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Shared Design Framework for Autonomous Vehicles and Land Use Interface

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1 ABSTRACT

Technologies around Autonomous Vehicles (AVs) have improved enormously in the last decade. Autonomous vehicles are increasingly being tested on roads around the world. While the commercialisation of AVs seems imminent and researchers have explored various scenarios on the impact of driverless cars, trucks and buses on urban planning, the research around how AVs interface with land use and buildings remains scarce. This means that AVs may not be ready for full end-to-end transportation of passengers in high-density cities where drop off points are built within the buildings. This research study aims to fill the gap by examining the issues around the AV interface with land use and buildings, before these vehicles can become a viable option for commuters. Further research is required to investigate how these vehicles can navigate away from the roads into buildings, navigate within buildings, and then navigate out of buildings back onto the roads. This paper reviews current literature on the subject of autonomous vehicles and how they interact with and impact on the built environment. The findings identified a knowledge gap on how autonomous vehicles interface with buildings. The scant research in this area could slow the adoption of autonomous vehicles in a city like Singapore. Thus, this paper proposes a novel shared design framework plan for stakeholders, such as commuters, car manufacturers, building owners and design consultants, etc., to adopt so that building owners may enhance their assets for smoother access by autonomous vehicles. The inputs from a range of stakeholders could steer the formulation of guidelines for upgrading existing buildings to be AV-friendly and introduce relevant design considerations for new buildings to be AV-ready.

Keywords: Autonomous vehicles, Built environment, Land use, Shared design framework, Singapore

2 BACKGROUND

The USA leads the world in the Autonomous Vehicle (AV) industry. One of the most advanced developers of AVs, Waymo, has road-tested their driverless cars in over 25 cities and covered more than 20 million miles (Holt, 2021) in the last decade. AVs have also been put on road-trials as robo-taxis in a multitude of countries such as China (Toh, 2022), Australia (Cole, 2021), South Korea (Shim, 2021) and more than 10 European countries (European Commission, 2019). Since 2014, Singapore has trialled AVs in low traffic environments, for example a driverless taxi with MIT spin-off NuTonomy in the One North district and a driverless bus with Volvo in Nanyang Technological University (Kelleher, 2017; Tan, 2020; Toh, 2019). During the July 2021 Tokyo Olympics, Toyota showcased their leadership in the AV industry by deploying a fleet of driverless electric cars to ferry athletes between venues in the Olympic Village (Davis, 2021).

With so many trials going on around the world, it might seem that society is on the cusp of having AVs ply our roads. However, before AVs may be added as mobility options as personal cars, fleets of shared vehicles or for the transportation of goods, appropriate policies and laws will have to be enacted. Government policies and laws are still playing catch up in order to enable the adoption and smooth rollout of AVs and any supporting infrastructure (Freemark et al., 2019). While the results of these road trials on city streets and highways were deemed positive, there is little evidence for AVs manoeuvring into and out of buildings.

Based on the report of the European Commission (2019), tests on automated driving were conducted across 10 countries examining four functions: 1) Motorway Chauffeur – including driving up to 130 km per hour and lane changing; 2) Traffic Jam Chauffeur – a driver activated function in congested streets; 3) Urban Chauffeur – city driving which can respond to traffic lights and other road users; 4) Parking Chauffeur – the car manoeuvres itself into a parking lot. Notably, these tests did not explore how AVs could navigate the interface between the roads into the multi-storey carpark of a retail mall or, to the loading and unloading bay of a warehouse.

Many research studies have discussed the potential benefits and downsides of AVs. The range of anticipated benefits include: coupling AVs with ride sharing will result in lower car ownership and a smaller vehicle population (Townsend, 2020); fewer traffic accidents as a result of errant or drunk drivers (Anderson et al, 2014); lower demand for parking lots allows the repurposing of parking lots for urban farming or recreational uses (Bagloee et al, 2016); reduced pollution due to more efficient traffic management (Bahamonde-Birke et al, 2018); and big reduction in cost-per-trip due to shared vehicle cost and savings on drivers' salaries (Andersson & Ivehammar, 2019).

