RETHINKING THE RIGHT-OF-WAY:
EXPLORING SEATTLE'S AUTONOMOUS FUTURE

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ABSTRACT

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This thesis works to investigate the potential effects autonomous vehicles may have on the built environment. The objective of this thesis is to creatively explore a future scenario in which there has been a total shift in mobility and autonomous vehicles have superseded traditional forms of transportation. In order to do so, this paper will be broken down into three major sections. First, this thesis begins by establishing a clear understanding of autonomous vehicle technology and the potential implications of these vehicles, with special attention being paid to the potential impacts on the built environment. Second, this thesis considers what role design should play in a transition to autonomous mobility. A part of this consideration includes the argument that design and design frameworks need to play a significant role in this transition. This section of the research also includes an examination of design frameworks which focus on designing urban spaces for autonomous vehicles, as well as evaluating case studies that have explored varying approaches to designing for the future of autonomous travel. The end result of this research is six right-of-way design proposals using the City of Seattle as a case study. Evidence from the first two sections of the paper is utilized in order to make research-informed design decisions. These research-based design proposals make an effort to bridge the gap that exists in the literature between those considering the functions and impacts of autonomous vehicles, and those considering the role of design in this transition.

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INTRODUCTION

Looking back, there have been several transportation innovations that have greatly impacted urban land use and form. Early on, street cars and subways had significant impacts on the built environment. They provided urban inhabitants with easy access to areas that were previously inaccessible and spurred new development along their routes.[1] After the streetcar, perhaps the most significant transportation transformation, which had a profound impact on urban form, was the mass production of the personal automobile in the 1920's. Since that time, automobiles have worked to completely reshape cities in the United States and wholly transform urban life. Like street cars and subways, they provided easy access to areas that were once out of range for urban inhabitants, resulting in far reaching urban sprawl and many other implications.[2] Many walkable cities were transformed into drivable cities as downtown streets were redeveloped in order to better serve automobiles. Parking lots and other auto related land uses spread across the landscape. Heavy traffic, congestion, and environmental degradation became a common aspect of everyday urban life. After WWII, massive investments in automobile infrastructure worked to exacerbate these changes. These investments introduced massive highways into the urban landscape, which tore through neighborhoods and contributed to significant urban sprawl, and some would argue, urban decay.[3]

Planners and designers have, to varying degrees, worked to understand and anticipate the potential changes these transportation revolutions would have on the built environment, with varying levels of success. In some cases, the best of intentions resulted in dire consequences. In others, planners and designers reacted too slowly to contribute successful design guidelines or ideas that addressed these changes. There have been some incremental steps taken that have begun to consider a future less reliant on automobiles. Urban designers have begun to look beyond the automobile by introducing elements into the right-of-way that prioritize people-centric spaces which accommodate walking and bicycling in addition to vehicular traffic.[4] Furthermore, transportation planners have begun to rethink urban mobility and have planned for improved public transportation in cities. However, even with all of these changes in mind, it seems clear that we are still headed towards a future where automobiles continue to dominate the urban landscape.

Perhaps then, what is needed in order to massively overhaul urban mobility and it's impacts on urban form is another major transportation innovation, which many believe

1 Warner, *Streetcar Suburbs : The Process of Growth in Boston, 1870-190.*
2 Schloemer, "The Impact of Cars on Cities."
3 St. Clair, *The Motorization of American Cities.*
4 Mustafa and Mustafa, "The Great Streets Movement."

we are on the brink of. This transformation, which may radically impact urban form and mobility, is the automation of automobiles. While there is much debate as to when, how, and to what degree automated vehicles will enter the market, is it widely agreed upon that future vehicular travel will eventually be fully automated.[5] When this occurs, it will provide planners and designers with a unique and important opportunity to potentially completely rethink the massive amount of urban land dedicated to vehicles. This shift provides the opportunity to radically reimagine the right-of-way, parking infrastructure, and public space across a multitude of scales, and now is the time that urban designers and planners should begin to explore this potential change, in order to be best prepared for this inevitable shift in mobility.[6]

THESIS OUTLINE & SCOPE

The objective of this thesis is to creatively explore a future scenario in which there has been a total shift in mobility and autonomous vehicles have superseded traditional cars. However, in order to make research-informed design decisions a base understanding of autonomous vehicles and the role of design in such a transition must be established. Given this, this thesis is divided into three major sections, each of which works to address one of these subjects.

First, this thesis begins by working to establish a clear understanding of autonomous vehicles. This engages an examination of some of the basics of these vehicles, such what autonomous means, where the technology stands today, and the potential benefits of this technology. Next, the focus shifts towards exploring how a transition to full autonomous mobility may occur, with special attention being paid to establishing the importance of a shared mobility solution. Finally, the bulk of this section is dedicated to exploring existing literature investigating how a system of shared autonomous vehicles may operate and what impacts this system may have on the built environment. This includes examining studies that have utilized advanced transportation models in order to understand the number of vehicles that may be needed in this shared system, the impact on parking demand and roadway capacity, and effects on the built environment. Ultimately, this information is used in order to establish a base scenario used to carry out the design exploration and scenario development.

Second, this thesis considers what role design should play in a transition to autonomous mobility. A part of this consideration includes the argument that design, and design frameworks need to play a significant role in this transition in order to ensure the mistakes that have been made in the past are not repeated. This section then focuses on design literature that considers establishing frameworks for designing urban spaces for autonomous vehicles. Finally, this section concludes

5 Flemming et al., "Automated Vehicles: The Coming of the Next Disruptive Technology."
6 Skinner and Bidwell, "Making Better Places: Autonomous Vehicles and Future Opportunities."

with analyzing four case studies that have explored varying approaches to designing for the future of autonomous mobility.

The end result of this thesis is six right-of-way design proposals using the city of Seattle as a case study. As previously stated, evidence from the first two sections of the paper is utilized in order to make research-informed design decisions. A basic methodology is established, followed by a site analysis of the chosen location. A baseline scenario is established based on how these vehicles may operate in a shared system, and a design framework is utilized in order to apply specific policies and principles to six chosen sites. For the purpose of this study one specific design framework, the *Blueprint for Autonomous Urbanism*, is used as a foundational framework guiding design decisions. In order to do so, a more in-depth analysis of this framework's policies and principles is conducted. Finally, six sites are chosen within the study area in order to explore how these spaces may transform after a shift to autonomous mobility occurs. The current conditions for these sites, as well as any predictions for how these spaces may transform while this technology advances, is presented. This is followed by introducing the proposed conceptual designs and establishing the reasons for which specific decisions were made. These research-based design proposals make an effort to bridge the gap that exists in the literature between those considering the functions and impacts of autonomous vehicles, and those considering the role of design in this transition.

CRITICAL STANCE

Now is the time for urban designers and planners to begin thinking about and preparing for a shift to autonomous mobility. Although this technology is still in its infancy, it is expected to advance rapidly, with some automobile manufacturers hoping to produce fully autonomous vehicles as early as 2019.[7] This shift could provide a unique opportunity to rethink how we utilize large portions of urban land, and as it currently stands, is not something most municipalities are prepared to address. A recent study found that only 6% of long range transportation plans in most major cities in the United States even being to consider the potential effects of autonomous vehicles.[8] Furthermore, it is crucial that design plays a key role in this transition, as design can be used as to tool to both inspire and to guide. Rethinking the right-of-way and other urban land dedicated to vehicular travel provides a significant opportunity to reconsider traditional urban form and make progressive changes across the board. However, as history has shown, if municipalities do not properly plan for this major disruption in urban mobility we may find ourselves once again in a place where urban designers and planners work to serve a system in which the use of a new transportation technology dominates and disrupts, instead of works to improve, the urban landscape.

7 Jenkins, "GM Investor Day Outlines Bold 2019 Plan for Self-Driving Cars."
8 Dupuis, Martin, and Rainwater, "City of the Future: Technology & Mobility."

UNDERSTANDING AUTONOMOUS TECHNOLOGY

LEVELS OF AUTONOMY & CURRENT TECHNOLOGY

From automatic braking and assisted parking, to adaptive cruise control and autopilot, there are several features currently being used by automobiles that fall on a spectrum of autonomous mobility. These various autonomous functions can lead to some confusion about what exactly autonomous means, especially when considering the safety and use of this technology. In order to make sense of these varying levels of autonomousness the Society of Automotive Engineers (SAE) has developed a classification system for self-driving vehicles, which was recently adopted by the United States National Highway Traffic Safety Administration (NHTSA).[9] NHTSA's adoption of SAE's classification system brings the U.S. Department of Transportation in line with a growing global standard.

