It is anticipated that further infrastructure development will ensue to facilitate the introduction of AVs, including allocating specific highway lanes exclusively for AV use.

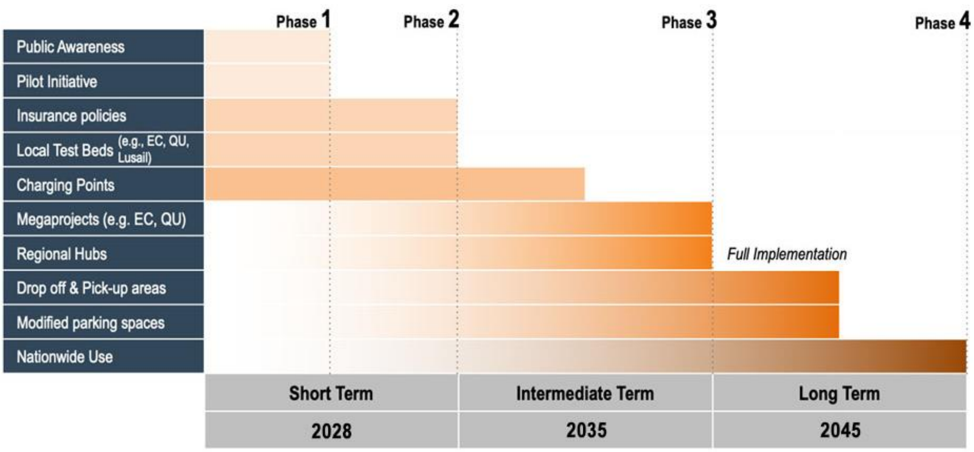

Figure 5. Short, intermediate and long-term goals for autonomous vehicles application in Doha, Qatar (source: authors).

4. Conclusion

The rapid increase in population has profoundly impacted the urban framework of Doha, especially with the exacerbating traffic congestion in recent years. Such threats include an increase in parking demands and an increase in allowable building height and plot size. As this study proposes, introducing AVs in Doha has the potential to be the ultimate solution to mobility challenges in Doha. The forces of globalization are currently driving socio-economic changes and growth throughout the world. Megaprojects such as Qatar University have been the testing ground for some technological trials. Education City's mobility strategy primarily revolves around trams and the People Mover System (PMS). Based on the previous analysis, these examples fit as AMD pilot and testing sites. Recommendations can be formulated to advocate using AVs that include green and sustainable concepts.

To sum up, AVs are becoming more prominent in educational campuses, airports, or other mega projects. Adopting SAVs provides a glimpse into the imminent future, where vehicles autonomously operate nationwide. Whether individuals prefer autonomous driving or manual driving will only be a matter of preference. Therefore, it is feasible to modify urban spaces that can physically and socially accommodate AVs and integrate them with the surrounding urban environment. This will not only help reduce traffic by establishing a shared transportation system but also reduce the need for parking spaces. Eventually, the incorporation will optimize road space planning. This is considered a good approach for the foreseeable future, as it aligns with global ideas of sustainable mobility.

Author contributions: Conceptualization, AAM, MM and SAT; methodology, AAM and MM; software, AAM, MM and SAT; validation, AAM, MM, SAT, GB, AAK and RF; formal analysis, AAM, MM and SAT; investigation, AAM, MM and SAT; resources, GB, AAK and RF; data curation, GB, AAK and RF; writing—original draft preparation, AAM, MM and SAT; writing—review and editing, AAM, MM, SAT, GB, AAK and RF; visualization, AAM and MM; supervision, GB, AAK and RF; project administration, GB, AAK and RF; funding acquisition, GB. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: This research study was developed as part of two research project schemes awarded and funded by Qatar University: [QUST-2-CENG-2023-1643] Student Grant 2023 Cycle #2, Aug 2023-Dec 2023, 'Impact of Globalization on Transforming the City: Urban Megaprojects. The Cases of Msheireb Downtown Doha and Masdar City in Abu Dhabi', LPI: Goze Bayram, Goze, LPI: Sarah Al Thani, PI. The authors would like to acknowledge DAUP and Qatar University for its research-oriented vision and its support for sustainable development in the State of Qatar. Additionally, the authors express their gratitude to several government agencies and ministries in the State of Qatar, including the Ministry of Municipality and Environment (MME), Qatar Rail, Qatar Museums Authority, Ashghal Public Works Authority, and Qatar Rail. These organizations collaborated with the authors by participating in meetings, sharing visual data, providing important documents related to the research objectives, and engaging in discussions regarding the results and conclusions of this investigation. Furthermore, the authors wish to extend their thanks to the anonymous reviewers whose valuable comments and feedback contributed to the improvement of this paper. It is important to note that the authors take full responsibility for the statements and content presented in this work.

