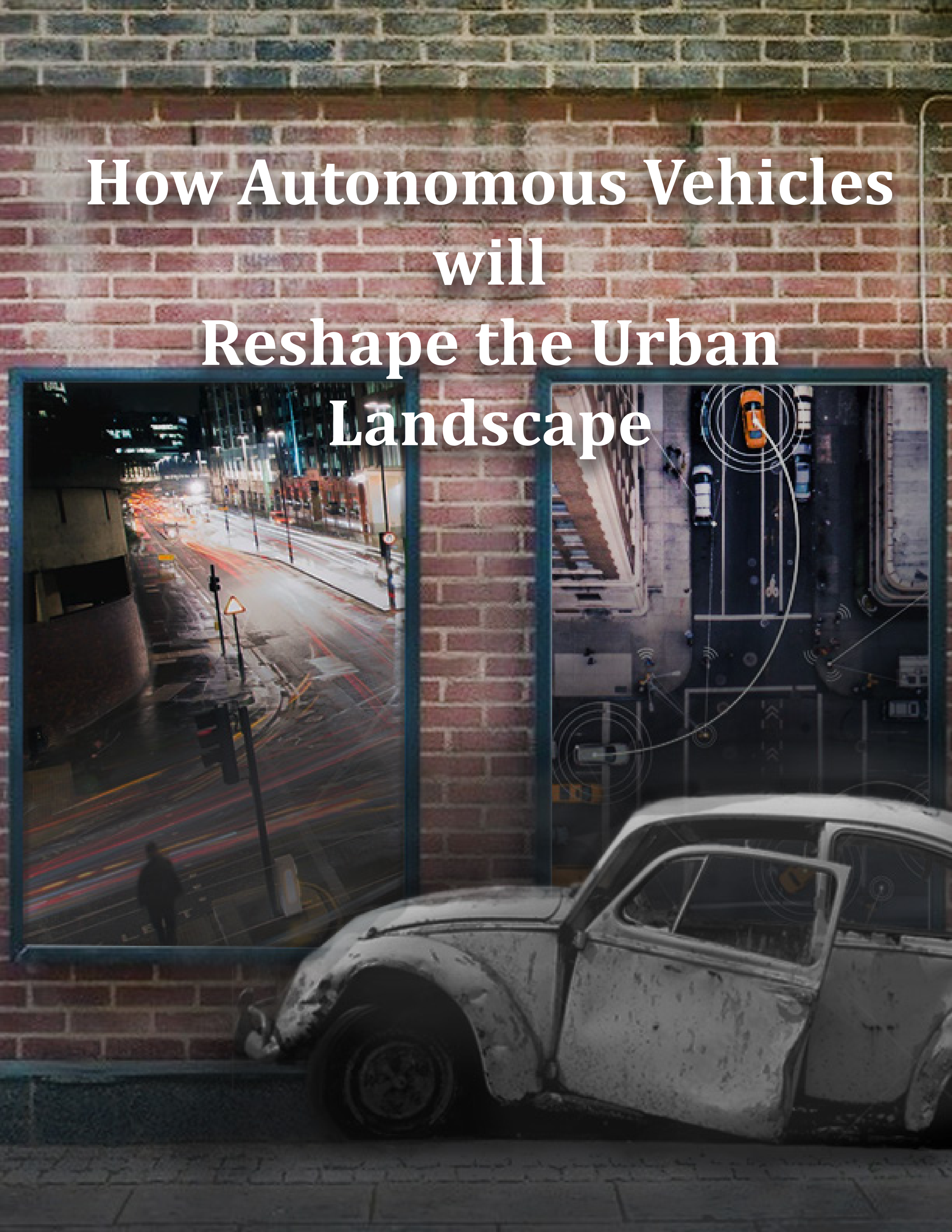
How Autonomous Vehicles will Reshape the Urban Landscape



APPROVAL PAGE

Title: How Autonomous Vehicles will Reshape the Urban Landscape

Author: Ian McCarville

Date Submitted: March 2019

Amir H. Hajrasouliha Senior Project Advisor	____________________ Signature	____________ Date
Michael Boswell CRP Department Head	____________________ Signature	____________ Date

How Autonomous Vehicles will Reshape the Urban Landscape

by

Ian Robert McCarville

CRP Faculty Advisor: Amir H. Hajrasouliha

Senior Project

City and Regional Planning Department

California Polytechnic State University

San Luis Obispo

2019

Acknowledgments

I would like to take this opportunity to thank all faculty members, professors and colleagues who have helped me throughout my academic career and achieve my Bachelors of Science Degree (BSCRP), with the Department of City & Regional Planning (CRP), at Cal Poly San Luis Obispo. I would like to give a special thanks to Professor Amir H. Hajrasouliha for his guidance throughout this project and my academic career, his willingness to listen and his encouragement for me to take on new challenges.

Table of Contents

Introduction

Autonomous vehicles (AVs) will bring one of the largest revolutions to the nation's transportation system, with major changes in planning policies and the urban environment. While AVs have already been introduced to our mobility network, they still require a human operator behind the wheel. In coming years, as AV technology becomes more sophisticated, it will begin to dominate the roadways due to the technologies ability to maneuver at a much high accuracy and predictability than human drivers. This transition into an AV oriented future will promote road safety, increase productivity, reduce travel and labor costs, and reinvent the urban landscape.

Autonomous vehicles will progressively play a larger role in our transportation system and will significantly impact the built environment. The ability to adapt and plan for this new form of mobility will be a crucial role of planners. AVs have yet to reach their full potential, but within a decade, the advances in this technology will be exponential. Anticipating the influences that AVs will have on our cities and regions and being able to conceptualize these changes is the next step into integrating AVs into the transportation system. Autonomous vehicles have the potential to reshape the urban landscape and functional design is central to its success.

The purpose of this report will be to discuss, analyze, and visualize the different conceptual design elements needed to integrate AVs into cities. Redesigning the urban landscape for AVs will require planners to rethink street design standards, how to incorporate AV technology, and how to re-imagine the public realm for pedestrians, bicyclists, and transit riders. Complete streets serving all users will need to be created, and shared mobility will need to be a priority. This report will use case studies and external research to conceptually demonstrate how AV design elements can successfully be integrated into a city. The final product will be a design vision that shows how different types of mobility and urban areas will be affected by the AV revolution.

What are Autonomous Vehicles?

Autonomous vehicles are currently classified by the level of autonomy, with level 0 meaning no automation and level 5 meaning full automation. Figure 1 shows the five levels of autonomy with their coinciding meanings. Currently, the only AVs on the road have level 3 automation, such as the Tesla Model 3, which means hands free driving, however, still requires an attentive human being behind the wheel. In the next 5-10 years we are expected to see that transition into level 5 automation (Walker, 2018). This will be the start to the AV revolution, which will eventually encapsulate all vehicles from private, to ride share, to freight, to public transportation.

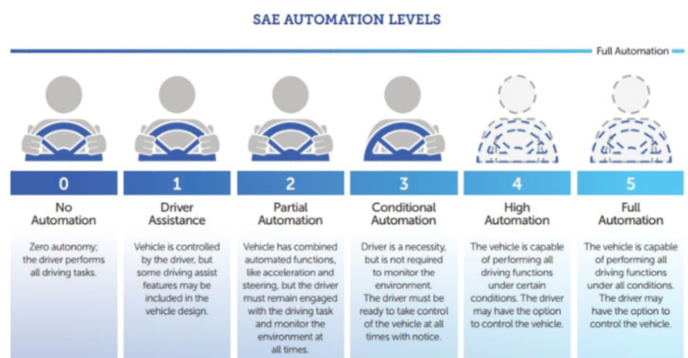


Figure 1 - Different levels of automation.

The technology behind AVs consist of "a combination of sensors, cameras, high performance GPS, AI and Machine Learning," (Jajal, 2018). Figure 2 illustrates how numerous types of technology help self-driving cars "see" the road. This allows AVs to collect, process, and react to real time data, such as a pedestrian crossing the street, all with a split second. Cities can also implement their own AV technology in terms of cloud-based infrastructure (Jajal, 2018). This means that sensors on roads, traffic lights, bridges, parking lots, and many more elements of transportation infrastructure can be digitally improved in order

to better connect and transmit data to AVs and other smart connected devices. Figure 2 illustrates the different types of AV technology allowing the car to connect to and detect its surroundings. AVs that are connected to their environment will serve a great purpose and will be an important part of the autonomous revolution.