This classification system defines six levels of automation, which auto manufacturers, tech companies, suppliers, and policymakers can use to categorize various autonomous systems. These six classifications are briefly defined in Figure 2.1.

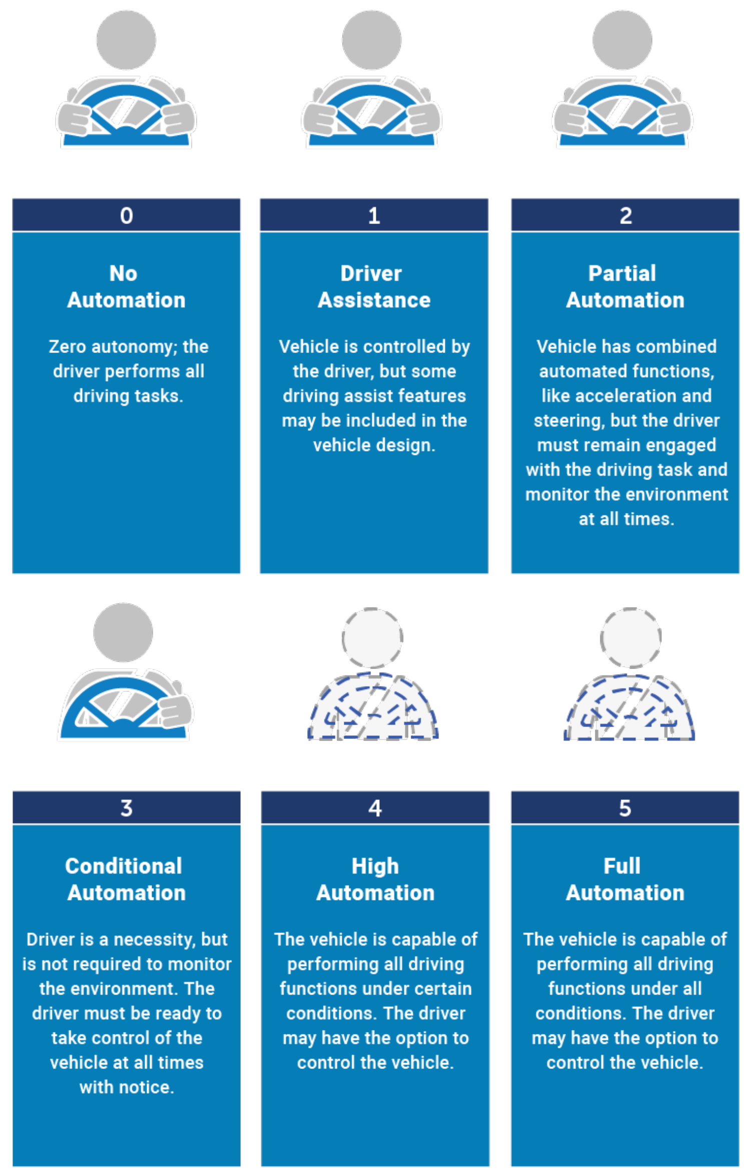


Figure 2.1: Society of Automotive Engineers Automation Levels (Source: Nhtsa.gov, 2018)

9 National League of Cities, "Autonomous Vehicles: A Policy Preparation Guide."

As Figure 2.1 shows, the classification system begins with level zero, *No Automation*. This category includes all standard vehicles on the road today. Level one, *Driver Assistance*, includes vehicles that under specific conditions can perform certain functions while the driver performs all other aspects of driving. These functions include automatic braking systems, adaptive cruise control, and lane-keep technology. One important aspect of level one automation is that the vehicle can assist the driver with steering or braking/acceleration, but never both at the same time.[10] Level two, *Partial Automation*, is where these systems become much more advanced, although they very in sophistication. This technology can include everything from vehicles that can park themselves to Tesla's controversial Enhanced Autopilot system. Although level two technology is able to control multiple driving functions of an automobile, the driver must be prepared at all times to intervene and immediately take control of the vehicle.[11]

The "jump in complexity" between level two and level three is perhaps the largest in SAE's classification system, due the fact that at the *Conditional Automation* stage autonomous systems are "capable of taking full control and operating independently during select parts of a journey when certain operating conditions are met".[12] Again, the driver is expected to remain available to regain control of the vehicle should the autonomous system encounter a scenario in which it is unable to navigate, but they are no longer required to monitor their surroundings continuously, as the vehicle would provide sufficient transition time. One example of this technology is Audi's Traffic Jam Autopilot, which takes full control of a vehicle traveling below 37 mph (60 km/h) on a limited-access divided highway with appropriate lane markings, and with another vehicle traveling directly in front.[13] This system goes as far as allowing the driver to watch TV on the heads-up display when it is engaged, and the company is currently seeking general road approval in the United States and Europe.

Vehicles that meet the level four, *High Automation*, benchmarks are those that are able to complete an entire journey fully autonomously. Drivers are not expected to intervene at any stage, and the ability to be able to manually drive the vehicle is not a requirement. However, it is expected that many level four vehicles may continue to feature driver controls, such as a steering wheel and pedals, as by definition these vehicles will have some constraints. These may be geographic, in that the autonomous use may to limited to or prohibited in certain locales, or they may be limited by other things such as maximum speed or extreme weather events.[14] Level four vehicles are those that are currently being tested across the United States by a variety of ride share, tech, and automobile companies, such as those featured in Figure 2.2.

10 National Highway Traffic Safety Administration, "Automated Vehicles for Safety."
11 Hyatt and Paukert, "Self-Driving Cars: A Level-by-Level Explainer of Autonomous Vehicles."
12 Hyatt and Paukert.
13 Halvorson, "We Let the 2019 Audi A8 Drive Itself with Traffic Jam Pilot."
14 Car and Driver, "Path to Autonomy: Self-Driving Car Levels 0 to 5 Explained."

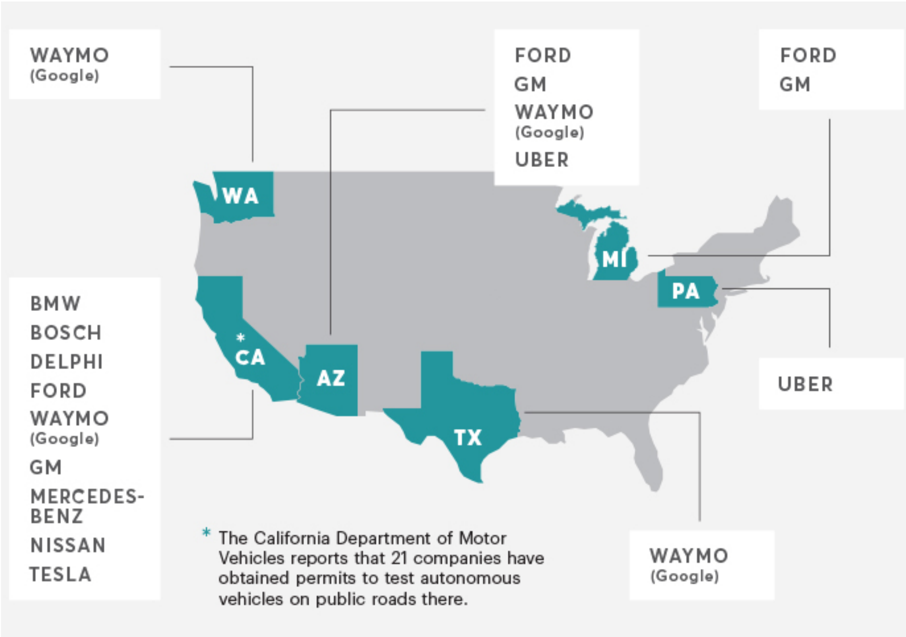


Figure 2.2: States Testing Autonomous Technology (Source: Consumer Reports, 2017)

Figure 2.3: Jaguar Electric I-PACE, Outfitted with Self-Driving Technology by Waymo (Source: The Atlantic, 2017)

Level four vehicles being tested by Waymo (see Figure 2.3), owned by Google's parent company Alphabet, lead the way in total autonomous vehicle miles traveled. In 2017 alone, these vehicles traveled two-million miles in autonomous mode, bringing their total autonomous miles traveled to four-million since 2009.[15] Is it expected that Waymo will ramp up their testing in preparation to launch a fully autonomous ride share service in 2020. Waymo estimates that their fleet of 20,000 all electric Jaguars will be capable of completing a million trips each day by that time.[16] Furthermore, Volvo plans on releasing a level four capable consumer grade vehicle in 2021.[17]

Finally, the level five automation classification *Full Automation* features vehicles that are capable of operating on any road and in any conditions which human driver could negotiate.[18] These vehicles would require no human intervention and would most likely not feature any manual driving controls. Level five vehicles would also not be limited by any geographical constraints. Passengers would be free to spend their travel time as they wish, never needing to focus on the road. No level five vehicles currently exist, and when they might enter the market is up for debate. Not only would these vehicles be technically capable of performing in a fully autonomous mode, state and federal regulations would need to allow their usage on public

15 Moon, "Waymo Drove 2 Million Autonomous Miles in 2017."
16 Madrigal, "Waymo Makes Most Important Self-Driving Car Announcement Yet."
17 Volvo Car Group Global Media Newsroom, "Volvo Cars and Autoliv Team Up with NVIDIA to Develop Advanced Systems for Self-Driving Cars."
18 Car and Driver, "Path to Autonomy: Self-Driving Car Levels 0 to 5 Explained."

roads. That being said, there are plans for these vehicles to enter the market soon. As previously stated Waymo plans to lunch its fully autonomous rideshare fleet by 2020, and General Motors (GM) currently has plans to produce a consumer version of their fully autonomous model *Cruise* in 2019.[19] This vehicle would not include any manual driving controls, as seen in Figure 2.4.