Some researchers highlighted the possible negative impacts of AVs such as: the massive loss of jobs for drivers of trucks, taxis and buses (Strömberg et al., 2021); as personal car ownership declines, businesses such as car insurance, car repair and maintenance, may become irrelevant (Anderson et al, 2014); the reduced costs of shared AVs may incentivise commuters to switch from mass public transit and buses to shared AVs, thereby increasing the number of trips and energy consumption (Kellett et al, 2019); eliminating the drive in and out of town as well as the need to park their cars, AVs may induce office workers in the CBD to live farther away in the suburbs, and leading to urban sprawl (Freemark et al., 2019; Duarte & Ratti, 2018).

Until AVs are widely adopted in various cities, whether the benefits will exceed the downsides remains uncertain.

As a small country of 728 square kilometres, Singapore has limited resources. The small land mass supports a 5.45 million population. The majority of Singapore's population work in, and live in, high density urban districts. The Land Transport Authority (LTA) recognised the value that AVs would bring to Singapore such as, increased mobility options for commuters and transportation of goods, improved sustainability of the transportation system for the city state, reduction in road accidents, optimised use of road space and the creation of higher value jobs related to AVs. The aim of this paper is to identify the issues and challenges of integrating AVs into Singapore's land use with a particular focus on how AVs navigate away from the roads into buildings, within the buildings and then out of the buildings back onto the roads.

3 LITERATURE REVIEW

While researchers are exploring various scenarios around the pace of adoption and penetration of AVs to ease mobility, policy makers and urban planners remain unprepared to deal with the disruptions that AV technology could bring (Faisal et al., 2019; Freemark et al., 2019; Milano, 2019; Mondschein, 2014). Legislation needs to be introduced to allow the AV technologies and commuter adoption to grow, while ensuring the safety of passengers and road users (Townsend, 2020).

At present, expected benefits and negative repercussions of introducing AVs into the transportation mix are forward looking and speculative (Townsend, 2014). For instance, the Rudin Centre for Transportation Policy & Management applied the four alternative future scenarios, ("Growth", "Collapse", "Constraint" and "Transformation") for mobility and transportation systems in the USA by 2030 (Townsend, 2014). Growth refers to a future where present trends are extended. Collapse refers to a future where negative events lead to critical systems failing. Constraint refers to a future where growth is slowed due to resource limitations. Transformation refers to a future disrupted by innovation resulting in steep growth conditions.

Milakis et al. (2017a) considered the future of transportation in the Netherlands using a 2 by 2 matrix to develop 4 scenarios based on an "intuitive logics method." The 4 scenarios were labelled "AV in standby," "AV in doubt," "AV in bloom" and "AV in demand" to imagine what the transportation landscape could look like in the years 2030 and 2050. They estimated the penetration rates of AVs and the possible implications on road usage. Similarly, Fagnant and Kockelman (2015) examined the impact of 10%, 50% and 90% AV market penetration on quantifiable parameters such as traffic accidents, congestion, cost savings and policy needs. The data from these quantitative simulations were used to substantiate the recommendations to policy makers. Some studies also looked at future scenarios based on the first order, second order and tertiary order effects of AV presence in the transportation mix (Milakis et al., 2017b; Bahamonde-Birke et al., 2018).

3.1 Positive Outcomes On The Use Of AVs

Most of the research conducted on AVs highlighted positive outcomes of their inclusion in a mobility system according to economic, environmental and social benefits as shown in Table 1.

Benefits	Areas	Description	Underpinning Literature
Economic	Lower operating costs and reduced total costs of ownership	The salaries of truck drivers, including overtime pay or additional allowances for night shifts, will be saved. For passenger car drivers, the time saved from driving may be allocated to productive work. Parking costs will be reduced. Lower risks of driver-induced accidents will imply lower insurance fees and reduced maintenance expenses for individual-owned AVs. Shared ownership of AVs will reduce idle time.	Andersson & Ivehammar (2019), Anderson et al. (2014), Bagloee et al. (2016), Bahamonde-Birke et al. (2018), Bösch et al. (2018), Fagnant & Kockelman (2013), Litman (2022), Pettigrew et al. (2018), Solon (2016), Strömberg et al. (2021), Townsend (2014)
	More high skilled jobs will be created	New jobs will be added for fleet operations and management of AVs. Skillsets for maintenance and repairs of AVs will require workers who are able to program software of the AVs and calibrate on-board instruments such as LIDAR, RADAR and visual cameras.	Anderson et al. (2014), Pettigrew et al. (2018), Townsend (2014)
Environmental	Less emissions from cars and trucks	Reduced fuel consumption as fleet owners optimise routes. AVs are assumed to be almost 100% electric vehicles.	Anderson et al. (2014), Mondschein (2014), Fagnant & Kockelman (2013), Milakis et al. (2017b), Townsend (2020)
	Less congestion	Overall car population will be reduced as the convenience of car sharing and ride sharing grows on commuters. Route optimisation for fleet-owned AVs will balance out traffic flow.	Kellett et al. (2019), Milakis et al. (2017a), Townsend (2020)
Social	Accessible to more people	Shared AVs with their lower cost per trip can increase accessibility to low-income households and improve travel for persons with mobility issues such as the elderly or young children.	Bagloee et al. (2016), Fagnant & Kockelman (2013), McCormick (2019), Strömberg et al. (2021), Townsend (2020)