The technology behind AVs consist of "a combination of sensors, cameras, high performance GPS, AI and Machine Learning," (Jajal, 2018). Figure 2 illustrates how numerous types of technology help self-driving cars "see" the road. This allows AVs to collect, process, and react to real time data, such as a pedestrian crossing the street, all with a split second. Cities can also implement their own AV technology in terms of cloud-based infrastructure (Jajal, 2018). This means that sensors on roads, traffic lights, bridges, parking lots, and many more elements of transportation infrastructure can be digitally improved in order to better connect and transmit data to AVs and other smart connected devices. Figure 2 illustrates the different types of AV technology allowing the car to connect to and detect its surroundings. AVs that are connected to their environment

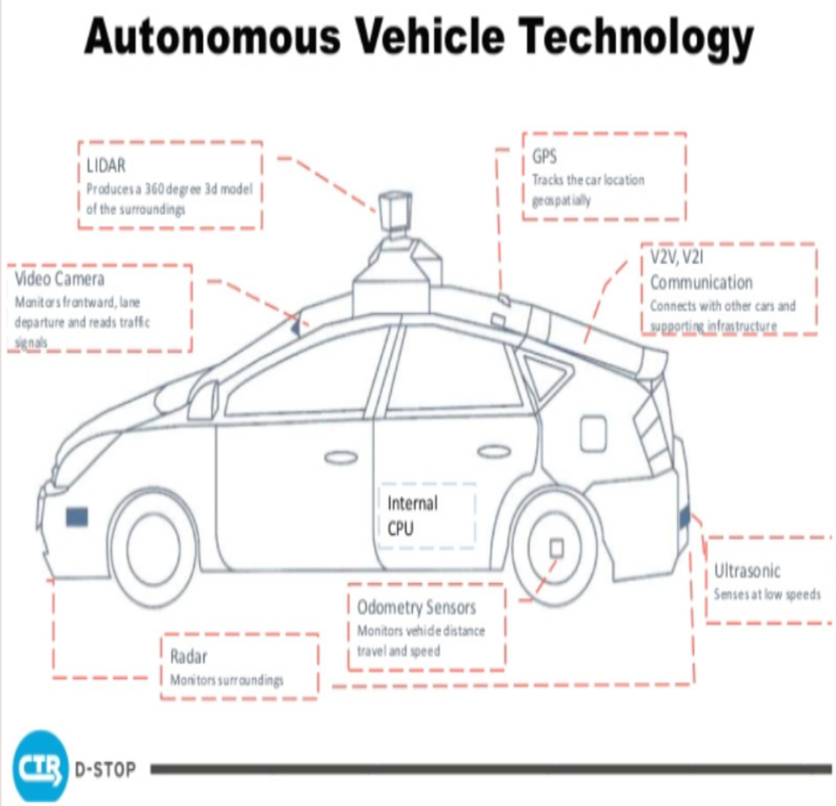


Figure 2 - Autonomous vehicle technology.

What will Autonomous Vehicles do to our Society?

Autonomous vehicles will have both positive and negative side effects to society, but if planned for efficiently, they will bring many benefits to the future of our cities. In Blueprint for Autonomous Urbanism, it states how automation can either, "serve the goals of safety, equity, public health and sustainability," or "Traffic and emissions could skyrocket, "roboroutes"-walls of autonomous vehicles with few gaps-could divide communities, people could be relegated to inconvenient and unpleasant pedestrian bridges, and high-priced, inequitable mobility could supplant transit," (NACTO, 2017, p. 8 & 11). These two different outcomes will be dependent on how AVs are implemented, and if sustainable practices such as ride sharing, minimal private ownership, and automated public transit is adopted.

When AVs are integrated successfully positive changes to our transportation system, cities, and way of life will be recognized. Some of the first tangible effects will be safer streets, increased access for all ages and abilities, better affordability and reliability, and more frequent mobility (NACTO, 2017). As AVs become more integrated the entire public realm will expand, streets will become greener, lane width will decrease, and an overall decluttering of streets will take place. The urban realm will be the most visibly affected by the adoption of AVs, however other non-tangible effects will take place. These benefits will include a significant reduction in urban travel, transportation networks become cheaper to operate, road infrastructure is lower, and the value of time increases due to less road congestion (Fulton, Mason, & Meroux, 2017).

Figure 3 - A complete street. Different pavers delineate the sidewalk from the road, moveable seating and other traffic calming elements further increase the safety and enjoyability of the public realm.

Another important benefit of AVs will be that they drastically increase the safety of our streets. In present day, cars dominate the roads. Pedestrians are stopped frequently by inefficient signal lengths, and crosswalks tend to be either poorly spaced or too long to cross in the allotted time frame. This can make the public realm a much less desirable place for pedestrians to navigate and increase the possibility of a collision occurring. When designing for automated vehicles and pedestrian priority, the streetscapes become a much safer, and maneuverable space (Calvard, 2018). Pedestrians and bicyclists would be able to cross the street almost anywhere due to the slower street speeds and the AVs ability to precisely identify people and which way they are moving. Some streets will completely transform into something similar to a complete street, as seen in Figure 3. These streets prioritize other forms of mobility, such as walking and biking, and utilize traffic calming measures and street furniture to create a more enjoyable and safe space.

The Importance of Shared Mobility

For AVs to have a beneficial impact on our transportation system and urban landscapes, shared mobility is essential. This term of shared mobility refers to car sharing, bike sharing, ridesharing, and on demand ride services such as Uber or Lyft. This also includes alternative transit services such as paratransit, shuttles, buses and rail services. While all these will be important, ridesharing will be the most necessary for AVs to succeed sustainably and economically in society.

Ridesharing services would drastically reduce the number of vehicles on the road. A recent MIT simulation found that, mathematically and logistically, a fleet of 3,000 vehicles with a capacity

of four passengers could meet 98% of the trip demand of 14,000 New York City taxies, with ride wait times averaging just 2.7 minutes (Alonso-mora, Samaranayake, Wallar, Frazzoli, & Rus, 2017). This research helps demonstrate the impact ridesharing could have on our transportation network, and how many cars could be taken off the road. However, with this also comes the concern that people may increasingly choose to rideshare over walking and biking, and increase congestion, vehicle miles traveled and travel times, (Fulton, Mason, & Meroux, 2017). This example shows that good planning and design could help eliminate this outcome by planning for alternative modes of transportation rather than cars. If ridesharing is accepted and used correctly, ride hailing services will cost 50% less" (Fulton, Mason, & Meroux, 2017, p.7), and other forms of transportation such as walking, and biking will be

Redesigning Streetscapes and the Public Realm for Autonomous Vehicles - Signage

The transition to accommodate AVs on the road is most likely going to be slow, and additional signage is going to be necessary. Drop off zones will need to be delineated from traditional parking, certain lanes will have to be demarcated differently, and many other types of signage will need to be implemented in order to have both AVs and human operated vehicles coexist on the same roadways. However, once AVs make up a large majority of the vehicles on the road, signs, lane stripping, and even stop lights will be able to be removed (Riggs, Crute, Chapin, & Stevens, 2018, p. 44). This is due to the Vehicle to Vehicle (V2C) and V2I technology, which eliminates the need for visible signage, and instead allows AVs to interact wirelessly and in real time (Lombardo, 2018). This creates opportunity to vastly improve the aesthetics of both the streets and sidewalks and create a much more enjoyable space for pedestrians and bicyclist. The only required signage would be for pedestrians or other types of transportation, which would allow creative and attractive forms of way finding or other features to be adopted. This shift to less cluttered streets would also create opportunity to "bring forward high quality, and high-density communities enhanced by open and green spaces," (Parsons Brinkerhoff, WSP, & Farrells, 2016, p.11). Figure 4 represents what a street could potentially look like when signage is removed, and when the public realm is focused on pedestrians. This model is very similar to a complete street design, where there are slow moving cars, increased street furniture, and greater use of landscaping. While this sort of design would only be possible on lower capacity roads, its methodology can be implemented throughout all different types of roadways.

Figure 4 - Street design demonstrating what minimal signage and enahnced open space would look like.