AUTONOMOUS TECHNOLOGY

In order to reach level five autonomy a combination of both new and old technology is needed in order to safely operate these vehicles. This technology includes equipment that is used to both visualize and interpret / react to the world around the vehicle. For visualization key components include cameras, radar, and lidar, each of which perform distinct functions, and at specific ranges, in the process of visualizing what is happening around an autonomous vehicle (see Figure 2.5). High-quality cameras can detect objects up to eight-hundred feet in distance, in order to keep the vehicle traveling safely. They do so by detecting the location of other vehicles, traffic signs and signals, lane markings, pedestrians and bicyclists, and more.[20] Radar, or radio detection and ranging, sensors work at both short and long ranges to determine the distance and speed of objects surrounding the vehicle. Finally, Lidar (light detection and ranging) sensors work to detect changes in light, such as brake lights, as well as changing road conditions. They also work in combination with data from

19 Hawkins, "GM Will Make an Autonomous Car Without Steering Wheel or Pedals by 2019."
20 Gilbertsen, "Here's How The Sensors in Autonomous Cars Work."

Figure 2.4: Interior of the GM Cruise (Source: San Francisco Chronicle, 2018)

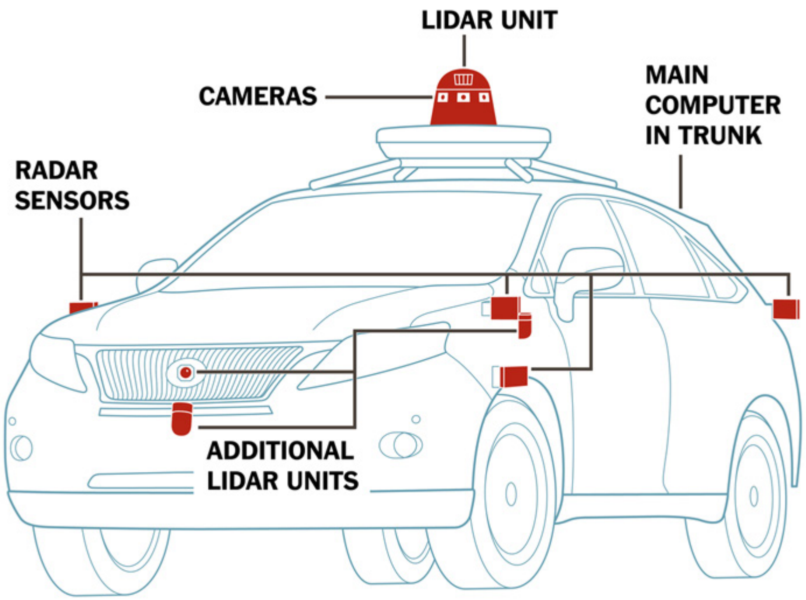


Figure 2.5: Autonomous Vehicle Technology (Source: The New York Times, 2017)

the cameras to create a 3D image of the vehicle's environment.[21] Typically, many of these visualization sensors are also built to be utilized as backup systems should other systems fail. Although all of this sensing equipment predates autonomous automobiles, many of these technologies have been significantly improved upon for these vehicles. For example, Waymo recently developed and introduced two totally new categories of Lidar in order to generate highly accurate 3D visualizations of the environment surrounding their autonomous vehicles.[22]

Once all the visual data is collected by the on-board sensors it needs to be processed for the vehicle to properly respond to surrounding conditions. This is done using advanced computational techniques, and at the center of it all is the vehicle's main computer. This on-board computer works to analyze all of the incoming visual information and then makes real-time calculations that provide instructions to the vehicle on how to operate. These instructions stem from advanced computational algorithms, which make complex and instantaneous decisions based on the incoming data.[23] These algorithms are constantly improving thanks to machine learning, artificial intelligence, and advances in computer science.

In addition to the visualization hardware and decision-making computer processes, there are two important components that work to safety guide autonomous vehicles. The first is a high-performance GPS system. Like traditional GPS systems, this feature works to provide the vehicle with location information and guidance instructions, but at a more precise scale. The second component is a vehicle to vehicle communication system. These systems are typically connected through the cloud and perform a variety of functions, including providing nearby vehicles with information that may be beyond the scope of their sensors. They can also work to share data in order for vehicles to learn collectively through machine learning.[24] Vehicles that speak to one another are known as connected-autonomous vehicles (CAVs). These CAVs have the potential to introduce additional benefits to autonomous mobility such as increased road capacity, however there are currently no regulations or policies in place that would require autonomous vehicles run by different companies to communicate with one another.[25] Should companies providing autonomous mobility solutions choose not to work together, these benefits may be lost.

21 Gilbertsen.
22 Korosec, "Waymo Reveals The Tech Inside Its Self-Driving Chrysler Minivans."
23 MIT Technology Review, "What's Driving Autonomous Vehicles."
24 MIT Technology Review.
25 Bansal and Kockelman, "Forecasting Americans' Long-Term Adoption of Connected and Autonomous Vehicle Technologies."

BENEFITS OF AUTONOMOUS MOBILITY

As previously stated, autonomous and CAVs promise many benefits for the future of mobility. These include social, transportation, environmental, and economic benefits. Several of these will be explored in greater detail in later sections, and for those benefits that will not be explored in greater detail, a brief overview is worthwhile.

Safety: Arguably the most significant benefit that would come from a total shift to autonomous mobility would be the substantial increase in safety. Although this is a bold claim, it is has been predicted that autonomous vehicles could have the potential to "eliminate most of the 93% of collisions that currently involve human error."[26] Furthermore, even when the reason behind a crash is attributed to something other than the driver, such as the vehicle, roadway, or environment, "additional human factors such as inattention, distraction, or speeding are regularly found to have contributed to the crash occurrence and/or injury severity."[27] Eliminating human error and inattention would not only work to make things safer for drivers and passengers, but also for pedestrians and bicyclists. This is extremely significant, especially when you consider that motor vehicle collisions are the number one cause of death in the United States for those aged 15-25. In 2015 alone, over thirty-five thousand people were killed in the United States as a result of motor vehicle crashes.[28] Any significant decrease in these numbers would work to establish autonomous mobility as a lifesaving technology.

Economic: Economic benefits would stem from a range of potential sources, one of which relates directly to safety. A study conducted by the National Highway Traffic Safety Administration found significant costs associated with automobile crashes. They found that in 2010 vehicle crashes cost "$242 billion in economic activity, including $57.6 billion in lost workplace productivity, and $594 billion due to loss of life and decreased quality of life due to injuries."[29] Reducing the majority of vehicle crashes could largely work to eliminate these costs. A 2013 report produced by Morgan Stanley found significant savings in a variety of areas. The widely cited report estimated an annual $158 billion in fuel savings, a $422 billion savings in productivity, and a $149 billion savings in congestion costs.[30] All of these savings were found to originate from the efficiency of autonomous travel. One point of concern for many is the potential loss of jobs due to the adoption of autonomous vehicles. While this concern has some merit, due to the fact that nearly five-millions Americans are employed in driving related professions, it is also important to consider the larger economic benefits of a transition to autonomous mobility. One recent study found that autonomous vehicles may generate $7

26 Flemming et al., "Automated Vehicles: The Coming of the Next Disruptive Technology," 16.
27 Fagnant and Kockelman, "Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations," 169.
28 National Highway Traffic Safety Administration, "Automated Vehicles for Safety."
29 National Highway Traffic Safety Administration.
30 Morgan Stanley, "Autonomous Cars: Self-Driving the New Auto Industry Paradigm."

trillion worth of economic activity by 2050.[31] This would include a significant amount of new job opportunities. So, while there may be losses in certain sectors, the overall economic benefit of autonomous mobility is positive.