Table 1: Some key benefits Autonomous Vehicles are expected to bring.

3.2 Negative Outcomes On The Use Of AVs

Researchers have also expressed concerns about various negatives that could arise from the use of AVs, based on economic, environmental and security perspectives as shown in Table 2.

Downsides	Areas	Description	Underpinning Literature
Economic	Government budgets	Convenience of AVs for door-to-door transport may reduce the usage of mass public transit (e.g. buses and trains), leading to an increased need for subsidies. Parking revenue, parking fines and traffic fines are expected to drop.	Anderson et al. (2014), Andersson & Ivehammar (2019), Driverless Seattle (2017), Kellett et al. (2019), McCormick (2019), Siddiq et al. (2021), Townsend (2020)
	Millions of jobs lost	The jobs and income of truck drivers, taxi drivers and bus drivers will be affected. The need for traffic police officers could be reduced. Education system needs to consider training them for AV related vocations.	Bagloee et al. (2016), Pettigrew et al. (2018), Solon (2016), Strömberg et al. (2021), Driverless Seattle (2017)
	Financial losses	City governments and building owners who have invested in new AV infrastructure and technologies risk rapid technology obsolescence and system failures.	Driverless Seattle (2017), Litman (2022), Townsend (2020)
Environmental	More congestion	AVs increase accessibility to a wider range of users and the increased demand for car trips which replaced buses, cycling or walking will lead to more traffic jams.	Anderson et al. (2014), Fagnant & Kockelman (2013), Kellett et al. (2019)
	Redundant carparks	Demand for carparks will be reduced significantly. A majority of carparks such as the multi-storey and basement carparks in buildings may be too costly to repurpose.	Anderson et al. (2014), Duarte & Ratti (2018), González-González et al. (2020), Autonomous Vehicles and Their Impact on Real Estate (2018)
Security	Hackers and bad actors	The system controls of AV fleets could be hacked by terrorists to create accidents or bring a city's traffic to a standstill.	Fagnant & Kockelman (2013), Litman (2022), Townsend (2020)
	Privacy and surveillance	Individuals' locations and travel data could be monitored. Hackers with malicious intent could spy on the activities of individuals to cause harm to them, their companies or society. Governments may track citizens' through the movement of AVs.	Fagnant & Kockelman (2013), Townsend (2020)

Table 2: Some of the potential downsides arising from the widespread adoption of Autonomous Vehicles.

4 METHODOLOGY

This research uses a qualitative method combining a systematic literature review and selected case studies to examine the potential issues and challenges associated with AVs and the built environment. Case study data was collected from multiple sources to ensure data credibility (Patton, 1990; Yin, 2014). This research has reviewed publications written in English while reports published in Chinese on AV trials (for example by companies such as BYD, DiDi, AutoX, Pony.ai, etc) and articles published in Japanese, Korean and other European languages were not considered.

The case studies reviewed in detail are studies that considered the introduction of AVs into the mobility systems in the cities of Zug in Switzerland (Bösch et al., 2018), Seattle in USA (Driverless Seattle, 2017) and Adelaide in Australia (Kellett et al., 2019). Based on the literature review and undertaken case studies, the positive (Table 1) and negative (Table 2) outcomes were identified among global cases. These issues and challenges are then compared to Singapore's context so that the integration of AVs into Singapore's built environment can be considered. Given the high density urban typology of Singapore's built environment, we examine how AVs navigate away from the roads into buildings, within the buildings and then out of the buildings back onto the roads.