Curbside Management - Drop-off Zones

Curbsides are also going to be largely impacted by the adoption of AVs, and this will bring the need to increase, and rethink, curbside management. The biggest impact will be the need to implement drop off hubs. There will no longer be a need to park, drop-off zones will be a large part of successfully integrating AVs into society. As mentioned in "Planning for Autonomous Mobility," "if AVs shift the priority from parking to drop-offs, on street parking spaces may be retrofitted into drop-off lanes," (Riggs, Crute, Chapin, & Stevens, 2018, p. 43). This is another example of how the required infrastructure for AVs already exist, and the transition from traditional uses to AV oriented uses can be both cost efficient and effective. In a video discussing easy policy and design solutions to help cities prepare for the AV transition, it references the ability to convert "parking spots and valet zones" into AV drop-off and pick zones, and ultimately eliminate the need for parking (Brulte & Company, 2017). This establishes the notion that AV street design elements and infrastructure can be cost effective and retrofitted from old infrastructure.

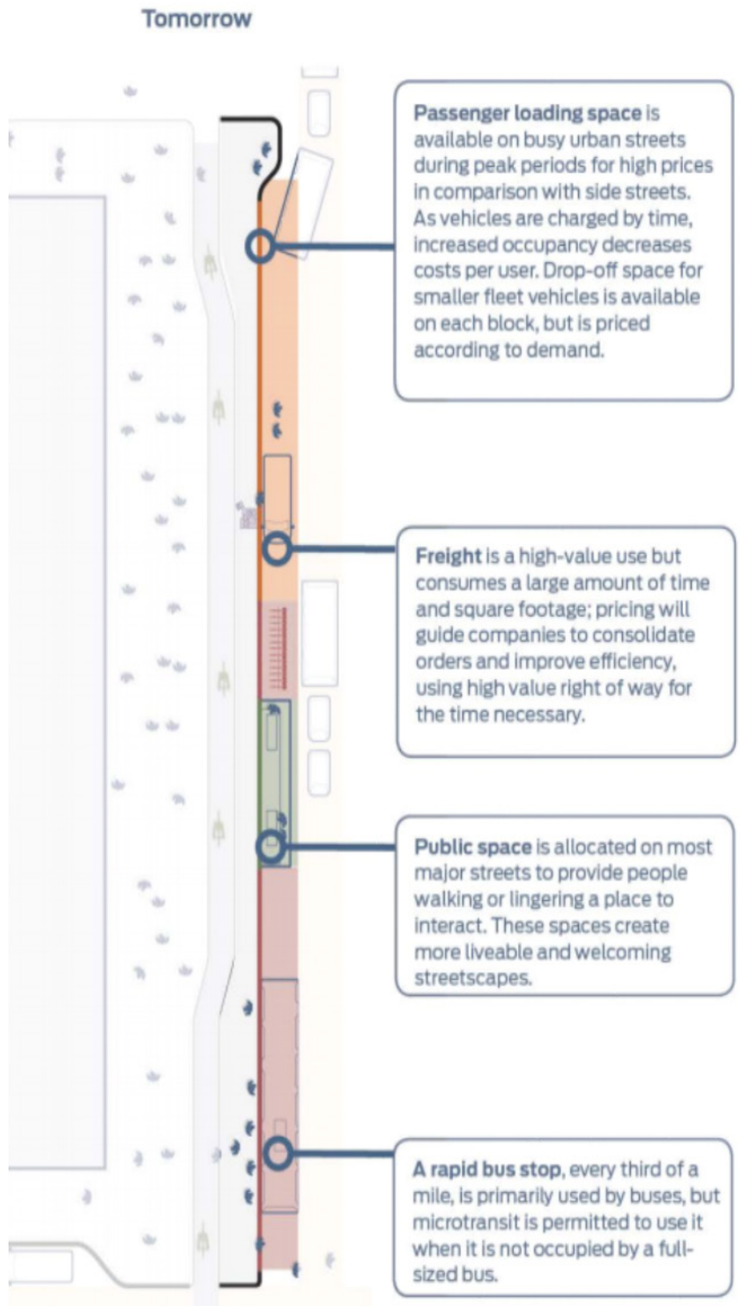


Figure 5 - Coding the curb for a multitude of uses (NACTO, 2017, p. 57)

Cubside Managment - Code the Curb

Digitally visible curbsides increase legibility and democratizes curbside access, while safe guarding safe function of the roadway. In the future, curbsides will serve a variety of functions throughout the day; ranging from bike share stations, kiosks and even vendors. Curbs can then be managed and priced by the city to generate revenue. Real-time curbside management can create a more dynamic and nimble system which would give private companies and public agencies more tools to get the most out of their curbside space (NACTO, 2017,

p.57). Figure 5, from Blueprint for Autonomous Mobility, depicts how a curbside can be managed in numerous different ways. Due to the removal of unnecessary parking, this renovation of new space will then be priced and optimized. An example would of this would be if a city wishes to prioritize ride share or public transportation, then the price for low occupancy vehicles would be higher. Ultimately, coding the curbside will allow cities to support the values of their community, receive revenue, and improve the dynamics and flow of their streets.

Curbside Management - Mobility Hubs

Similar to drop-off and pick-up zones, mobility hubs will encourage ride-share and coordinated trips with other people while limiting the need for on street parking. Medians, curb space, or simple signage can be used to indicate these hubs. The hubs can be permanent or non-permanent depending on the need, creating flexibility when needed, like if there is an event, and significantly improve the dynamic of the street (NACTO, 2017, p. 24).

Parking

The shift into an AV oriented roadway will greatly reduce the need for parking and may be one of the most noticeable changes within cities. Since there will be a much smaller demand for parking, an additional 15-20% of developable area will be opened in urban centers (Parsons Brinkerhoff, WSP, & Farrells, 2016, p. 10). While cities become more compact due to infill development, travel demand and distances will also decrease (Fulton, Mason, & Meroux, 2017, p. 3). Pedestrians, bicyclist, and other forms of transportation will benefit from denser development, and it will contribute to the general livability and desirability of the area. In an article published back in 2013, How will driver-less cars affect our cities, Issi Romem speaks on the fact that the densified urban landscape will become more walkable, and new generation of walkable locations will be created (Romem, 2013). While the benefits of less parking are clear, it is only speculated about how much developable space will actually be available, depending on what percent of AVs will be shared use. In an estimate done by Nelson Nygaard & Perkins + Will, parking demand would "decrease by 80% in a scenario in which 100% of our vehicle fleet is shared. If automobiles continue to be private mobility resources, parking demand might drop far less dramatically, though the space required to store private vehicles still might shrink," (Nelson Nygaard & Perkins + Will, 2016, p. 7). This relates back to the previous section on the topic of shared mobility, and mobility hubs, and reinforces the idea that a truly successful future with AVs must involve shared mobility. While surface parking can be easily developed, non-surface parking, such as parking structures, are much more challenging to retrofit into a different use. Parking structures are frequently located in urban centers and throughout other parts of a city, and it is expected that autonomous vehicles will disrupt the $100 billion industry of worldwide parking (Brulte, 2017). In the article Preparing Communities for Autonomous Vehicles, it is speculated that parking garages will, "become highly automated and serve double-duty as recharging stations," (Coyner & Henaghan, 2018, p. 17). While this will require electrical infrastructure to be installed, it will still create a use out of the space which would otherwise become unfeasible to develop. This would essentially create hubs for AVs to charge and dock within dense areas and reduce the need to build any additional infrastructure.

Lane Width

Figure 6 - Example of a typical city street (left) and of a city street oriented towards autonomous vehicles (right). Reduced lane width increases the public realm and allow for street furniture and larger sidewalks.

With the adoption of AVs, there will be less room needed for them to safely navigate our streets. "Sensors will allow autonomous vehicles to travel closer together than human-controlled vehicles, reducing the necessary pavement width and freeing up space for wider sidewalks, bike lanes, and other amenities," (American Planning Association, 2018). Figure 6 shows how smaller lane width and a more dynamic flow of traffic can completely transform the streetscape, as well as the public realm around it.

With AVs, widths of ten feet or less will suffice, while streets without large transit vehicles can be even smaller. In the long term, lanes should not be demarcated by markings, but instead take on the form of a complete street; street is flush with the sidewalk, and elements such as textured pavers and other street calming elements should be implemented. However, this transition into smaller lanes will have to take place over an extended period due to non-autonomous vehicles still navigating the roads. As mentioned in Planning for Autonomous Mobility, "as AVs are adopted, all roadways may be designed with narrower lanes, which will leave more space for bicycle and pedestrian facilities, active streetscapes, or green spaces," (Riggs, Crute, Chapin, & Stevens, 2018, p. 41). These elements will elevate the experience of the street as a public space and promote other forms of mobility.