Mobility: Autonomous vehicles may completely transform the lives of various groups of people who do not currently have access to personal transportation. This includes those who are unable to operate an automobile on their own, such as the 14% of the population that is registered disabled and the 25% of the senior population (over 65) that don't have a license.[32] There are also various other groups of individuals, such as those prohibited from driving or those unable to afford a car, who would benefit greatly from an increase in accessibility. This is especially important to consider when you acknowledge that for many "employment or independent living rests on the ability to drive."[33] One recent study found that in the United States autonomous vehicles may provide up to two-million new employment opportunities for those with disabilities.[34]

Environmental: One of the often-cited proposed benefits of autonomous vehicles is that they will be more environmentally friendly. Multiple studies have considered the environmental impacts of autonomous vehicles and what they identified was that compared to a traditionally driven vehicles, self-driving cars would result in significant reductions in greenhouse gas emissions, energy use, sulfur dioxide, carbon monoxide, oxides of nitrogen, carbon dioxide, and volatile organic compounds.[35,36] One of the major limitations of these studies is the fact that they failed to consider any electric, hybrid-electric, or other alternative fuel vehicles as part of their models. It is widely believed that as autonomous vehicle and battery technologies both advance, the majority of fully autonomous vehicles would move away from fuel combustion engines. While it is impressive that there are major improvements in emissions in these studies, given that they were conducted under the assumption that fuel technology would remain the same, it does seem as though these reports may be minimizing the potential environmental gains of a switch to a shared autonomous fleet by failing to include alternative fuel vehicles in their models. There was one study that did consider the fact that autonomous vehicles would most likely utilize alternative fuel sources, however it was not performed under the assumption of a fully shared autonomous system. This report compared the potential greenhouse gas emissions of a fleet of electric autonomous taxis to both 2014 conventional vehicles, and 2030 hybrid electric vehicles. What they found was that the autonomous taxi fleet would produce 87-94% less greenhouse gas emissions than 2014 vehicles, and 63-83% less than 2030 hybrids.[37]

31 Morris, "Autonomous Vehicles Will Have $7 Trillion in Economic."
32 Flemming et al., "Automated Vehicles: The Coming of the Next Disruptive Technology."
33 National Highway Traffic Safety Administration, "Automated Vehicles for Safety."
34 Ruderman Family Foundation, "Self Driving Cars: The Impacts on People with Disabilities."
35 Fagnant and Kockelman, "The Travel and Environmental Implications of Shared Autonomous Vehicles, Using Agent-Based Model Scenarios."
36 Martinez and Viegas, "Assessing the Impacts of Deploying a Shared Self-Driving Urban Mobility System: An Agent-Based Model Applied to the City of Lisbon, Portugal."
37 Greenblatt and Saxena, "Autonomous Taxis Could Greatly Reduce Greenhouse-Gas Emissions of US Light-Duty Vehicles."

THE PATH TOWARDS AUTONOMOUS MOBILITY

Perhaps two of the most encompassing and difficult questions to answer regarding a transition to autonomous mobility are when will this transition occur and who will own these vehicles? Part of the reason these questions are so difficult to answer is due to the rapid advancement of autonomous technology. In 2004, The Defense Advanced Research Projects Agency (DARPA), America's foremost military-research agency, organized a competition in the Mojave Desert to test the possibility of autonomous travel. At that time twenty-one teams qualified for the competition which "required driverless vehicles to navigate a 150-mile off-road course."[38] Due to a variety of mechanical failures and other mishaps only twelve of the twenty-one teams even made it across the starting line, and the vehicle that made it the furthest traveled a meager seven miles before catching on fire. Eighteen months later in the fall of 2005 DARPA again held this competition, this time with twenty-three teams competing. The second time around five teams were able to successfully navigate the entire 150-mile course, and all but one beat the previous year's record.[39] The amount of progress made in those eighteen months is exemplary of how quickly autonomous vehicle technology has progressed as a whole. Since that time DARPA has held additional and more difficult challenges, requiring vehicles to navigate complex urban environments, and each time autonomous vehicles were able to meet the challenge. Moreover, since those early competitions tech, automobile, and ride-sharing companies have begun mass testing of autonomous vehicles, and several of these companies have plans to introduce fully autonomous level-five vehicles in the next few years. With all of this being said, currently there are more questions than answers as to exactly when and how this transition will occur. There have however been several of studies that have worked to answer these questions, which will be briefly discussed below.

AUTONOMOUS VEHICLE TIMELINES

A report titled *Autonomous Vehicle Implementation Predictions: Implications for Transport Planning* is one of the most cited publications that attempts to predict the future sales of fully autonomous vehicles. This study bases their prediction on the distribution and adoption rates of previous vehicle technologies, such as airbags, GPS systems, automatic transmissions, and hybrid vehicles. Using this methodology, the author suggests that by the year 2050 autonomous vehicles will make up 50% of the total vehicle fleet, 90% of total vehicle sales, and 65% of all vehicle miles traveled.[40] While this is an interesting approach, there is one major disadvantage to

38 The Economist, "Autonomous-Vehicle Technology Is Advancing Ever Faster."
39 Defense Advanced Research Projects Agency, "The DARPA Grand Challenge: Ten Years Later."
40 Litman, "Autonomous Vehicle Implementation Predictions: Implications for Transport Planning."

this study, in that it treats autonomous technology as a new component of existing vehicular travel. Some have argued that this is not a legitimate approach, as a shift from traditional vehicles to autonomous vehicles more closely resembles other major shifts in mobility such as the shift from horses to combustion powered automobiles.[41]

There have been other studies within the academic literature that have taken different approaches to predicting when this technology may become the norm. Bansal and Kockelman from the University of Texas utilized a survey in order gauge respondent's willingness to pay (WTP) for this technology, and then used this information to create eight different scenarios to calculate potential adoption rates. These scenarios varied based on WTP, drops in technology prices, and changes in government regulations that support this technology.[42] A summary of these scenarios and their findings can be found in Table 2.1 and Table 2.2.

This study yielded interesting results, however, like most of the studies that attempt to predict autonomous vehicle adoption rates, it falls short in that it fails to account for a scenario in which a system of shared autonomous vehicles is adopted. In addition to conducting their own study, Bansal and Kockelman also performed a comprehensive literature review of other studies which considered autonomous vehicle adoption rates. A summary of their findings can be found in Table 2.3.

Scenario	Annual increase in WTP	Annual technology price reduction rate	Regulations
1	0%	10%	No
2	0%, but no zero WTP	10%	No
3	0%, but no zero WTP	5%	Yes
4	0%, but no zero WTP	10%	Yes
5	5%	5%	Yes
6	5%	10%	Yes
7	10%	5%	Yes
8	10%	10%	Yes

Table 2.1 - WTP rise, technology-price reduction, and regulation scenarios.
(Source: Bansal and Kockelman, 2017)

Scenario	2025	2035	2045
1	11.1	28.6	43.0
2	10.2	28.7	43.8
3	5.2	15.0	24.8
4	10.2	28.5	43.4
5	10.8	27.2	43.2
6	15.1	38.3	70.7
7	13.8	36.4	59.7
8	19.4	44.2	87.2

Table 2.2 - Percentage of Vehicles with Full Autonomous Technology
(Source: Bansal and Kockelman, 2017)

41 The Economist, "Autonomous-Vehicle Technology Is Advancing Ever Faster."
42 Bansal and Kockelman, "Forecasting Americans' Long-Term Adoption of Connected and Autonomous Vehicle Technologies."

Source	AV ownership & access forecasts / Sales & cost forecasts
Laslau et al., 2014	92% and 8% of world vehicles to have Level 2 and 3 automation in 2030 / Year 2030 revenues from Level 2 plus Level 3 sales: $21B for the U.S. and $20B for Europe
Morgan Stanley, 2013	Nearly 100% of U.S. light-duty vehicles are Level 3 and 5 vehicles by 2030 and 2055, respectively
Bierstedt et al., 2014	25% of U.S. vehicle fleet to be autonomous by 2035
IHS Automotive, 2014	Entire global fleet is expected to be to be fully-autonomous by 2050
Harrop and Das, 2015	The number of self-driving capable cars to reach 8.5 million by 2035 in the U.S
Rowe, 2015	100% of U.S. vehicles are Level 4 AVs by 2060
ABI REsearch, 2013	50% of all new vehicle sales to be Level 4 AVs by 2032
Mosquet et al., 2015	U.S. sales of Level 5 AVs will reach about 10% of all new light-vehicle sales by 2035
Alexander & Gartner, 2014	U.S. AV sales to reach around 18 million (or 75% of all light-duty vehicles) by 2035
Hars, 2014	90% of all person-trips in U.S. will be in Level 4 AVs by 2030, and car ownership will decline by 20% decline by 2030

Table 2.3 - Summary of Findings from Prior Autonomous Vehicle Adoption Studies.
(Source: Bansal and Kockelman, 2017)

Perhaps the most interesting aspect of these findings is how widely the results vary. For example, two different studies that consider the percentage of light-duty autonomous vehicle sales in the year 2035 come up with very different result at 10% and 75%. Furthermore, IHS Automotive predicted that the entire global fleet of vehicles would be fully autonomous by the year 2050, in stark contrast to Litman's 50% prediction. This again suggests just how difficult it currently is to accurately predict exactly when a full shift to autonomous mobility may occur.