5 SINGAPORE CONTEXT

Singapore supports the 2030 Agenda for Sustainable Development guided by the Sustainable Development Goals (SDGs). Singapore's commitment to cut down on carbon emissions is evident, as outlined in the Green Plan 2030. Significantly, to encourage the use of electric vehicles (EV), Singapore introduced a policy to invest in 60,000 charging stations and make all towns EV-ready by 2030 (LTA, 2021). Another affirmative action concerned a reduction in the number of parking spaces and designated new residential neighbourhoods and business precincts as "car-lite" areas. In the past decade, such car-lite areas with reduced parking availability were gazetted in 10 areas around Singapore. According to the government, there are more than 12,000 carparks in Singapore, providing about 1.4 million parking lots spread across public housing estates, private residential areas, open air and curb-side carparks, retail malls, offices and industrial buildings (Lin, 2021). The adoption of AVs could allow a large number of carparks to be repurposed for greater social and economic value.

The evident potential of such reforms has resulted in Singapore's growing interest in adopting AV technology. Efforts to support AVs began with road trials in 2014 (Kelleher, 2017). This was followed by the opening of the Centre of Excellence for Testing & Research of Autonomous Vehicles (CETRAN) in 2017 and the building of a 1.8 hectares trial AV test circuit. The Land Transport Authority (LTA) has also published its roadmap for the deployment of AVs (albeit without any target dates) (LTA, n.d.).

As part of public engagement under the Long-Term Planning Review, the Urban Redevelopment Authority (URA) held a public exhibition entitled "Reimagining Urban Mobility with Autonomous Vehicles" in January 2022. The public engagements are intended to increase stakeholder awareness and adoption, particularly among commuters. At this exhibition, the URA highlighted that urban regeneration brought about by the efficiency of AVs would allow road lanes to be reclaimed as cycling paths and walkways, maximising links between residents and nature. Through these engagements, property developers and building owners are reminded of the government's commitment to introduce AVs as part of the transportation mix.

6 DISCUSSIONS OF FINDINGS

This research aims to identify issues and challenges of integrating AVs into Singapore's land use and built environment. We reviewed literature on the subject of autonomous vehicles and how they interact with and impact the built environment. There is sufficient engineering literature and data from road tests to confirm that AVs are able to navigate the streets using maps, street markings and road signs. However, the findings identified a knowledge gap on how autonomous vehicles interface with buildings: how AVs navigate away from the roads into buildings, within the buildings and then out of the buildings back onto the roads. Given the high built-up density of Singapore, AVs would be required to manoeuvre into and out of buildings (e.g. shopping malls, office buildings, schools, factories, condominiums, hotels, etc.) to pick up and drop off commuters and goods. Any issues around the interface of AVs with land use and buildings need to be resolved completely before AVs can be deployed into high-density urban settings.

The majority of literature on AVs in Singapore has been engineering-focused, such as in the areas of computer vision and mobility trials, etc. (Toh, 2019; Smart Nation Singapore, n.d.). A handful of recent papers surveyed commuters' perceptions and concerns around AVs (Chng & Cheah, 2020; Wang & Zhao, 2019) There is a lack of published research on issues and challenges concerning the deployment of AVs in Singapore such as social impact, financial benefits and traffic optimisation.

The case studies reviewed, namely Zug in Switzerland (Bösch et al., 2018), Seattle in USA (Driverless Seattle, 2017) and Adelaide in Australia (Kellett et al., 2019), were relevant to the Singapore context on various fronts. However, a key difference is that these papers studied the specific context of the cities whose built environment and population densities are much lower than Singapore's. At about 8,300 population per square kilometre, Singapore has one of the highest population densities in the world. Therefore the majority of the building typology is high-rise, and we are concerned that the movement of AVs into such high density, high-rise built environments has not been adequately considered. In contrast, Zug, Adelaide and Seattle have population densities of between 1,400 and 3,400 persons per square kilometre.

As shown in Table 3, literature and case study reviews tended to focus on economic, technology, social, legal and stakeholder aspects of AV usage. Where there is mention of the built environment and land use, they are mainly related to the reduced demand for parking lots and whether commuters will choose to live further from business districts, causing urban sprawl to be worsened (e.g. Duarte & Ratti, 2018). Studies in relation to the AV interface with land use and buildings are not available.