The reduction of lane width will also translate into decreased intersection size, protected bike lanes, widened sidewalks, medians, street furniture, and other elements that could be implemented to increase safety, slow traffic, and invigorate the streetscape (NACTO, 2017). The addition of medians would allow pedestrians to cross in shorter length intervals and provide a space to wait between vehicles, while protected bike lanes would make active transportation easier for the public; both would increase street safety significantly. Additional elements such as kiosks and street furniture could also incorporated within this newly created space and further create a

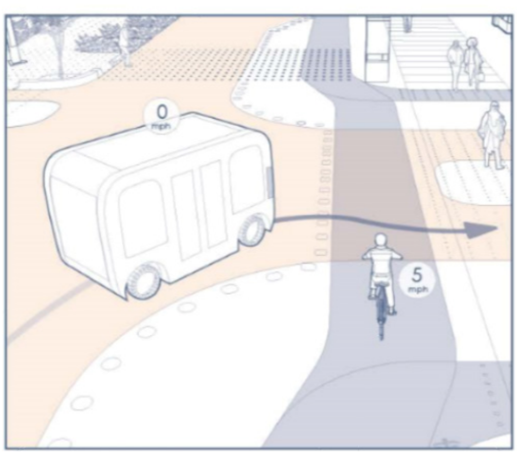


Figure 7 -"Cycling Through Intersections" (NACTO, 2017, p. 44)

Conclusion

While the future of autonomous vehicles may hold some level of uncertainty, there is no doubt that there will need to be a transition in the way we plan and design our streets. Principles of pedestrian and autonomous vehicle-oriented design will need to be implemented in order to increase the livability of our cities. Streets should be organized in a way that can be easily crossed, with a prioritization of public transit, desensitized low-occupancy vehicles, protected bike lines and wider sidewalks to incorporate street furniture and seating for restaurants. In a future where autonomous vehicles are correctly planned for, the public realm will be an active and lively place, with safety, accessibility and functionality as a priority.

The streets of the future may take on numerous forms, however, this report will focus on three possible outcomes: A mixture of AVs and regular cars, all private AVs, and AVs with shared mobility. Each scenario will utilize the design elements established in the earlier sections while incorporating methodologies shown in the case studies. There is no single way to successfully plan for the AV revolution, however the models presented in this report will illustrate street design methods suitable to each scenario and highlight the opportunities and constraints of each possible outcome. Overall, these models will demonstrate the possible urban transformations that can take place when planning for autonomized streets.

Autonomous vehicles are frequently associated with the idea of "smart cities". Smart cities will incorporate new technologies, such as artificial intelligence, smart connected devices, renewable energy, and autonomous vehicles, as shown in Figure 8, to solve many of the issues cities currently face (AXA, 2017). Creating infrastructure to support these new technologies can be a slow process, and in the instance for autonomous vehicles implementation, only a few cities have taken that first step. The following case studies, Masdar City and Google's Smart Neighborhood in Toronto, will examine what initial actions are being taken in order to prepare cities for the autonomous revolution.

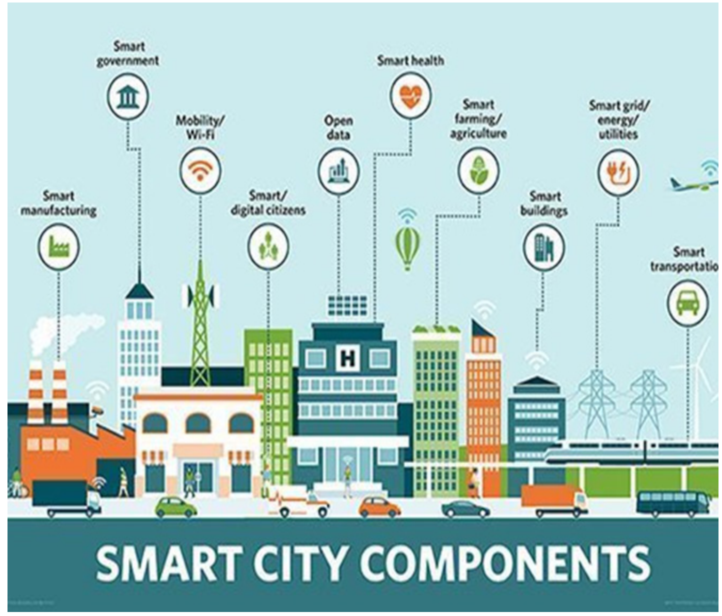


Figure 8 - Key Components to a functioning Smart City.

Masdar City

Masdar City is in Abu Dhabi and is built on the three pillars of economic, societal and environmental sustainability. Initiated in 2008, the City has taken on the challenge of becoming the world's most sustainable eco-city through smart investments. Masdar Institute of Science and Technology, a research university that focuses on cutting-edge solutions in the field of sustainability and energy, is located at the center of the city. New businesses, schools, restaurants and apartments are built around the nuclei, and when complete, "40,000 people will live in Masdar City, with an additional 50,000 commuting every day to work and study," (Mubadala, 2018).

Masdar City has already successfully accomplished implementing a Personal Rapid Transit (PRT), Figure 9, which is operational 18 hours a day, runs underground, and meets their commitment of sustainable transportation. Now, as the City is continuing to grow, they are implementing a new, above ground, autonomous vehicle fleet in 2018. "The Autonom Shuttle (see Figure 11) is a self-driving electric vehicle dedicated to first and last-mile transportation. It has a top operational speed of 25 kilometers per hour," (Bridge, 2018). The fleet of autonomous vehicles can carry a maximum of 12 people, follows a specific route, and provides continuous all-day service between the parking area and the main area for the 4,500 people currently living and working in the City.

Figure 9 - The vision of Masdar City.

cand working in the City.
While there are only seven Autonom Shuttles expected to be operational in 2019, over the next decade they expect self-driving transport to “become a staple of everyday life,” (Ryan, 2018). Masdar City is an excellent case study due to its dedication to alternative forms of transportation, and its focus on shared mobility. Ibrahim Sarhan Alhmoudi, acting executive director of the Abu Dhabi Department of Transport’s Surface Transport Sector, believes that “by eliminating the need for drivers we will eliminate the risk and improve the quality of life for us all,” (Ryan, 2018). By embracing shared and autonomous mobility, Masdar City expects huge economic and social benefits and its ideologies should be used as a model when planning for the autonomous revolution in all cities.

Figure 10 - Personal Rapid Transit (PRT) operating in underground tunnels.

Figure 11 - Autonom Shuttle

Google Neighborhood - Toronto

Sidewalk Labs, who works under an offshoot of Google parent Alphabet, is transforming a Toronto neighborhood into a complete community. They plan to “merge the physical and digital realms, creating a blueprint for the 21st-century urban neighborhood. The neighborhood will prioritize place making, with an adaptable mix of building uses and amenities that stay active at all hours of every day,” (Sidewalk Labs, 2017). Figure 12 shows the 800-acre waterfront neighborhood where this project is taking place, named Quayside, with an estimate of about a billion-dollar investment to bring these innovations to scale (The Intercept, 2018).

Sidewalk Labs, who works under an offshoot of Google parent Alphabet, is transforming a Toronto neighborhood into a complete community. They plan to “merge the physical and digital realms, creating a blueprint for the 21st-century urban neighborhood. The neighborhood will prioritize place making, with an adaptable mix of building uses and amenities that stay active at all hours of every day,” (Sidewalk Labs, 2017). Figure 12 shows the 800-acre waterfront neighborhood where this project is taking place, named Quayside, with an estimate of about a billion-dollar investment to bring these innovations to scale (The Intercept, 2018)

Figure 12 - Toronto waterfront property being developed into a smart city, Quayside.

This project is very similar to Masdar City in the sense that they are building a smart city from the ground up while implementing smart planning tactics and technology. Focusing more on the autonomous vehicle integration side of it, they share the same goal of shared mobility as Masdar City, however, they hope to completely restrict private vehicles in the area. Quayside is already at risk of becoming a car-dominated area due to the proximity to two major highways, and to achieve walking, cycling, and transit like dense downtown neighborhoods, they are considering numerous methods to promote these alternative modes of transportation. The street grid will, "be designed specifically for pedestrians, cyclists, and shared, self-driving vehicles," (Sidewalk Labs, 2017, p. 144). Many of the design element noted earlier, such as complete street like designs, connected technologies, and coding the curb will be integrated, as well as a major reduction of parking to promote other forms of mobility. Figure 13 shows what an active street in this neighborhood could look like, emphasizing the idea that it is designed for the pedestrians and bicycles, not cars.