Conflict of interest: The authors declare no conflict of interest.

References

Abuhijleh, A. (2020). Examining Preference for Autonomous Vehicle (Av) Among Qatari Residents [Qatar University].

Al Fadala, E. S., Furlan, R., Awwaad, R., et al. (2023). Rethinking urbanism in Doha: The Qatar National Museum transit-oriented development. Journal of Urban Regeneration & Renewal, 16(4), 421–444.

Al Wahedi, A., Bicer, Y. (2020). A Case Study in Qatar for Optimal Energy Management of an Autonomous Electric Vehicle Fast Charging Station with Multiple Renewable Energy and Storage Systems. Energies, 13(19), 5095. https://doi.org/10.3390/en13195095

Al-Malki, A., Awwaad, R., Furlan, R., et al. (2022). Transit-Oriented Development and Livability: The Case of the Najma and Al Mansoura Neighborhoods in Doha, Qatar. Urban Planning, 7(4), 124–139. https://doi.org/10.17645/up.v7i4.5608

Al-Mohannadi, A., Major, M. D., Furlan, R., et al. (2023). Investigation of Spatial and Cultural Features in Contemporary Qatari Housing. Urban Science, 7(2), 60.

Al-Mohannadi, M., Awwaad, R., Furlan, R., et al. (2023). Sustainable Status Assessment of the Transit-Oriented Development in Doha's Education City. Sustainability, 15(3), 1913.

Batarags, L. (2019). The same city has been ranked the most expensive city in the world for 5 years running, and it's partially because of the cost of buying a car. Business Insider. Available online: https://www.businessinsider.com/most-expensive-city-in-the-world-singapore-2019-1 (accessed on 14 August 2023).

BBC. (2013). Driverless cars to be tested on UK roads by end of 2013. BBC. Available online: https://www.bbc.com/news/technology-23330681 (accessed on 3 August 2023).

BBC News. (2023). Cruise self-driving cars investigated after two accidents. Available online: https://www.bbc.com/news/technology-67133409 (accessed on 30 September 2023).

Beachey, A. (2020). How driverless cars will affect insurance. Available online: https://www.raconteur.net/finance/insurance/driverless-car-insurance-impact/ (accessed on 15 August 2023).

Beedham, M. (2020). Autonomous driving isn't a reality in 2020—And it's getting people killed. Available online: https://thenextweb.com/news/autonomous-driving-isnt-reality-2020-its-getting-people-killed-autopilot-propilot (accessed on 15 August 2023).

Berne. (2015). Swisscom reveals the first driverless car on Swiss roads. Available online: https://www.swisscom.ch/en/about/news/2015/05/20150512-MM-selbstfahrendes-Auto.html (accessed on 30 August 2023).

Bijukumar, A. (2020). Local startup aims to test autonomous delivery vehicle in Qatar by year-end. Available online: https://thepeninsulaqatar.com/article/07/10/2020/Local-startup-aims-to-test-autonomous-delivery-vehicle-in-Qatar-by-year-end (accessed on 28 August 2023).

Bissell, D. (2018). Automation interrupted: How autonomous vehicle accidents transform the material politics of automation. Political Geography, 65, 57–66. https://doi.org/10.1016/j.polgeo.2018.05.003

Bridge, S. (2020). Revealed: how popular autonomous vehicles are in the UAE. Available online: https://www.arabianbusiness.com/transport/437481-revealed-how-popular-autonomous-vehicles-are-in-the-uae(accessed on 1 September 2023).