Case Study	Economic	Social	Technology	Legal	Stakeholders	Built Environment
Seattle	✓	✓	✓	✓	✓	✗
Zug	✓	✗	✓	✓	✗	✗
Adelaide	✓	✓	✓	✓	✓	✓
Singapore	✗	✗	✓	✗	✓	✗

Table 3: Comparison of Economic, Social, Technology, Legal, Stakeholder and Built Environment parameters covered by 3 case studies versus the AV literature in Singapore.

6.1 Economic factors

Simulations by Bösch et al. (2018) for the city of Zug revealed that when commuters switch to shared AV transport, it would result in reductions in the costs of automated public transport, vehicle population and reduced travel time for commuters. However, depending on the policies enacted, there are risks of increased costs due to additional Vehicle Kilometre Travelled (VKT) for vacant trips to pick up passengers.

When consumer sentiment around car ownership or resistance to technology adoption were excluded, Kellet et al. (2019) found that around 18% of the current vehicle fleet would be sufficient to service commuters during peak demand hours. This full adoption scenario would be of considerable financial and time savings to consumers in the long term. With ride sharing, a full AV fleet could further decrease this percentage. Considering the survey results indicated that two-thirds of drivers would prefer not to share rides, the remaining one-third would use a communal service fleet. In this modified version of the full adoption scenario, 73% of the current fleet could service peak-hour demand. During the transition, assuming a maximum AV occupancy of two-thirds, they determined that 82% of the current vehicle fleet could meet peak demand. The survey results also revealed that lower AV costs would encourage consumer uptake, consistent with results provided by other researchers (e.g. Kyriakidis et al., 2015).

Driverless Seattle (2017) highlighted several other economic factors to consider. The report recommended the city government to invest in AV infrastructure through collaboration with strategic industry partners and stakeholders such as researchers and standards groups. In addition, they cautioned about the significant financial impact on municipal revenues. Given that AVs are expected to reduce the numbers of road accidents, the number of traffic infringements and parking tickets, a large part of Seattle's $29.2million traffic fines could be removed from the city's annual budget. Alternative sources of revenues would need to be developed, such as AV registration fees and taxing commuters for VKT.

6.2 Social

In Adelaide, Australia, commuter surveys by Kellet et al. (2019) revealed that the major factors affecting adoption are commuter attitudes to driving and AVs, the costs of owning and operating AVs and consumer attitudes to ride sharing. Survey respondents were willing to accept AV technology, but the pleasure of driving cars, along with the social status of car ownership may inhibit mass-adoption of ride sharing. Such factors would affect adoption models for e.g. 10, 50, 75% AV presence in the vehicle fleet. As riders of public transport shift to AVs, this could lead to an increase in "peak period vehicle flows," which would be likely to increase congestion, particularly at choke points.

Driverless Seattle (2017) highlighted that the introduction of AVs have implications for social justice and equity. AVs are expected to bring "tremendous mobility benefits" to groups that are restricted in mobility options due to age or disability. They recommended that policy makers in Seattle consider disadvantaged groups when developing new transport policies to incorporate AVs into the transportation mix.

6.3 Technology

Townsend (2020) stated that safety of lives inside and outside the AVs cannot be compromised. If the transportation industry wanted to see consumers' support for and use of AVs grow in the near future, the safety record of AVs on public roads with respect to lives would have to be impeccable. To quote the author, "we either perfect self-driving, or there won't be an industry to speak of."

One of the key benefits touted for AVs is the reduction of traffic accidents and the expected drop in traffic fatalities due to the elimination of driver error. The National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation stated that "the major factor in 94 percent of all fatal crashes is human error" (NHTSA, 2017). According to NHTSA's statistics, there were more than 38,000 deaths arising from traffic accidents across USA in 2020 (NHTSA, 2022). This implies that tens of thousands of lives may be saved every year in the USA once AVs were widely adopted.

Paradoxically, the assumption that safety is treated with the highest priority may be one reason why many researchers focus on other aspects of technology: such as data security, privacy, stability of IT systems and communications systems. The research teams of Bösch et al. (2018) and Kellet et al. (2019) modelled traffic flow with AVs assuming that the technology for shared fleets of AVs will be rolled out smoothly.