One additional way of considering how autonomous vehicle market penetration may occur would be to consider when automakers plan on introducing autonomous features into their vehicles. While this does not provide a long-range timeline, it does provide an interesting perspective of how quickly things may begin to change. A recent survey of the top 11 global auto manufacturers was conducted to determine when they plan on introducing autonomous vehicles.[43] A summary of the results can be found in Figure 2.6.

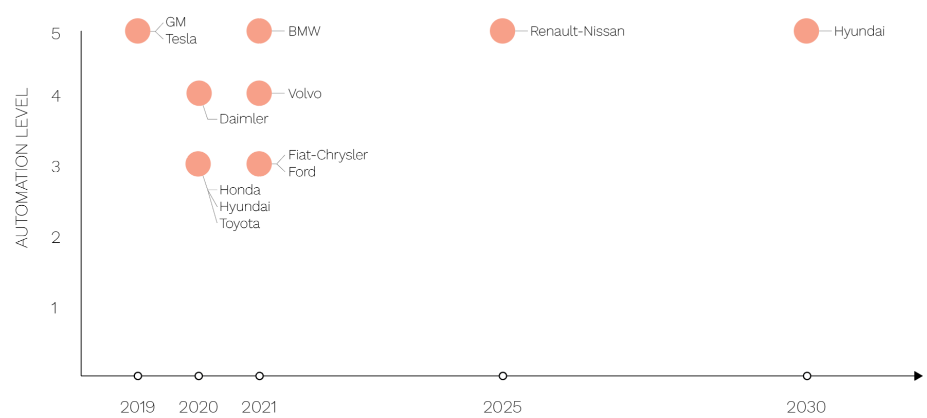


Figure 2.6: Timeline of Top 11 Global Auto Manufacturer's Autonomous Predictions
(Data Source: Bansal and Kockelman, 2017)

43 Walker, "The Self-Driving Car Timeline - Predictions from the Top 11 Global Automakers."

Ultimately, it is unlikely that any of the current predictions are fully accurate. At this point in time it appears that they are simply too many unknown variables to correctly predict when this transition may occur. Beyond the availability of these vehicles and consumers' willingness to utilize them, one of the most important variables to consider will be the implementation of federal, state, and local policies that either allow or limit the use this technology. A topic that is worthy of its own study, but as previously, stated lies beyond the scope of this research. One prediction that does seem to be well agreed upon is the inevitability that this technology, at some point in time, will completely transforming mobility as we know it.[44,45]

SHARED VS PERSONAL VEHICLE OWNERSHIP: WHY SHARING MATTERS

As with predicting an autonomous mobility timeline, the ability to predict who will own autonomous vehicles in the future is also a difficult. However, it is an important point to consider should we acknowledge the premise that a full shift to autonomous mobility is inevitable. Although this is a difficult prediction to make, that hasn't hindered individuals and organizations from attempting to forecast these ownership dynamics.

Financial Analysts at UBS utilized a cost-based approach to respond to this question, and their model predicted that by the year 2035 80% of people will use shared autonomous vehicles (vehicles that pick-up riders on demand, typically using a subscription-based service, but do not require passengers to share rides at the same time) in cities where they are accessible, and that urban car ownership will fall by 70%. They came to this conclusion based on the assumption that in the future shared autonomous services would cost approximately $0.70 a mile, which is significantly less than the $1.20 a mile it costs, on average, to run a private car.[46] The potential savings predicted for shared autonomous services compared to that of private car ownership could be one of the greatest benefits of autonomous mobility, if consumers are willing to adopt a transportation-as-a-service model (TaaS).

There are however others who do not believe that cost savings alone will be enough to sway consumers. Two authors cited personal belongings, diversity of form and function, loss of control, an overall decrease in the cost of owning a car today, and the appeal of new vehicle purchases as reasons why consumers may be unwilling to make the switch.[47] These authors go on to suggest these reasons alone could actually increase car ownership in the United States. This line of reasoning does not seem to be widely accepted in the literature, and there are some researchers that have refuted these claims. One such example

44 McCarron, "Autonomous Vehicle Adoption Is When, Not If, According to Industry Observers."
45 IHS Automotive, "Emerging Technologies: Autonomous Cars- Not If, But When."
46 The Economist, "Why Driverless Cars Will Mostly Be Shared, Not Owned."
47 Kurman and Lipson, "Why the Rise of Self-Driving Vehicles Will Actually Increase Car Ownership."

is a recently released report published by ReThinkX, a think tank co-founded by Stanford instructor Tony Seba and tech investor and philanthropist James Arbib. This study concentrated on cost savings as a means to reduced car ownership, and the authors claim that "the scale of the cost differential will override all other factors that influence consumer choice. Many of the perceived barriers to TaaS will be overcome as consumers are exposed to and experience" shared autonomous vehicles (see Figure 2.7).[48] The ReThinkX report goes on to make additional predictions including:

- Private car ownership will drop 80% by 2030 in the US
- The number of passenger vehicles on American roads will go from 247 million in 2020 to 44 million in 2030
- Using electric ride-shares will be four to 10 times cheaper per mile than buying a new car by 2021 (And each family could save up to $5,600 per year, compared to purchasing and maintaining a traditional vehicle)
- Global oil demand will peak at 100 million barrels per day by 2020, and decrease to 70 million barrels per day by 2030
- Savings on transportation costs will result in a boost in annual disposable income for US households totaling $1 trillion by 2030[49]

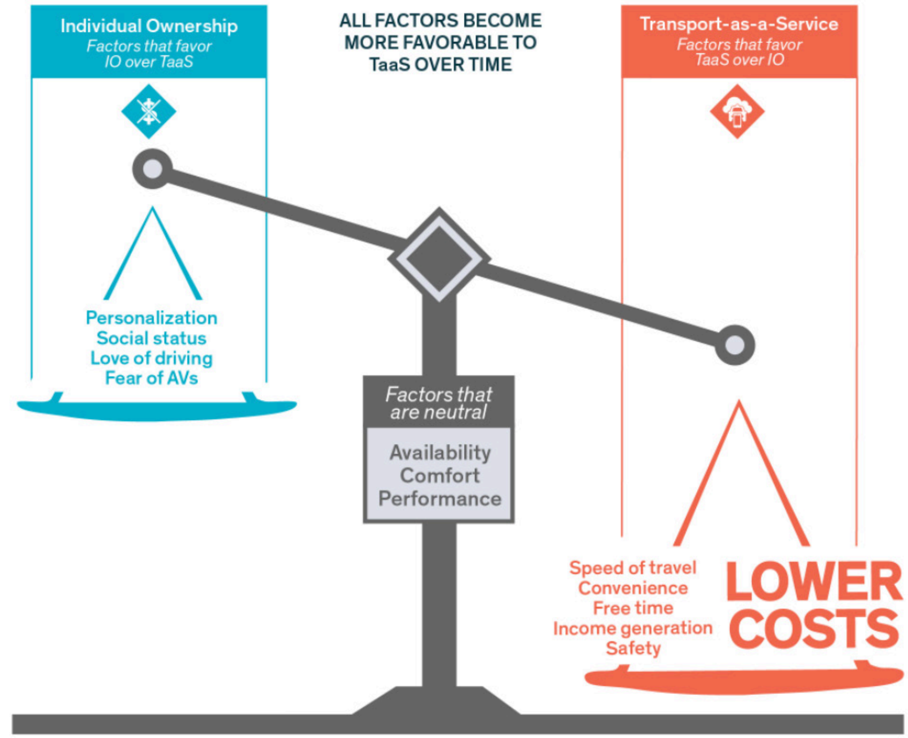


Figure 2.7: Factors Affecting Consumer Choice (Source: Seba & Arbib, 2018)

48 Arbib and Seba, "Rethinking Transportation 2020-2030," 24.
49 Arbib and Seba.

The response to the question regarding who will own autonomous vehicles will have far reaching impacts, which may transform every aspect of mobility, our urban fabric, and society as a whole. As Jeff McMahon, a University of Chicago lecturer and writer for Forbes, summarized it:

> "Autonomous vehicles could be a blessing for society if they are electric and shared, a disaster if gasoline-powered and individually owned. In the blessing scenario, carbon emissions plummet, traffic lightens, accidents and fatalities disappear, and vast expanses of roadway and parking space open to reuse. In the disaster scenario, emissions increase, gridlock strangles cities, people become more obese and diseased as their robot cars do everything for them."[50]

Many of the proposed benefits of autonomous mobility hinge upon this outcome. As many of the benefits are a shared autonomous system are addressed in the next section of this chapter, the impacts of the potential drawbacks of the opposite are worth mentioning here. As previously stated, a "disaster scenario" in which autonomous vehicles are owned in a similar fashion as traditional automobiles today would potentially result in dire consequences. First, overall environmental quality could significantly decrease due to a substantial increase in overall vehicle miles traveled. In this scenario these vehicles may travel a substantial number of miles empty as they would travel back and forth the meet the needs of a single owner. Traffic is also expected to increase, thanks in part to the increase in vehicle miles traveled. The amount of traffic that could result from private ownership has been described as "walls of autonomous vehicles with few gaps that could divide communities" and create an urban environment in which "people could be relegated to inconvenient and unpleasant pedestrian bridges."[51] Finally, one other enormous concern could be a significant increase in urban sprawl. This would be due to the fact that vehicle occupants "would be free to engage in other activities during the trip, in turn reducing the time costs of travel and facilitating urban sprawl."[52]

With all of these potential consequences in mind, it is worth considering if there are other ways, beyond cost, that consumers might be swayed to make a switch to a shared system. It has been suggested that policy solutions could be one avenue worth pursuing. Government could end or severely limit existing effective subsidies for private car ownership and replace them with subsidies for shared vehicles.[53] It has also been suggested that in order to discourage private driving in cities curbside parking could be fully eliminated and replaced with passenger / cargo loading and unloading zones. Finally, cities could further limit private driving by establishing a maximum number of "cars that its streets can support and install a form

50 McMahon, "How Car Sharing Can Save The World From The Autonomous-Vehicle Robot Apocalypse."
51 National Association of City Transportation Officials, "Blueprint for Autonomous Urbanism," 11.
52 Millard-Ball, "Pedestrians, Autonomous Vehicles, and Cities," 2.
53 Leslie, "Will Self-Driving Cars Usher in a Transportation Utopia or Dystopia?"

of congestion pricing potent enough to ensure that this number isn't exceeded."[54] This type of policy might also work to ensure that shared autonomous vehicles only circulate while empty when absolute necessity.

In addition to policy solutions, it is believed that providing consumers with a vision of what a shared autonomous system may look like could also work to nudge them towards accepting this type of scheme. This includes providing them with both visual representations of how the built environment may change, as well as how these vehicles may function.[55] The first of those suggestions is the focus of the third section of this document, and that potential future will be explored in depth there. On the vehicle side of things, the design firm Ideo recently presented a compelling conceptual vision of how shared vehicles may operate. At the heart of this concept is a futuristic glassy four-seater minivan that can "toggle between ride sharing and car sharing."[56] Although this concept may be viewed as an idealistic version of the future, it is one that is within the realm of possibility, and it is the designer's hope that it will inspire both potential passengers and automotive companies (see Figure 2.8).

Figure 2.8: Ideo's Conceptual Vision of a Share Autonomous Future (Source: Wired, 2017)

54 Leslie.
55 Grabar, "How Will Self-Driving Cars Change Cities?"
56 Stinson, "IDEO Provides a Fascinating Glimpse at How We'll All Carpool in 2027."

IMPLICATIONS OF A SHARED AUTONOMOUS SYSTEM.

Due to the novelty surrounding autonomous vehicles, there has yet to be a study that fully captures every aspect of how a shared autonomous vehicle system would function. The majority of the research being conducted on this type of system tends to focus on one or two aspects of autonomous technology. With this in mind, in order to obtain a comprehensive understanding of this technology, at least in regard to the limits of this research, it will be necessary to survey existing research from different perspectives. Combining these varying perspectives should help to provide a base understanding of how autonomous vehicles may impact the built environment, and what role designers and planners might play during this transition.

A significant number of studies within this arena focus on one key topic, working to understand how a switch to an autonomous fleet may impact the total number of vehicles needed to meet the needs of an urban population. These studies, and their findings, vary considerably in a variety of ways. Many utilize real world traffic modeling, while others use simulated urban environments. The style of shared system, as well as market penetration rates also vary significantly. The findings of these studies are significant for this research, as they, along with other studies, will be used to establish an informed scenario for my design case study. These studies are also significant due to the fact that the number of vehicles on the road directly impacts other variables which have the power to impact urban form, such as roadway capacity and parking demand.

TRAFFIC MODELING: REAL WORLD DATA

Real world scenarios make up the bulk of these studies and propose circumstances that are somewhat similar; a 100% market penetration rate and a switch to a fleet of shared autonomous vehicles. Based on this scenario, Dia and Javanshour used real world traffic data in order to gauge the number of autonomous vehicles that would be required to serve the needs of Melbourne, Australia. They modeled two different scenarios, one in which there was no wait time before being picked up, and one in which there was a five-minute wait time before being picked up by the vehicle. Under the five-minute model they found that compared to the base case scenario modeled on current behavior (human-driven single-occupant vehicles) there would be an 88% reduction in the number of vehicles in the network.[57] The author's model also predicted that under this scenario there would be a slight (10%) increase in total vehicle kilometers traveled, due to the fact that these vehicles would at times drive empty in order to best reposition themselves. However, the authors note that this increase in travel would likely be mitigated by increased travel and vehicle efficiency. Finally, although the authors admit that there are

57 Dia and Javanshour, "Autonomous Shared Mobility-On-Demand: Melbourne Pilot Simulation Study."

several limitations to this model, such as that it fails to consider future shifts in travel choice in the age of autonomous mobility, or the impacts on light & heavy rail and public transport buses, this study is very well organized and comprehensive. The authors even justify the shared vehicle system by citing a recent study that found that over half of millennials stated that they prefer public transportation and vehicle sharing over owning their own automobile.[58]

Three additional studies that consider a switch to a fleet of shared autonomous vehicles under a 100% market penetration rate were conducted using real world traffic data from Berlin, Singapore, and Ann Arbor, MI. In the case of Ann Arbor, the authors of the report *Transforming Personal Mobility* found that a fleet of 18,000 shared autonomous vehicles could replace the 120,000 conventional vehicles that were driven only in the city and less than 70 miles per day. This is an 85% reduction in vehicles needed to serve this population.[59] Burns and colleagues also found that their model exhibited very little empty vehicle driving, and a significant reduction in cost per mile of driving the autonomous vehicles (as low as $.41/mile) compared to conventional vehicles ($1.65/mile). Unfortunately, the authors in this study did not consider the end cost of a consumer participating in this service.

In the Berlin study, Bischoff and Maciejewski looked at trips made in conventional vehicles that originated and ended within city limits, representing approximately 35% of all trips taken by any mode each day. Although this is only slightly more than one-third of all trips, these trips still account for roughly 1,100,000 conventionally driven vehicles. What they found was the about 100,000 shared autonomous vehicles could replace all of the conventionally driven vehicles, a more than 90% reduction.[60] This is particularly impressive when you consider that the authors did not include any empty vehicle repositioning to meet potential forecasted demand in this study, and still found that the average wait time would be two minutes and twenty-eight seconds.