Figure 13 - Complete street design.

The network of autonomous vehicles in Quayside will be a Taxibot Network, and will support door-to-door services, discounts for low-income residents, and serve high volume routes with multi-passenger self-driving vans, (Sidewalk Labs, 2017, p. 148). These services, along with other basic ridesharing services, will be deployed by Waymo and other providers such as lyft. The emphasis on shared mobility in Quayside is extremely significant, and Figure 14 demonstrates how an area similar in size, Greater Toronto Equivalent, needs approximately 37,600 private cars, 59 buses, and 8 street cars to serve their community in contrast to the 1,440 shared taxibots and 456 Vanbots in Qauyside. With fewer cars on the road and a focus on shared mobility, there will be a reduction of conflicts between cyclist/ pedestrians and vehicles, almost no need for parking, all of which will promote cleaner and more sustainable environment.

Quayside demonstrates how smart and connected technologies can create a unique and sustainable neighborhood. By implementing both policy and design elements associated with the autonomous revolution, Sidewalk Labs establishes the idea that urban areas can function both effectively and sustainably without privately owned cars. As a case study, it is clearly important to recognize that this neighborhood would not be successful without shared mobility. Both Quayside and Masdar City have the benefit of starting from scratch, with investments geared toward smart and sustainable technology. While other cities will have the opportunity to slowly incorporate smart technology into their infrastructure, the success of autonomous vehicles will stem from the emphasis and prioritization of shared mobility.

	Greater Toronto Equivalent	**Eastern Waterfront Projected**
Automobiles	37,600 Private Cars	1,440 Shared Taxibots
Local Transit	59 Buses 8 Streetcars	456 Vanbots

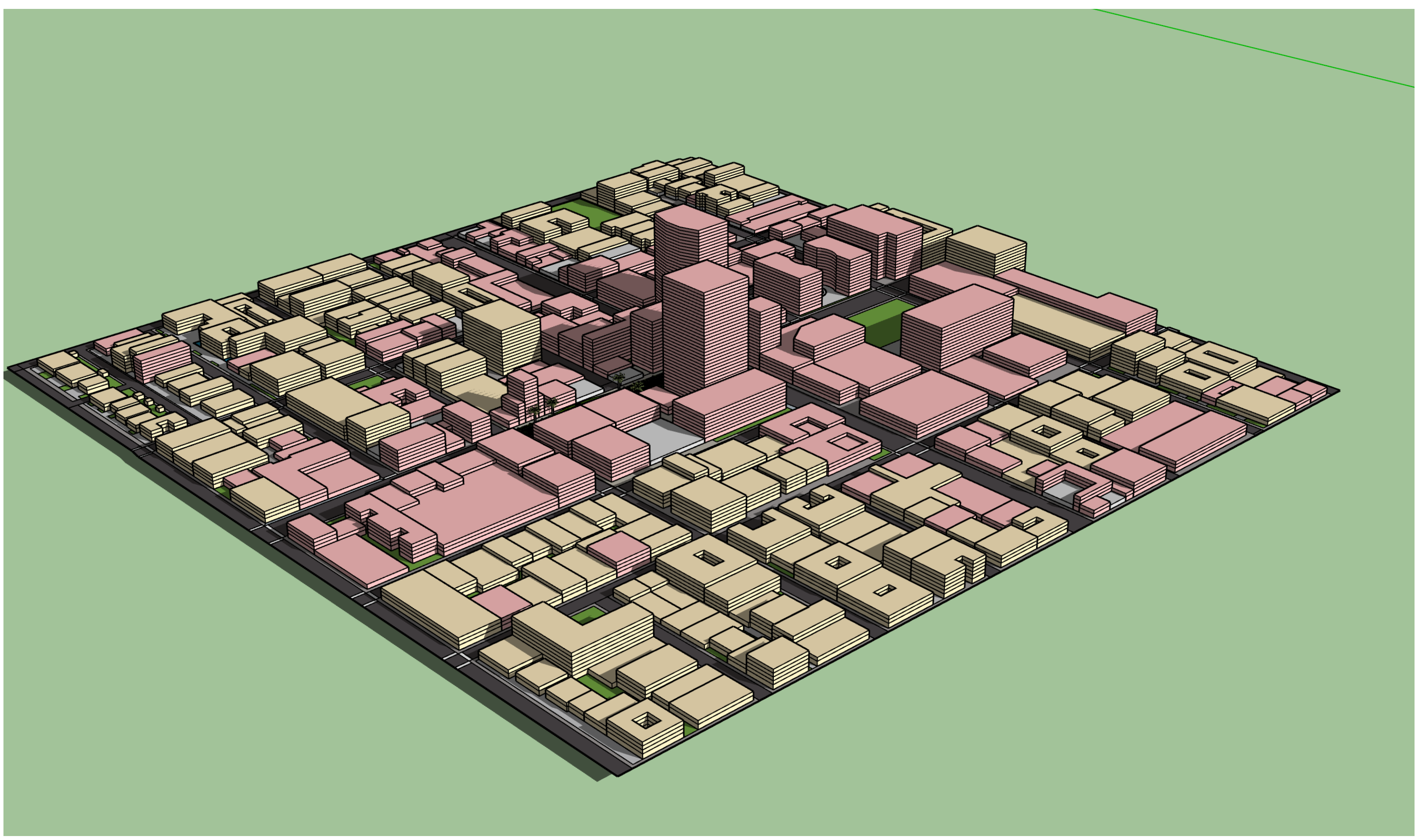
Figure 14 - Comparing two neighborhoods of equal size (Quayside left) and their estimated vehicular use (Sidewalk Labs, 2017, p. 149)

Design Scenarios

As autonomous vehicles begin to integrate into our mobility network the urban landscape will transform. This section of the report will conceptualize three different scenarios of autonomous vehicles transforming the urban landscape. Scenario 1: 100% shared autonomous vehicles. Scenario 2: 50% shared autonomous vehicles and 50% traditional vehicles. Scenario 3: 100% private autonomous vehicles and traditional vehicles A 4x4 block will be used to demonstrate how parking and infill development will differ between each scenario. Additionally, there will be three different street types represented within this area; Urban Center, Commercial Neighborhood and Residential. Each street will be modeled using the design elements discussed in the background and case study section of this report.