The AV interface with the built environment will be facilitated by Vehicle-to-Infrastructure (V2I) communication, prompting further experiments such as data sharing between nearby cities to enable smooth transition of AVs between locations and cooperation in vehicle testing (Driverless Seattle, 2017). AV communication with the built environment is a broad area that requires regulations to be enacted to support technology standards to be set. For example, the standards and bandwidth for Wifi, Bluetooth or Dedicated Short-Range Communications (DSRC) that enable Vehicle-to-Vehicle (V2V) and V2I communications so that AVs can navigate the roads and prevent collisions need to be determined (Kenney, 2011).

Apart from the regulations around info-comm technology, automotive standards need to be set. For example, the roadworthiness of AVs, maintenance requirements, licensing or pre-qualification of car manufacturers, setting performance measures such as emissions, noise limits and their ability to operate under inclement weather.

6.4 Legal

In all three cases reviewed, the researchers have recommended policymakers catch up with technology improvements in AVs and urban mobility (Bösch et al., 2018; Driverless Seattle, 2017; Kellett et al., 2019). Existing policies and laws are specific to the current configuration of automotive technology. Policy makers will first have to understand the breadth of the AV spectrum, either developing laws to cover all iterations of the technology or to promote deployment of specific variations and delivering more focused regulation. For example German transport officials dislike Tesla's "Autopilot" terminology, as the name suggests the drivers need not pay attention when this mode is engaged (Driverless Seattle, 2017).

Researchers from Rand Corporation (Anderson et al., 2014) summarised legislations already enacted in 15 states across USA. The common denominator amongst policy makers in the 15 states was defining AVs as "vehicles with the capability to self-drive without being actively controlled or monitored by a human operator." Surprisingly, the research concluded that it was not clear that laws were required to permit testing or actual road use of driverless cars. Perhaps this was because existing laws around transportation and vehicles did not explicitly account for scenarios where cars could operate by themselves.

Bösch et al. (2018) detailed the ways in which policy makers can influence the transport system: directly managing existing infrastructure or introducing new services or infrastructure to optimise movement; taxes and subsidies to promote the use of certain modes of transport or reduce the cost of public transport altogether; legislation to regulate the way the current systems are utilised and organised (e.g. speed limits, priority lanes); finally the use of advertising to change attitudes towards various modes of transport. They highlight that an optimal transport system needs to transfer goods and people rapidly yet safely and sustainably, while minimising costs on the consumer end. They suggest policy be used to improve current systems, such as implementing AVs in areas where public transport services are poor or low frequency and assessing how to use excess land in a more optimised road system. Policymakers need to consider the form in which the AVs will enter the market, i.e. as a private or public service, and acknowledge that automated services will be an attractive alternative for commuters. Ignoring or prolonging intentional organisation of these services will result in "the market organising itself", likely resulting in suboptimal function, and delaying further adoption.

Models produced by Kellett et al. (2019) estimated potential reduction in the vehicle fleet that would be made possible by the adoption of AVs, adapting their models for consumer preferences. They discussed issues likely to occur during the transition such as increased CBD congestion as the vehicle fleet expands, as well as issues related to parking. Government policies such as, grants for shared public transport, parking restrictions and taxation of non-AVs could be introduced to accelerate consumer adoption of AVs.

AVs are anticipated to "communicate" with buildings, sharing data to allow smooth transition between the roads and the built environment. Cities will also have to communicate to coordinate smooth transition of AVs across multiple jurisdictions. Policy standardisation of communication methods and data standards may help to alleviate some of these invisible borders (Driverless Seattle, 2017).

Note that policy recommendations from any research paper need to be viewed against the unique context of their cities and states. Any governments at the city, state or national levels would need to work on a wide range of policy areas if they were serious about rolling out AVs on their roads.

6.5 Stakeholders

The stakeholder groups considered in current literature are focused on commuters (or AV users), policymakers and transport operators, as exemplified by the studies of Bösch et al. (2018) and Kellett et al. (2019).

Driverless Seattle (2017) went a step further by calling on policymakers to consider stakeholders "traditionally under represented" during policymaking, e.g. those in "socio-economically disadvantaged communities." They recommend more diverse stakeholder considerations to assess the impacts of AVs and the responses to the policies developed to accommodate their adoption.

Strömberg et al. (2021) highlighted the need for inclusive regulations and encouraged more dialogue between stakeholders such as urban planners, AV car makers and future AV users or commuters. The opinions of urban planners has occasionally been included in the literature, for example by Legacy et al. (2019) and Smolnicki & Sołtys (2016), but these tend towards city-wide, municipal and transport planning. Stakeholders in the built environment, such as facility managers and building owners, are rarely surveyed for their views about AVs.