California DMV. (2023). DMV Statement on Cruise LLC Suspension. Available online: https://www.dmv.ca.gov/portal/news-and-media/dmv-statement-on-cruise-llc-suspension/ (accessed on 4 September 2023).

Carrese, F., Sportiello, S., Zhaksylykov, T., et al. (2023). The Integration of Shared Autonomous Vehicles in Public Transportation Services: A Systematic Review. Sustainability, 15(17), 13023. https://doi.org/10.3390/su151713023

Center for Law and the Public's Health. (2023). Autonomous Vehicle Legislation by State. Available online: https://publichealth.jhu.edu/center-for-law-and-the-publics-health/research-resources/autonomous-vehicle-legislation-by-state (accessed on 5 September 2023).

Center for Sustainable Systems. (2023). "Autonomous Vehicles Factsheet. Available online: https://css.umich.edu/publications/factsheets/mobility/autonomous-vehicles-factsheet#:~:text=Autonomous%20vehicles%20(AVs)%20use%20technology,1 (accessed on 6 September 2023).

Chng, S., Cheah, L. (2020). Understanding autonomous road public transport acceptance: A study of Singapore. Sustainability (Switzerland), 12(12), 1–12. https://doi.org/10.3390/su12124974

Cohen, S. A., Hopkins, D. (2019). Autonomous vehicles and the future of urban tourism. Annals of Tourism Research, 74, 33–42. https://doi.org/10.1016/j.annals.2018.10.009

Cole, C., Mccullough, K., Mcchristian, L., Corbett, R. (2016). Journal of Insurance Regulation Regulatory Issues Related to Autonomous Vehicles. 35(7).

Designboom. (2016). AUDI urban future initiative brings automated parking garage for self-driving cars to boston-area. Available online: https://www.designboom.com/design/audi-urban-future-initiative-11-20-2015/ (accessed on 15 September 2023).

Dimitrove, A. (2019). Lyon launches an autonomous shuttle as part of its public transport network. Available online: https://www.themayor.eu/en/lyon-launches-an-autonomous-shuttle-as-part-of-its-public-transport-network (accessed on 8 August 2023).

Dobby, C. (2011). Nevada state law paves the way for driverless cars. Available online: https://financialpost.com/technology/nevada-state-law-paves-the-way-for-driverless-cars (accessed on 20 August 2023).

Du, M. (2022). Autonomous Vehicle Technology: Global Exploration and Chinese Practice. Springer Nature.

Duvarci, Y., Akpinar, F. (2012). Contribution of the Personal Rapid Transit (PRT) systems to the road safety: A scenario-based comparative evaluation. Proceedings of the 17th International Conference of Hong Kong Society for Transportation Studies, HKSTS 2012: Transportation and Logistics Management, 325–332.

Emirates News Agency-WAM. (2023). Smart and Autonomous Vehicles Industries cluster launches at Masdar City. Available online: https://wam.ae/en/details/1395303209326 (accessed on 22 August 2023).

Faggella, D. (2020). The Self-Driving Car Timeline—Predictions from the Top 11 Global Automakers. Available online: https://emerj.com/ai-adoption-timelines/self-driving-car-timeline-themselves-top-11-automakers/ (accessed on 28 August 2023).

Fagnant, D. J., Kockelman, K. (2015). Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. Transportation Research Part A: Policy and Practice, 77, 167–181. https://doi.org/10.1016/j.tra.2015.04.003

Furlan, R., Al-Mohannadi, A., Major, M. D., Paquet, T. N. K. (2022). A planning method for transit villages in Qatar: Souq Waqif historical district in Doha. Open House International, 48(2), 425–446. https://doi.org/10.1108/OHI-05-2022-0121

Furlan, R., Grosvald, M., Azad, A. (2022). A social-ecological perspective for emerging cities: The case of Corniche promenade, "urban majlis" of Doha. Journal of Infrastructure, Policy and Development, 6(2), 1496. https://doi.org/10.24294/jipd.v6i2.1496

Furlan, R., Sinclair, B. R. (2021). Planning for a neighborhood and city-scale green network system in Qatar: the case of MIA Park. Environment, Development and Sustainability, 23(10), 14933–14957. https://doi.org/10.1007/s10668-021-01280-9

Furlan, R., Zaina, S., Patel, S. (2021). The urban regeneration's framework for transit villages in Qatar: the case of Al Sadd in Doha. Environment, Development and Sustainability, 23(4), 5920–5936. https://doi.org/10.1007/s10668-020-00853-4

Gambrell, J. (2016). Dubai pushes the pedal to the metal on driverless cars. Available online: https://apnews.com/article/b2867736dcd344fcb14e9e0788fd9c55 (accessed on 4 September 2023).