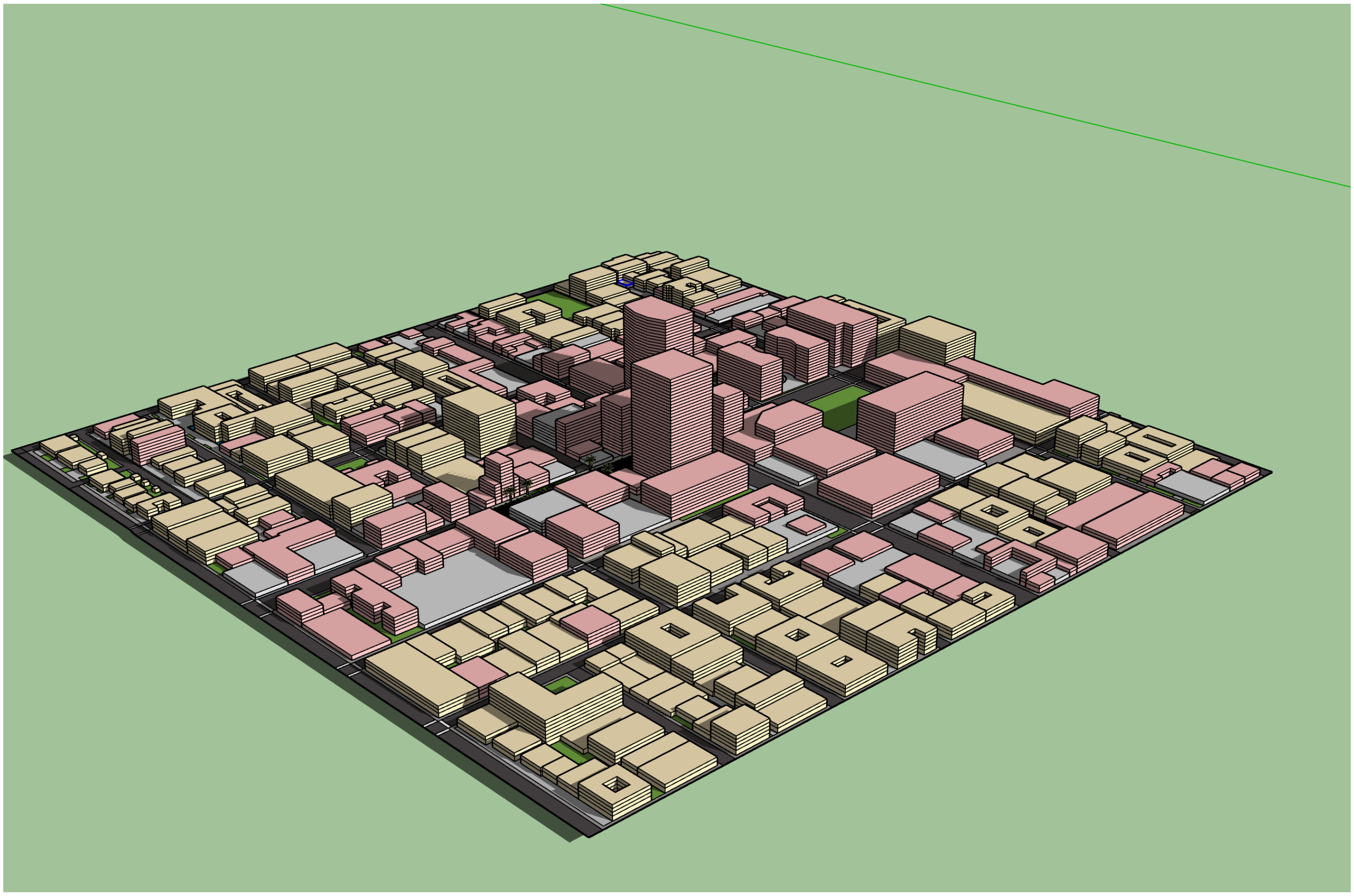
To estimate the effect autonomous vehicles will have on infill development, an urban area from LA was re-created to use as a base line and the gross floor area, number of parking spots and apartments was calculated using the extension Modular in SketchUp. The estimate that a fleet of 100% shared AVs would reduce parking by 80% (Nelson Nygaard & Perkins + Will, 2016, p. 7), was used for scenario 1 and halved for scenario 2. Additionally, the new developable space created was added to residential and commercial at a ratio of 1:3. This is due to larger amounts of parking being located in the urban core and being surrounded by commercial land uses. On-street parking and private parking was not calculated in these models, therefor, infill development has a larger effect on commercial areas rather than residential.

1) 100% Shared AVs



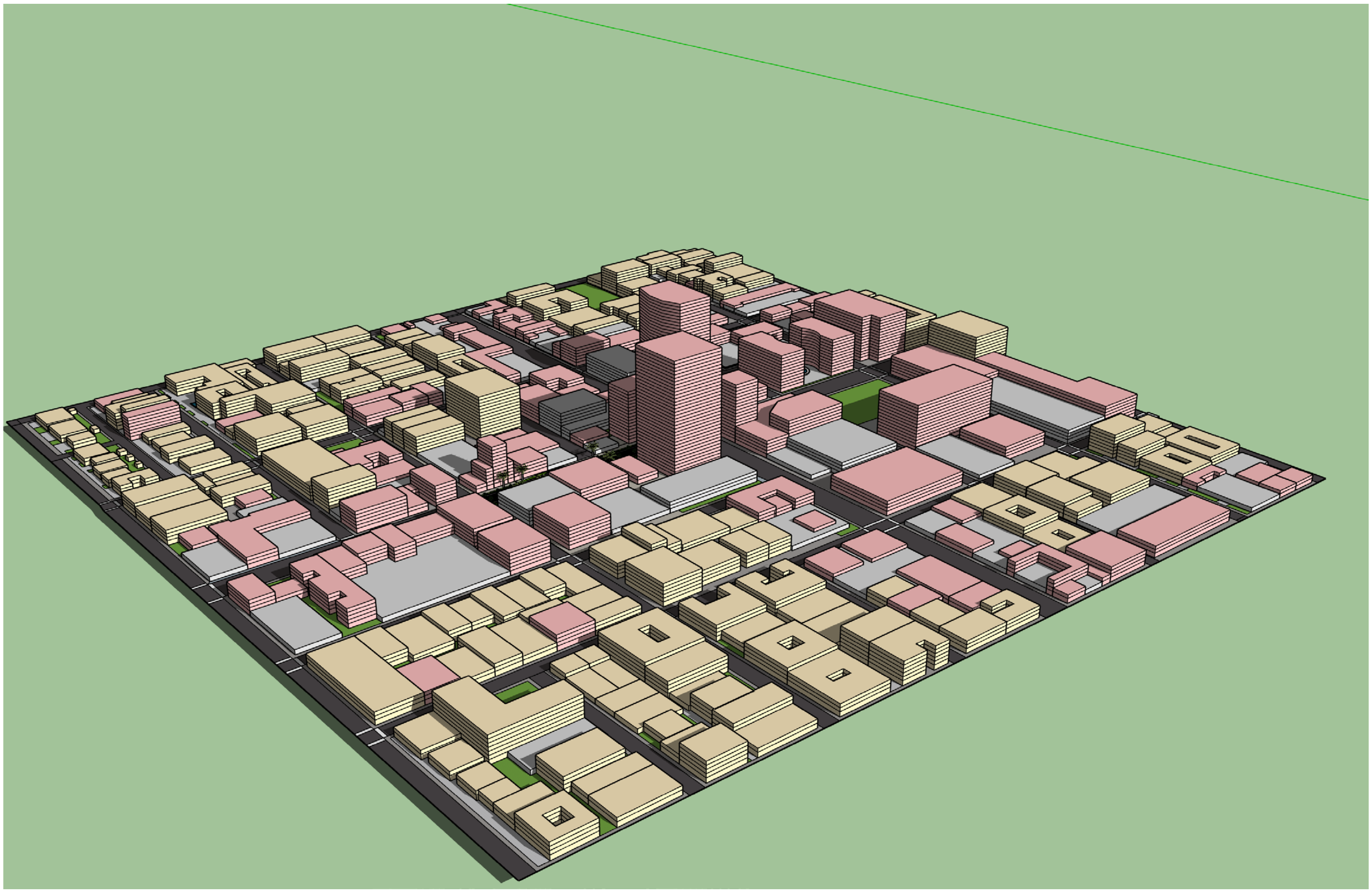
Land Use	Gross Floor Area (ft²)	# of parking spaces/apartments	Difference to Base Line Area/# of parking spaces and apartments
Parking	413,800	1,538	-1,655,200/-6149
Residential	8,207,680	10,180	+551,680/+680
Commercial	9,702,860	N/A	+1,102,360

2) 50% Shared AVs and Traditional Vehicles



Land Use	Gross Floor Area (ft²)	# of parking spaces/apartments	Difference to Base Line ft²/#
Parking	1,241,400	4,612	-827,600/-3075
Residential	7,931,840	9,840	+275,840/+340
Commercial	9,150,680	N/A	+551,180

3) 100% Private Private AVs and Traditional Vehicles



Land Use	Gross Floor Area (ft²)	# of parking spaces/apartments
Parking	2,069,000	7687
Residential	7,656,000	9,500
Commercial	8,599,500	N/A

These models demonstrate that significant infill development can occur when shared autonomous vehicles are the preferred choice of transportation.

Design Scenarios - City Center

Scenario 1

Shared mobility and public transportation will transform urban centers into green, accessible and attractive spaces. Using the center lanes for public transportation and single lanes for shared autonomous vehicles, much of the public space will be reclaimed for the pedestrian. Sidewalk widths will increase and more space will be dedicated to pedestrian amenities, such as seating and kiosks, or the space can be used by businesses. Landscaping and green infrastructure can help the city address the Urban Heat Island affect while providing more shade and a space for people to enjoy. This scenario also would create streets to be easily crossed and there would be much greater connectivity between blocks. Instead of "jaywalking," pedestrians would be able to safely cross the street at any point and go directly to their destination. Bike lanes would be protected and would make active transportation easy and safe for everyone.