6.6 Built Environment

The introduction of AVs, coupled with the post-Covid Work-From-Home arrangements, could lead to the dispersion of cities, i.e., city boundaries expand as residents seek wider spaces and more affordable homes in the suburban areas. Post-Covid, many large companies have relaxed the need for staff to work from offices in the CBD. The reduced daily commute means that living in a lower-cost and larger home further from the city is now a more attractive proposition. Furthermore, even if the travel time exceeds an hour, commuters in AVs do not lose productive time as they may work from the AVs and at arrival, they are dropped off at their destinations without having to walk from a station or bus-stop to the destination (Townsend, 2020). Exposure to the weather and other inconveniences will also be minimised. Workers have more incentives to shift their abodes to the suburbs and this could lead to urban sprawl.

Traffic studies by Kellett et al. (2019) also suggest that mass AV adoption could lead to an increase in urban sprawl. Their survey results suggest that a substantial reduction in city centre parking would allow more diverse land use in the CBD, however parking may become more concentrated around amenities. Urban policy would need to be prepared to counter such negative effects.

Another part of real estate that will be impacted by the adoption of AVs is carparks. Carparks located in the CBD, where land value is high, will be most impacted (Fagnant & Kockelman, 2013). Personal AVs may drop their owners off and cruise out to the city-fringe's parking lots that are less expensive. Shared AVs will simply drop off passengers and move to the next pick-up or drop-off point. Parking lots will increasingly be under-utilised and lawmakers should consider allowing their conversion to other uses rather than to let them remain as vacant unproductive space (which could cost landlords in terms of cleaning and periodic maintenance).

It is clear that AVs will impact land use, the built environment and privately-owned or government-owned real estate. Current literature regarding the impact of AVs on the built environment are largely focused on inner city carparks and urban sprawl (Townsend, 2020; Sagástegui, 2020). For AVs to cover the last mile in delivering commuters and goods to their destinations, the views of stakeholders in the built environment need to be sought.

7 TOWARDS A SHARED DESIGN FRAMEWORK FOR AV-LAND USE INTERFACE

Strömberg et al. (2021) reported that urban planners who participated in their research study "struggled with how to handle AVs, asking themselves how they could integrate future mobility into planning." This is supported by Faisal et al. (2019) who stated that presently, "urban planning as a profession is largely unprepared for AVs."

In addition to urban planners, we see a need to conduct deeper research with other stakeholders in the real estate industry (i.e. property developers, building owners, architects, facility managers) on how AVs might disrupt real estate assets and when they are progressively deployed in high density cities such as Singapore.