Gavanas, N. (2019). Autonomous Road Vehicles: Challenges for Urban Planning in European Cities. Urban Science, 3(2), 61. https://doi.org/10.3390/urbansci3020061

Government of Dubai. (2023). Mohammed bin Rashid issues law regulating operations of autonomous vehicles in Dubai. Available online: https://mediaoffice.ae/en/news/2023/April/14-04/Mohammed-bin-Rashid-issues-law-regulating-operations-of-autonomous-vehicles-in-Dubai (accessed on 4 September 2023).

Gulf News. (2023, July 3). UAE Cabinet approves testing of self-driving vehicles on its roads. Available online: https://gulfnews.com/uae/transport/uae-cabinet-approves-testing-of-self-driving-vehicles-on-its-roads-1.96763162 (accessed on 14 September 2023).

Hartmans, A. (2016). How Google's self-driving car project rose from a crazy idea to a top contender in the race toward a driverless future. Available online: https://www.businessinsider.com/google-driverless-car-history-photos-2016-10 (accessed on 14 September 2023).

Herzog, A. (2015). Driverless bus at EPFL. Available online: https://www.domusweb.it/en/news/2015/11/17/citymobil2_at_epfl.html (accessed on 16 September 2023).

Heubeck, L., Hartwich, F., Bocklisch, F. (2023). To Share or Not to Share—Expected Transportation Mode Changes Given Different Types of Fully Automated Vehicles. Sustainability, 15(6), 5056. https://doi.org/10.3390/su15065056

Ho, S. S., Leow, V. J. X., Leung, Y. W. (2020). Driving without the brain? Effects of value predispositions, media attention, and science knowledge on public willingness to use driverless cars in Singapore. Transportation Research Part F: Traffic Psychology and Behaviour, 71, 49–61. https://doi.org/10.1016/j.trf.2020.03.019

Ho, V. (2016). Driverless pods will run on Singapore's roads by end of the year | Mashable. Available online: https://mashable.com/article/driverless-pods-singapore (accessed on 8 August2023).

Intelligent Transport. (2019). Autonomous shuttles to be rolled out in Lyon. Available online: https://www.intelligenttransport.com/transport-news/92364/autonomous-shuttles-to-be-rolled-out-in-lyon/ (accessed on 16 September 2023).

Islam, N. (2016). The Huge Impact Driverless Cars Will Have on Parking & Urban Landscapes. Available online: https://www.semanticscholar.org/paper/The-Impact-of-Autonomous-Vehicles-on-Cities-Rodoulis/407e7ac6c6eeb9b6c16156c44095f6a3e2da809d (accessed on 20 September 2023).

Jolly, J. (2023). GM's Cruise CEO resigns amid concerns over driverless car safety. Available online: https://www.theguardian.com/business/2023/nov/20/gm-cruise-ceo-resigns-driverless-car-kyle-vogt (accessed on 20 September 2023).

Jones, R., Sadowski, J., Dowling, R., et al. (2023). Beyond the Driverless Car: A Typology of Forms and Functions for Autonomous Mobility. Applied Mobilities, 8(1), 26–46. https://doi.org/10.1080/23800127.2021.1992841

Kollewe, J. (2016). Insurer launches UK's "first driverless car policy." Available online: https://www.theguardian.com/business/2016/jun/07/uk-driverless-car-insurance-policy-adrian-flux (accessed on 22 September 2023).