In the Singapore study, the authors proposed a model very different from what others have been considering. While the previous studies considered the number of vehicles required to replace an existing personal automobile fleet, in this study the authors have proposed a “new and potentially transformative transportation solution” in which these shared autonomous vehicles are not just replacing conventional vehicles, but all current modes transportation.[61] What they found was that a fleet of 300,000 autonomous vehicles would be required in order to meet the entire travel demands of the city, replacing conventionally driven vehicles, taxis, buses, and subway lines. Although this fleet would replace all current modes of transportation, the authors still compared the size of this autonomous fleet to the number of conventionally driven

58 Zipcar, “Zipcar’s Annual Millennial Survey Shows the Kids Are All Right”
59 Burns, Jordan, and Scarborough, “Transforming Personal Mobility.”
60 Bischoff and Maciejewski, “Simulation of City-Wide Replacement of Private Cars with Autonomous Taxis in Berlin.”
61 Ballantyne et al., “Toward a Systematic Approach to the Design and Evaluation of Automated Mobility-on-Demand Systems : A Case Study in Singapore.”

vehicles in the city today (779,890). This is still a 62% reduction and would keep wait times under ten minutes. This study did however have another interesting component, in that it took an extensive look into the potential cost of service of an autonomous fleet. The authors performed this analysis not only for Singapore, but also for the United States. What they found was that in 2014 the average cost of owning and driving a vehicle in the United states was $11,315 per year, and that the estimated cost of service for a shared autonomous vehicle was $9,728 per year. These numbers do not include the hidden costs of driving, such as the value of time, parking, maintenance, tickets, and license fees. When you included these hidden costs into the final calculation, the true cost of a shared autonomous vehicle is 1/3 of a conventionally driven car.[62]

In addition to the studies that employed a 100% market penetration rate and a switch to a fleet of shared autonomous vehicles, there were also two other real-world studies that examined fleets of shared autonomous vehicles, but at lower penetration rates. Researchers in Austin, TX looked at the 12x24 mile urban core of the city and utilized a low 1.3% market penetration rate. Using these parameters, they found that one shared autonomous vehicle could replace 9.3 conventional vehicles. Average wait times were less than one minute, and for 94.3% of trips wait times were under 5 minutes.[63] These researchers also found that as market penetration increased wait times and empty miles traveled would decrease, while the number of conventional vehicles each autonomous vehicle could replace would increase. In another study, researchers utilized traffic data from Zurich, Switzerland, and a 10% market penetration rate. Here, the researchers found that with wait times up to ten minutes, and no vehicle redistribution, one shared autonomous vehicle could replace ten conventional vehicles.[64] One important thing to consider about this 90% reduction, is that it was achieved even in a study scenario that utilized a city far less dense than many others within the literature. Because these trips are more spread out, a few aspects of the fleet changed. While on average most other studies found that the peak usage of the vehicles was between 97-99% and the vehicles were utilized for around 16 hours each day, Boesch and colleagues found that in Zurich peak usage was 70% and the autonomous fleet was utilized for approximately eight hours each day.

These real-world studies are particularly encouraging. The majority of studies identified an 85% or greater decrease in the number of vehicles needed to meet the demands of an urban population, should that population switch from personal automobile ownership to a system of shared autonomous mobility (see Figure 2.9). It is however important to acknowledge that there are limitations to each of these studies. These traffic models were often limited to specific geographic boundaries, did not acknowledge potential shifts in travel mode, and did

62 Ballantyne et al.
63 Fagnant, Kockelman, and Bansal, "Operations of Shared Autonomous Vehicle Fleet for Austin, Texas, Market."
64 Boesch, Ciari, and Axhausen, "Autonomous Vehicle Fleet Sizes Required to Serve Different Levels of Demand."

not factor in the potential for some users to reject a shared system. Studies that limit the models to trips made within a specific section of the city, or to those that start and end within city boundaries may fail to consider the impacts out of town commuters might have on a new shared autonomous system. Should autonomous travel become extremely affordable it may be likely that users of other modes, such as biking or public transportation, might make the switch. In this case it could considerably increase demand and alter these models in a substantial way. Sharing is also another limitation. While in an ideal world all users of conventional automobiles would switch to a shared system, it is likely that there would still be users who would rather just pay more to own their own autonomous car. A mix of privately owned and shared autonomous vehicles could potentially diminish these reduction numbers. To their credit, many of the studies directly address these limitations, and recognize that more information, unfortunately including much that is currently unknown, would be needed to fully understand a switch to shared autonomous vehicles. In their Austin, TX study, Fagnant and colleagues state: "to fully understand the vehicle replacement implications, mode choice and vehicle ownership models are needed, as well as a greater examination of travel outside" of the established boundaries of the study.[65]

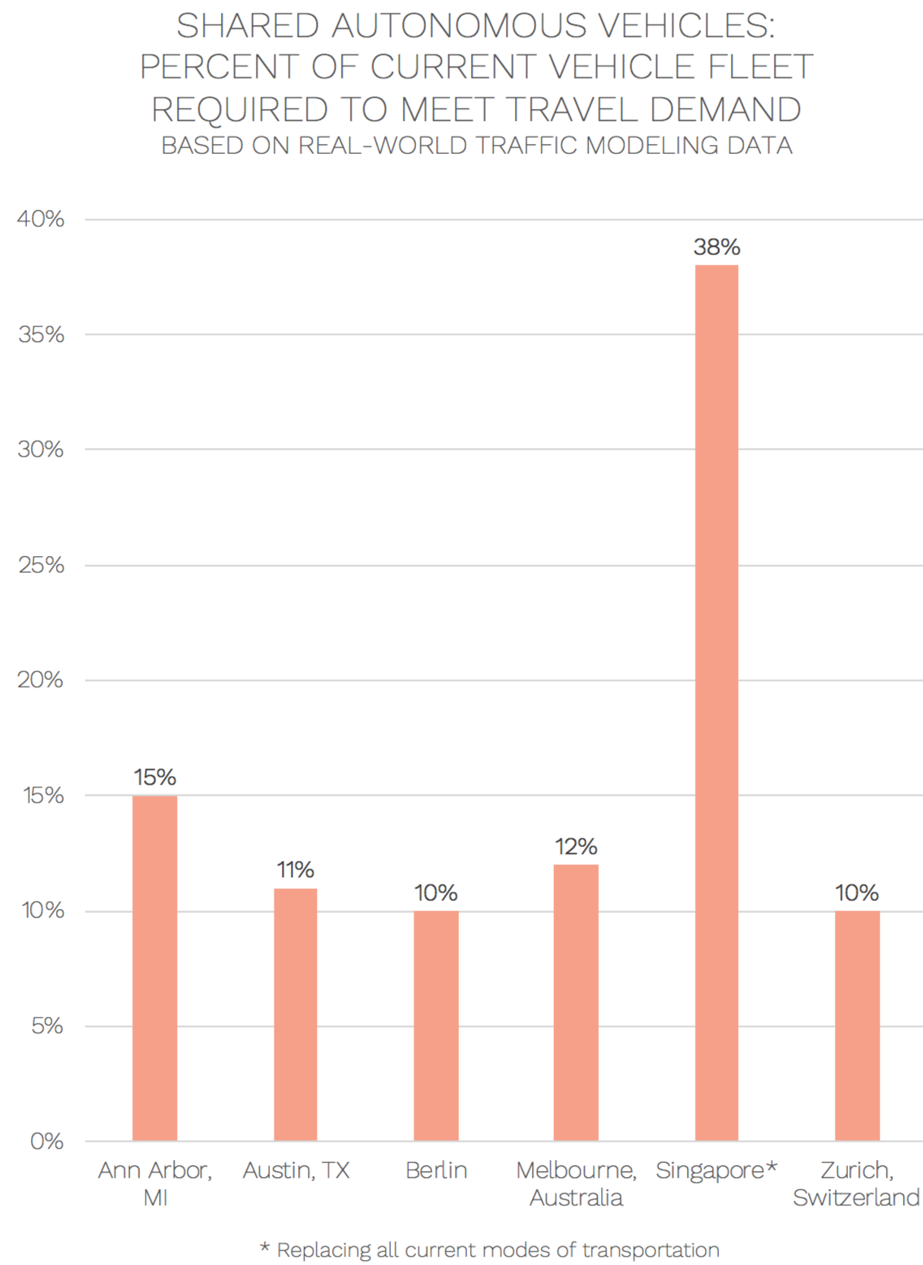


Figure 2.9: Summery of Shared Autonomous Vehicle Traffic Modeling Studies Using Real World Data

65 Fagnant, Kockelman, and Bansal, "Operations of Shared Autonomous Vehicle Fleet for Austin, Texas, Market," 103.

TRAFFIC MODELING: CHANGES IN TRIP MODE

Beyond studies that utilized real world traffic data to gauge shared autonomous vehicle fleet size, there are studies that utilized traffic models to gauge the impacts of autonomous vehicles on trip mode, at both the small and large scale. Perrine, Kockelman, and Huang considered the impacts of autonomous vehicles on larger national scale travel. Their study, which priced the cost of autonomous travel slightly above convention vehicles and priced value of time for autonomous travel at half of that for convention vehicles, indicated several of interesting things. First, air travel was reduced by 53%, which would have significant impacts on both the industry and potentially urban land use. The model also indicated that there would be an increase in personal vehicle trips (either autonomous or not), but surprisingly found a slight decrease of 6.7% in personal vehicle trip miles.[66] This seemed to suggest that while the introduction of autonomous vehicles may seriously decrease air travel, many travelers would choose travel destinations closer to home.