Scenario 2

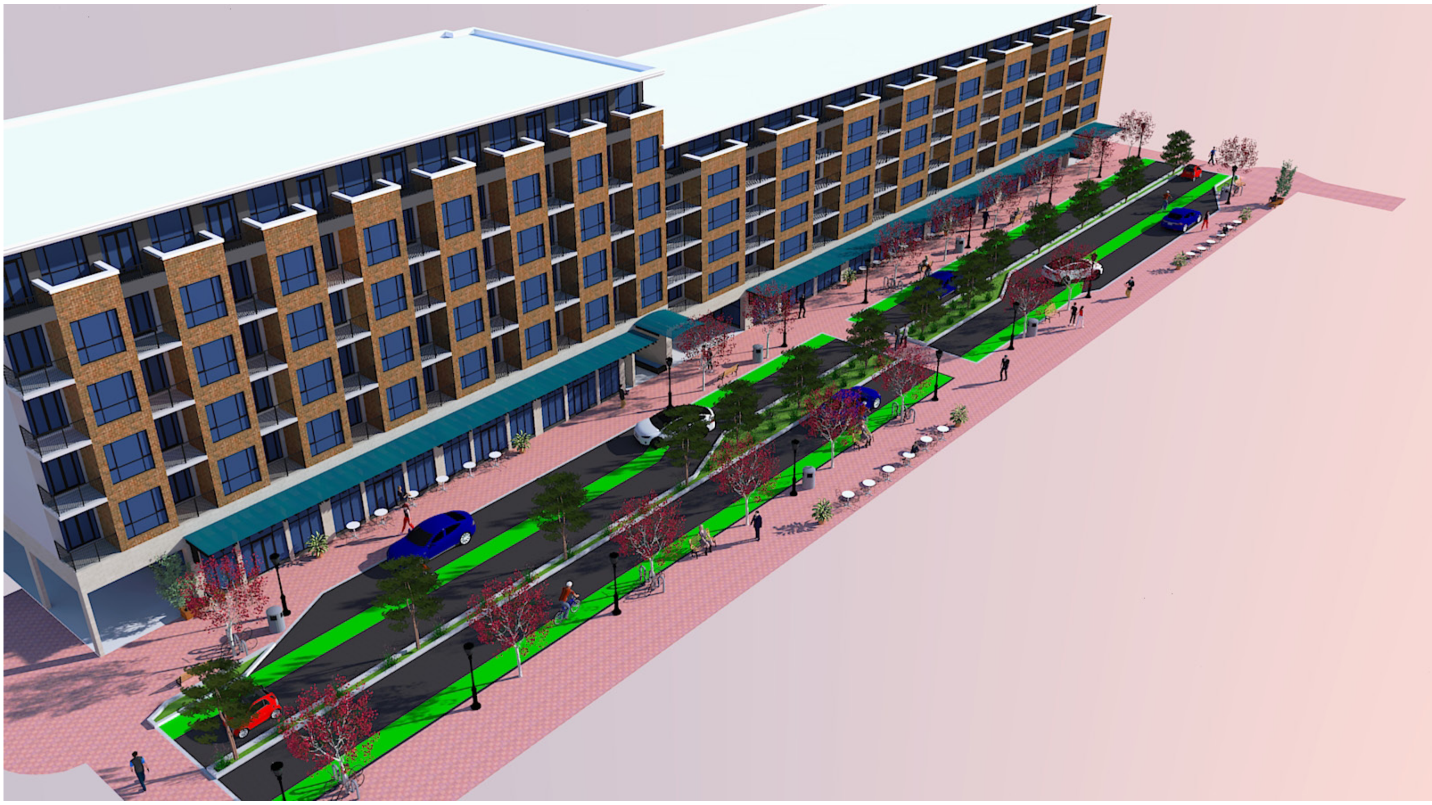
In this scenario, lane width would have to be large enough to accommodate non-autonomous vehicles, but the streets can still prioritize shared mobility by coding the curb. Street parking in the urban center could be restricted based off the time of day and what the city wishes to use the curb for. Both shared and private autonomous vehicles can use the right lane for drop off and pick up and the private autonomous vehicles can be instructed to park elsewhere in the city. This incentives shared mobility and makes private autonomous vehicle owners deal with the burden of paying for parking elsewhere. Traditional vehicles will also be forced to park elsewhere if the city chooses to restrict street parking.

This scenario also requires more signage and less streetscaping to occur when compared to the 100% shared-mobility scenario. Operators of traditional vehicles will still need to use way finding and traffic signals to safely navigate the street, however, streetscaping elements that were present in the 100% shared mobility scenario can still be incorporated into this scenario.

Scenario 3

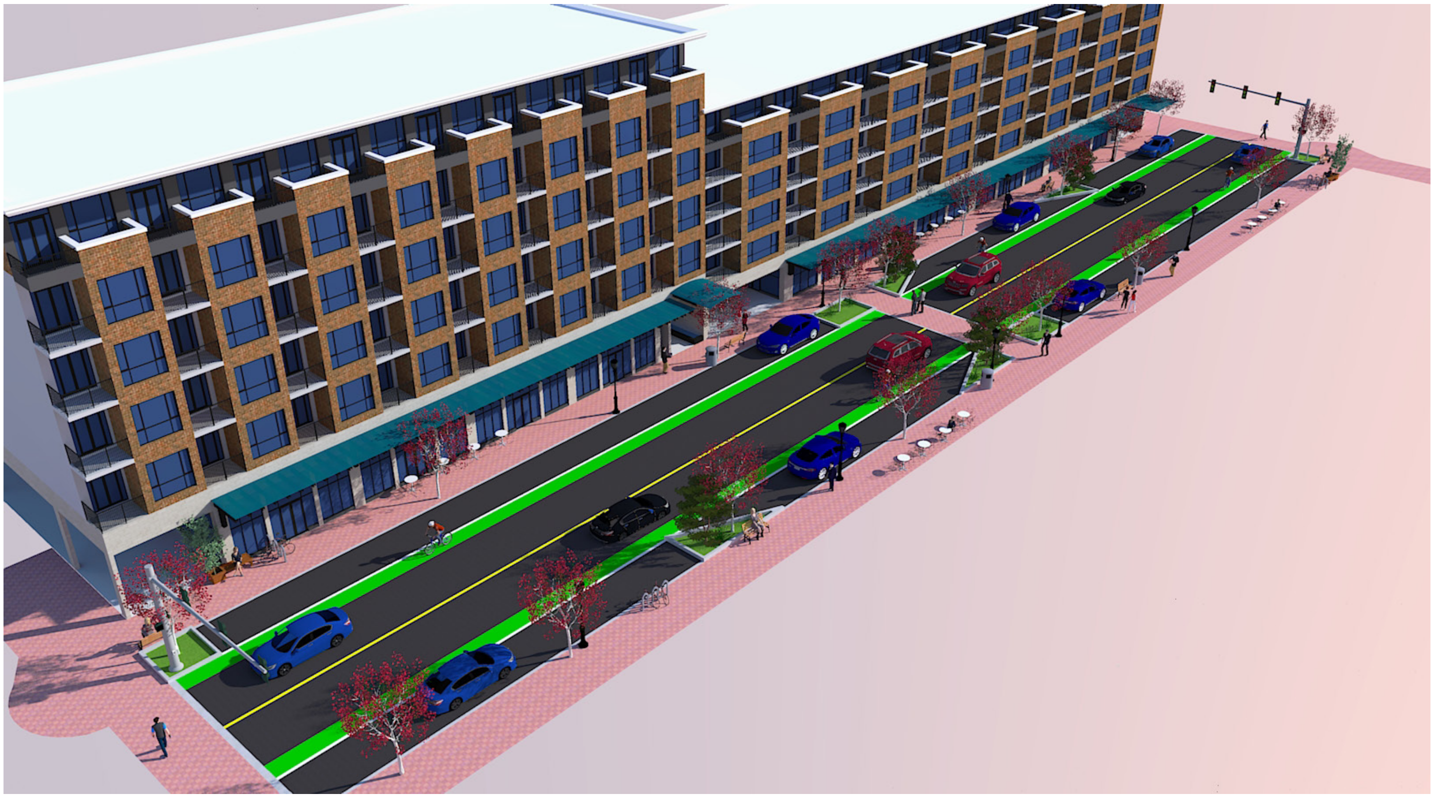
In a scenario where there is 100% private autonomous and traditional vehicles, the public realm will be car oriented. When comparing this scenario to the other two, the biggest difference would be the requirement for on-street parking in the city center and less space pedestrians and bicyclists. Public transit would not be prioritized and instead there would be bumper-to-bumper traffic and much higher travel times (Fulton, Mason, & Meroux, 2017). Lane width would increase while sidewalk width would decrease in order to accommodate parking. Cities would have the option to code the curb but it would not be to incentivize shared mobility or public transportation, instead it could be used for freight or as a revenue source for better parking.