Kopelias, P., Demiridi, E., Vogiatzis, K., et al. (2020). Connected & autonomous vehicles—Environmental impacts—A review. Science of The Total Environment, 712, 135237. https://doi.org/10.1016/j.scitotenv.2019.135237

Land Transport Guru. (2018). 2getthere ParkShuttle. Available online: https://landtransportguru.net/2getthere-parkshuttle/

Library of Congress. (2021, October 27). United Arab Emirates: Dubai to Introduce Regulations Governing Operation of Commercial Driverless Vehicles by 2022. Available online: https://www.loc.gov/item/global-legal-monitor/2021-11-16/united-arab-emirates-dubai-to-introduce-regulations-governing-operation-of-commercial-driverless-vehicles-by-2022/ (accessed on 16 September 2023).

Litman, T. (2018). Planning for Autonomous Vehicles (Issue January).

Litman, T. (2023). Autonomous vehicle implementation predictions: Implications for transport planning. Available online: https://www.vtpi.org/avip.pdf (accessed on 16 September 2023).

Liu, H., Yang, M., Guan, C., et al. (2023). Urban infrastructure design principles for connected and autonomous vehicles: a case study of Oxford, UK. Computational Urban Science, 3(1), 34. https://doi.org/10.1007/s43762-023-00110-0

Markoff, J. (2011). Google Lobbies Nevada to Allow Self-Driving Cars. Available online: https://www.nytimes.com/2011/05/11/science/11drive.html (accessed on 16 September 2023).

Marshall, A. (2020). The Intersection Between Self-Driving Cars and Electric Cars. Available online: https://www.wired.com/story/intersection-self-driving-cars-electric/ (accessed on 24 September 2023).

Masdar City. (2018). Mobility. Masdar City. Available online: https://masdar.ae/en/masdar-city/the-city/mobility (accessed on 24 September 2023).

Millard-Ball, A. (2019). The autonomous vehicle parking problem. Transport Policy, 75, 99–108. https://doi.org/10.1016/j.tranpol.2019.01.003

Millikin, M. (2011). Nevada enacts law authorizing autonomous (driverless) vehicles. Available online: https://www.greencarcongress.com/2011/06/ab511-20110625.html (accessed on 30 September 2023).

Ministry of Transport (MOT) of Qatar. (2021). Transportation Master Plan for Qatar (TMPQ) Qatar 2050. Available online: https://mot.gov.qa/sites/default/files/LT/TIP-DBMS/VOLUME%201_%20English.pdf (accessed on 8 August 2023).

Myles, P. (2019). VW Driverless Shuttle to Launch in Qatar. Available online: https://www.tu-auto.com/vw-driverless-shuttle-to-launch-in-qatar/ (accessed on 14 August 2023).

NACTO. (2019). Blueprint for Autonomous Urbanism: Second Edition (2nd ed.). The National Association of City Transportation Officials.

NHTSA. (2022). Automated Vehicles for Safety. National Highway Traffic Safety Administration.

Nunno, R., Laporte, A., Todoroff, A. (2021). Autonomous Vehicles: State of the Technology and Potential Role as a Climate Solution. Environmental and Energy Study Institute.

Patel, S., Furlan, R., Grosvald, M. (2021). A Framework for Enhancing the Spatial Urban Form of Informal Economies in India: The Case of Krishna Rajendra Market, Bangalore. SAGE Open, 11(2), 215824402110231. https://doi.org/10.1177/21582440211023184

Patella, S. M., Aletta, F., Mannini, L. (2019). Assessing the impact of Autonomous Vehicles on urban noise pollution. Noise Mapping, 6(1), 72–82. https://doi.org/10.1515/noise-2019-0006

Pathak, S. (2017). Driverless electric vehicles set to hit Qatar roads this year. Available online: https://www.qatar-tribune.com/news-details/id/53290 (accessed on 24 August 2023).

Rana, K., Gupta, G., Vaidya, P., Khari, M. (2023). The perception systems used in fully automated vehicles: a comparative analysis. Multimedia Tools and Applications. https://doi.org/10.1007/s11042-023-15090-w

Reilly, P. H., Bullard, E. M., McMiller, E. L. (2023). 2023 Legislative and Regulatory Developments Affecting Autonomous Vehicles.