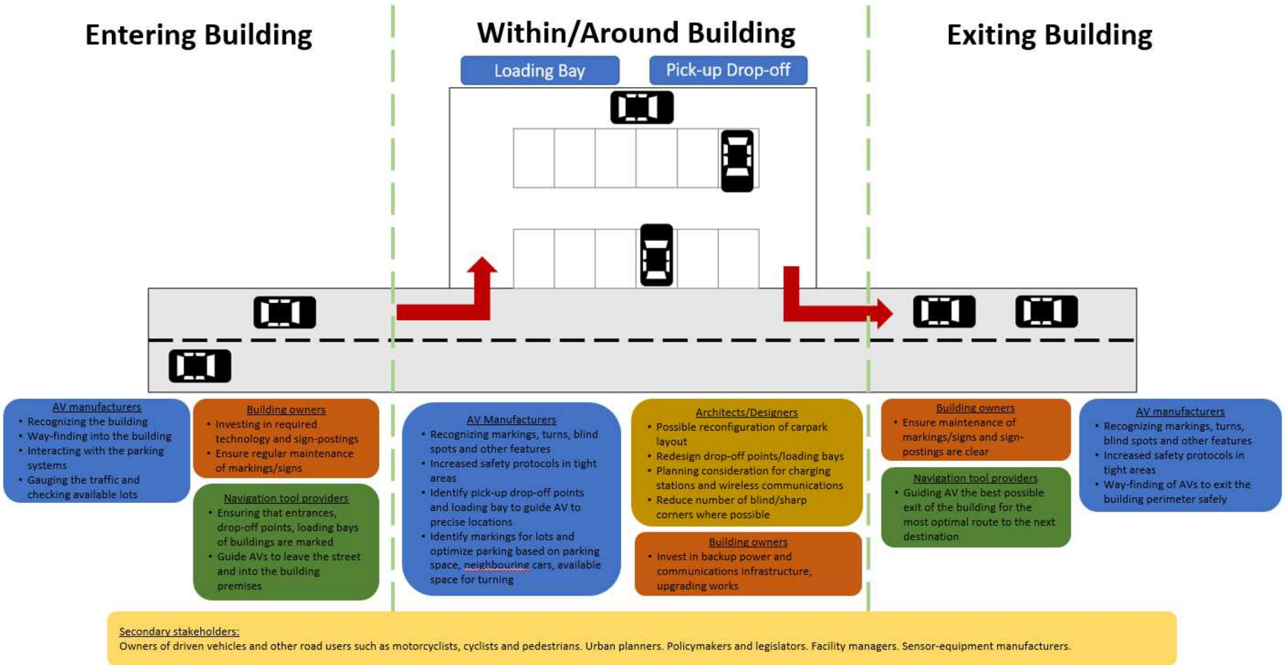

Fig. 1: Shared design framework plan for the AV-built environment interface.

Given the dearth of academic research linking AVs to land use and buildings, a proposed shared design framework and guidelines will be developed which will consider the concerns and ideas of stakeholders. Examples of primary stakeholders include, but are not limited to: 1) AV manufacturers, 2) building owners, 3) architects/designers and 4) navigation tool providers; secondary stakeholders would include 1) owners of driven vehicles and commuters (e.g. motorcyclists, cyclists and pedestrians), 2) urban planners, 3) policy makers, 4) facility managers, 5) sensor-equipment manufacturers and 6) insurance companies.

A novel shared design framework with a list of parameters is proposed for stakeholders to consider when designing new buildings, or when planning the retrofitting of existing buildings, to be AV-friendly. For a city to realise optimum benefits from the deployment of AVs, existing buildings need to be retrofitted and enhanced to allow the smooth navigation of AVs into, within and out of buildings. New buildings submitted for development approvals should be AV-ready when the construction works are completed.

Bringing stakeholders together to identify potential impediments of AV adoption in the existing built environment will help Singapore to realise the benefits of AVs sooner. The main objective of this shared design process is also to allow stakeholders to come to an agreement during the pre-deployment stage of AVs in a dense urban setting like Singapore. The shared design framework plan as shown in Figure 1 will be the guiding tool in furthering this recent research study.

8 CONCLUSION AND FURTHER RESEARCH

While recognising the negatives that AVs might bring to the transportation system, we are in agreement with the optimistic views of most of the AV researchers about the potential benefits that AVs could bring. However, we are concerned that the “last mile” gap for AVs has not been addressed, especially for high density built environments such as Singapore. There is a need to conduct studies on how AVs will interact with the built environment, i.e. going into, within and out of buildings. The absence of literature on how AVs would transition between roads and private properties such as office buildings, malls, condominiums and carparks is not surprising given the lack of research participation from stakeholders in the real estate industry such as property developers, building owners and facility managers. This indicates that cities, and in the case of our study, Singapore, are a considerable number of years from deploying AVs to pick up or drop off goods and passengers within the loading bays, carparks or driveways of buildings.

The research on the interface between AVs and land use is nascent and there are many areas in need of deeper consideration. From a real estate perspective, this “last mile” issue has to be addressed, especially in Singapore, where the hot and rainy weather necessitates passengers to be picked up and dropped off under shelter, including in basement lift lobbies where telecommunication signals may be weak or non-existent. Moreover, given the expected shift from self-driven cars to AVs, building owners would need to expand the capacity of pick-up and drop-off points and loading/unloading bays, perhaps by redesigning sections of carparks or by altering the ingress and egress connecting the buildings to the roads. Policymakers need to provide the guidelines to facilitate such renovations.

Indeed, “a future involving widespread use of AVs presents both land-use opportunities and challenges” (Faisal et al., 2019). Such potential provides ample motivation for the development of a shared design framework and guidelines to ensure smooth deployment of AVs in Singapore. Leveraging the Singapore government’s progressive stance on technology adoption and ambitions in making Singapore a smart city, this study will allow Singapore to gain an early advantage in deploying AVs.

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