Scenario 1



This scenario shows an active neighborhood commercial street. The wide sidewalks allow for the businesses on the street level to put out movable seating and create a lively place. The wide sidewalks allow the addition of streetscaping amenities like trash cans, benches, and bike racks, while also being wide enough for people to comfortable pass each other. The street is one lane each way with the addition of a mobility hub for easy drop-off and pick-up.

Scenario 2



The street can remain active and pedestrian oriented by reserving half the street for shared AVs and limiting parking. Bike lanes will now border the parking/drop off and pick lane which can create collisions, however, street speeds will remain low therefor increasing safety. Businesses can still utilize the sidewalk for temporary seating or merchandise display, however, some space will be taken up due to the need for vehicular signage and way finding.

Scenario 3

This scenario shows a car oriented street, raised sidewalks with a width over around 4ft. The street is much more difficult to cross and bikes now have to share the road with cars rather than having their own lane. Additionally, businesses no longer have room to utilize the sidewalk for seating or merchandise display.

Scenario 1

In a 100% shared AV scenario, a residential street becomes a space for residents to enjoy and connect with their neighbors. Children can safely play on the street and the overall aesthetic is improved by an increase in landscaping and green infrastructure. Due to the increase in public spaces bioswales can be installed along the streets to help reduce storm water runoff and create a more sustainable neighborhood. Garages can be converted into additional dwelling units (ADUs) to create a new revenue stream while the driveways can be used as recreational space. A single lane is used for one-way traffic and creates a safer place for everyone.

Scenario 2

This scenario shows a one way street, with a reduction of sidewalk space used for parking. This street is still very active and traffic calming measures are still present. Permeable surfaces can be used to delineate parking while helping with storm water run off. Lane width would increase in order to accommodate traditional vehicles and some garages and driveways would be used for vehicular storage.

Scenario 3

This scenario is car oriented and shows a two-lane residential street. The street is no longer a place for people to enjoy and the public realm has decreased significantly. Parking becomes a necessity and many street calming elements are gone. Sidewalk widths are severely decreased.

What can cities do to promote a future with shared autonomous mobility?

Cities can invest in public and active transportation infrastructure, update policies to restrict parking, promote ride share, and implement streetscaping elements that enhance the public realm. This report illustrated three different scenarios of shared autonomous mobility adoption: first, 100% of the fleet as shared AVs; secondly, 50% shared AVs, private AVs, and traditional vehicles; and thirdly, 100% private AVs and traditional vehicles. In the first and second scenarios, shared AVs depend on a cities willingness to restrict parking. The reduction of parking allows for protected or wider bike lanes and an increase in sidewalk width, leading to an overall expansion of the public realm. These two scenarios demonstrated that streets can become active and safer than traditional streets by including street calming elements and an increase of green infrastructure and pedestrian amenities. This makes the streets a more enjoyable place while forcing cars to slow down and allow pedestrians to cross the street and shorter distances.

Coding the curb also plays an important role in a cities ability to encourage shared mobility and control curb access. Throughout the day, the curb can be used for freight, parking, mobility hubs, or events, and can change depending on a city's objective. Shared AVs will be promoted by supporting mobility hubs, allowing businesses to expand onto the curb space, and restricting parking. In addition to coding the curb, cities can create policies to restrict access of non-shared AVs in certain areas, such as an urban center or downtown. Without the need for parking in certain areas, parking lots can be used for infill development, cities will become denser and more sustainable, travel times will decrease, and shared AVs will become the ideal source of transportation.

Shared AVs can have an enormous effect on the urban landscape, and cities will dictate how this transformation will take place depending on their stance on certain policies. Restricting parking, investing in active and public transportation, creating mobility hubs and coding the curb will be essential in creating a future where shared autonomous vehicles are the primary choice of vehicular travel. This revolution of mobility will take place for numerous decades, but with a focus on shared AVs, cities will become more accessible, safer and desirable places.

Citations

Alonso-Mora, J., Samaranayake, S., Wallar, A., Frazzoli, E., & Rus, D. (2017, January 17). On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment. Retrieved November 29, 2018, from http://www.pnas.org/content/114/3/462

American Planning Association. (2018). Autonomous Vehicles. Retrieved December 6, 2018, from https://www.planning.org/knowledgebase/autonomousvehicles/
AXA. (2017, March 30). Retrieved December 15, 2018, from https://www.youtube.com/watch?time_continue=19&v=RKWuj1OlDPo

Bridge, S. (2018, October). Masdar City unveils first autonomous transport system. Retrieved December 15, 2018, from https://www.arabianbusiness.com/technology/406646-masdar-city-unveils-first-autonomous-transport-system

Brulte & Company. (2017, March 30). Retrieved November 18, 2018, from https://www.youtube.com/watch?time_continue=34&v=0t62Hv_0-s8

Brulte, G. (2017, August 25). Autonomous Vehicle Drop-off and Pick-up Zones. Retrieved November 18, 2018, from https://www.brulteco.com/autonomous-vehicle-drop-off-pick-zones/

Calvard, N. O. (2018, August 14). To Make Self-Driving Cars Safe, We Also Need Better Roads and Infrastructure. Retrieved November 27, 2018, from https://hbr.org/2018/08/to-make-self-driving-cars-safe-we-also-need-better-roads-and-infrastructure

Chapin, T. S., Crute, J., Riggs, W., & Stevens, L. (2018, September). Planning for Autonomous Mobility. Retrieved November 18, 2018, from https://planning.org/publications/report/9157605/

Coyner, K., & Henaghan, J. (2018). Preparing Communities for Autonomous Vehicles[PDF]. Chicago: American Planning Association.

Fulton, L., Mason, J., & Meroux, D. (2017). Three Revolutions in Urban Transportation [PDF]. UC Davis Sustainable Transportation Energy Pathways of the Institute of Transportation Studies.

Goguen, D., & J.D. (2016). Bike Accidents: Collisions With Cars at Intersections. Retrieved November 17, 2017, from https://www.nolo.com/legal-encyclopedia/bike-accidents-collisions-with-cars-29549.html

Jajal, T. D. (2018, May 27). Trusting Autonomous Vehicles: The Tech Behind The Hype. Retrieved November 20, 2018, from https://medium.com/@tjajal/on-trusting-autonomous-vehicles-the-tech-behind-the-hype-c06b8aae8822

Citations

Lombardo, J. (2018, January). How Will Autonomous Vehicles Impact How We Build Roads? Retrieved from https://www.forconstructionpros.com/asphalt/article/20985026/how-will-autonomous-vehicles-impact-how-we-build-roads

Mubadala. (2018). About Masdar City. Retrieved December 15, 2018, from https://masdar.ae/en/masdar-city/detail/About-Masdar-City

NACTO. (2017). Blueprint for Autonomous Urbanism [PDF]. New York: NACTO.
Nelson Nygaard, & Perkins Will. (2016). Autonomous Vehicles and The Future of Parking [PDF]. American Planning Association.

Parsons Brinkerhoff, WSP, & Farrells. (2016). Making Better Places: Autonomous Vehicles and Future Opportunities [PDF]. Parsons Brinkerhoff.

Romem, I. (2013, March 25). How will driverless cars affect our cities? Retrieved November 19, 2018, from https://meetingoftheminds.org/how-will-driverless-cars-affect-our-cities-6526

Ryan, P. (2018, October 23). Abu Dhabi's Masdar City launches self-driving shuttle service. Retrieved December 15, 2018, from https://www.thenational.ae/uae/abu-dhabi-s-masdar-city-launches-self-driving-shuttle-service-1.783230

Sidewalk Labs. (2017). Sidewalk Labs Vision Sections of RFP Submission[PDF]. Sidewalk Labs.

The Intercept. (2018, November 13). Google's "Smart City of Surveillance" Faces New Resistance in Toronto. Retrieved December 15, 2018, from https://theintercept.com/2018/11/13/google-quayside-toronto-smart-city/

Walker, J. (2018, October 29). The Self-Driving Car Timeline - Predictions from the Top 11 Global Automakers. Retrieved November 20, 2018, from https://www.techemergence.com/self-driving-car-timeline-themselves-top-11-automakers/