SAE International. (2021). Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems.

Schedel, R. (2008). Darpa Urban Challenge 2007-Safe and autonomous driving. AutoTechnology, 8(1–2), 38–40. https://doi.org/10.1007/BF03247030

Sciaccaluga, M., Delponte, I. (2020). Investigation on human factors and key aspects involved in Autonomous Vehicles-AVs-acceptance: New instruments and perspectives. Transportation Research Procedia, 45(2019), 708–715. https://doi.org/10.1016/j.trpro.2020.02.107

Shambler, T. (2019). Driverless cars coming to roads in UAE by 2021. Available online: https://www.esquireme.com/content/41365-driverless-cars-coming-to-roads-in-uae-by-2021 (accessed on 18 August 2023).

Shoup, D. C. (2006). Cruising for parking. Transport Policy, 13(6), 479–486. https://doi.org/10.1016/j.tranpol.2006.05.005

Silberg, G., Wallace, R. (2012). Self-driving cars: The next revolution.

Singapore Ministry of Transport. (2015). Driverless vehicles: A vision for Singapore's transport. Ministry of Transport Singapore. Available online: https://www.mot.gov.sg/Transport-Matters/motoring/detail/driverless-vehicles-a-vision-for-singapore-s-transport (accessed on 18 August 2023).

Smith, B. W. (2014). Automated Vehicles Are Probably Legal in the United States. Texas A&M Law Review, 1(3), 411–521. https://doi.org/10.37419/lr.v1.i3.1

Soteropoulos, A., Mitteregger, M., Berger, M., Zwirchmayr, J. (2020). Automated drivability: Toward an assessment of the spatial deployment of level 4 automated vehicles. Transportation Research Part A: Policy and Practice, 136, 64–84. https://doi.org/10.1016/j.tra.2020.03.024

Tan, S. Y., Taeihagh, A. (2019). Adaptive and experimental governance in the implementation of autonomous vehicles: The case of Singapore. 30, 1–26.

Tannous, H. O., Furlan, R., Major, M. D. (2020). Souq Waqif Neighborhood as a Transit-Oriented Development. Journal of Urban Planning and Development, 146(4), 5020023. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000615

Tannous, H. O., Major, M. D., Furlan, R. (2021). Accessibility of green spaces in a metropolitan network using space syntax to objectively evaluate the spatial locations of parks and promenades in Doha, State of Qatar. Urban Forestry & Urban Greening, 58, 126892. https://doi.org/10.1016/j.ufug.2020.126892

U.S. Department of Energy. (2023). Alternative Fuels Data Center: Developing Infrastructure to Charge Electric Vehicles. Available online: https://afdc.energy.gov/fuels/electricity_infrastructure.html (accessed on 24 August 2023).

U.S. Department of Transportation. (2021). The Automated Vehicles Comprehensive Plan. U.S. Department of Transportation.

U.S. Green Building Council. (2023). LEED v4.1 BUILDING DESIGN AND CONSTRUCTION: New Construction beta guide for additional guidance.

Valdeolmillos, N. A. A., Furlan, R., Tadi, M., et al. (2023). Towards a knowledge-hub destination: analysis and recommendation for implementing TOD for Qatar national library metro station. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-023-03118-y

Vanderbilt, T. (2012). Autonomous Cars Through the Ages. Available online: https://www.wired.com/2012/02/autonomous-vehicle-history/ (accessed on 14 September 2023).

Weber, M. (2014). Where to? A History of Autonomous Vehicles. Computer History Program. Available online: https://computerhistory.org/blog/where-to-a-history-of-autonomous-vehicles/ (accessed on 1 August 2023).

Young, S., Lott, J. S. (2022). The Automated Mobility District Implementation Catalog: Safe and Efficient Automated Vehicle Fleet Operations for Public Mobility. National Renewable Energy Lab. (NREL), Golden, CO (United States).

Zhong, H., Li, W., Burris, M. W., et al. (2020). Will autonomous vehicles change auto commuters' value of travel time? Transportation Research Part D: Transport and Environment, 83(April), 1–14. https://doi.org/10.1016/j.trd.2020.102303