Levin and Boyles used smaller scale city level data to model how mode choice may shift with the introduction of autonomous vehicles. They also used Austin, TX as their case study, and worked to discover what impacts autonomous vehicles would have on public transit demand, personal vehicle trips, congestion, and link speed. They modeled their study around the concept that different user groups would adopt this technology based on cost and value of time. Not surprisingly they found that as cost was reduced public transit demand dropped significantly (up to 61.4%) and personal vehicle trips increased correspondingly. Although personal vehicle trips increased, congestion did not, as improved capacity (as a result of autonomous technology) offset these effects. However, the increase in personal vehicle trips did cause a very slight decrease in link speed.[67] This study provides interesting insights into the possible consequences of the introduction of autonomous vehicles, which may in turn have widespread impacts on urban design. However, there is one major flaw in its design. The model only considered the effects of a fleet of personal autonomous vehicles. Although this is a possibility, as previously stated it is widely believed that there will be an increase in shared mobility, as the prices for these services drop below that of vehicle ownership.

Finally, there was one additional study that also considered changes in trip mode, but in a unique way. Instead of studying the impacts of a shared autonomous system on mode choice, these researchers proposed an entirely new system of travel based on new mode options. These researchers used travel data from Lisbon, Portugal to introduce a radically new approach to urban travel. In their model, Martinez and Viegas proposed a system of shared autonomous taxis (similar to other studies, but with multiple passengers) and autonomous minibuses (seating eight-sixteen people, depending on the size). This model revealed several interesting findings, including a 97.2% reduction

66 Perrine, Kockelman, and Huang, "Anticipating Long-Distance Travel Shifts Due To Self-Driving Vehicles."
67 Levin and Boyles, "Effects of Autonomous Vehicle Ownership on Trip, Mode, and Route Choice."

in all vehicles. There was however a 568% increase in public vehicles, but a 21% decrease in total seats.[68] Moving beyond vehicle numbers, the model also found a 100% reduction in the need for the 150,000 on street parking spaces in the city, as well as a significant reduction in the need for the 50,000 off street parking spaces. Martinez & Viegas' model also found a significant reduction in kilometers traveled in the city (25-30%), and a significant reduction in CO2 produced by travel (32-38%). Finally, the overall cost of travel would decrease across the board. Taxi fares were found to drop by 35%, while public transportation fares dropped by 45%, resulting in an overall increase in transit accessibility.[69] While this may not be the most likely scenario to occur, the authors argue that transportation polices that begin to contemplate radically different approaches to urban mobility should be considered.

TRAFFIC MODELING: SIMULATED URBAN ENVIRONMENTS

There are also two studies that considered the impacts of autonomous fleets on simulated urban environments. These studies utilized simulated urban environments to test, among other things, the autonomous fleet size required to meet the demands of conventional vehicles. Both of these studies set up fairly similar simulated environments, both choosing to test a ten mile by ten-mile area with slightly different (3.5% vs 2%) market penetration rates. These similar models also had fairly similar results. In one study the authors found that one shared autonomous vehicle could replace fourteen conventional vehicles, with standard wait times less than two minutes.[70] The other found that one shared autonomous vehicle could replace eleven conventionally driven vehicles.[71] While both of these studies provide interesting insights into potential reductions in the number of vehicles on the road, the primary aspect of each was not to determine this number. Zhang and colleagues examined shifts in parking demand as a result of autotomizing travel, while Fagnant & Kockelman's research largely focused on the potential environmental impacts of autonomous vehicles.

PARKING DEMAND

As previously stated, the model produced by Zhang and colleagues works to answer the question of how much space dedicated to parking infrastructure will be required after a shift to a shared autonomous fleet. Their model proposed six different scenarios, based on willingness to share rides and permissible cruising time per automated vehicle. The most significant take away of this piece was that even under a scenario in which there was no willingness to share, and no allotted cruising time, the model still identified a 90% reduction in parking spaces. Should

68 Martinez and Viegas, "Assessing the Impacts of Deploying a Shared Self-Driving Urban Mobility System: An Agent-Based Model Applied to the City of Lisbon, Portugal."
69 Martinez and Viegas.
70 Zhang et al., "Exploring the Impact of Shared Autonomous Vehicles on Urban Parking Demand: An Agent-Based Simulation Approach."
71 Fagnant and Kockelman, "The Travel and Environmental Implications of Shared Autonomous Vehicles, Using Agent-Based Model Scenarios."

there be 50% willingness to share rides, and a ten-minute permissible empty cruising time, this parking space reduction could be as high as 96%.[72] Another study previously mentioned, which focused on Melbourne, found that the 88% reduction in vehicles correlated with an 83% reduction in parking spaces for the city (see Figure 2.10).[73]

One final study also uses the city of Austin in order to estimate the potential amount of space dedicated to parking that could be re-purposed after a switch to an autonomous fleet. What these authors found was that 90% of the land dedicated to parking could be re-purposed. This is a total of 27 acres, or 4.2% of the total land in the downtown area.[74] Unlike other papers, the authors then go on to suggest potential reuse strategies based on street typologies in the city. These suggestions include improving multi-modal transit on large urban thoroughfares, improving bicycle infrastructure on avenues with less traffic, and pedestrian focused improvements in commercial districts. This projection, as well the others, sets the stage for the potential to re-purpose large tracts of urban land. One item worth noting is that these studies all focus on public parking facilities. Because this thesis is will ultimately use the city of Seattle as a case study, it is important to consider alternative strategies for reconsidering parking. One important factor to consider is the large number of spaces found within private developments in the city, and the fact that 30% of these parking facilities currently sit unused.[75] A partnership between a shared autonomous vehicle service and these private developments could provide a potential opportunity to further reduce the amount of land dedicated to public parking infrastructure.

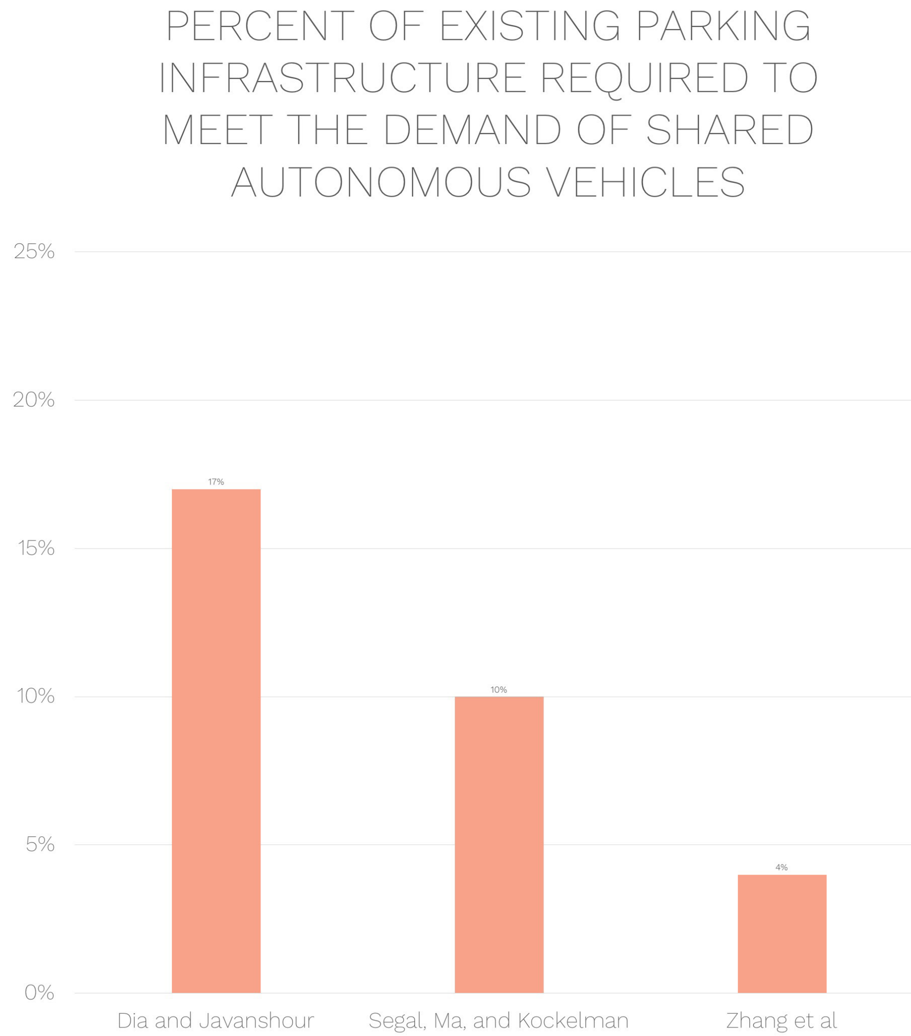


Figure 2.10: Summery of Parking Demand Studies

72 Zhang et al., "Exploring the Impact of Shared Autonomous Vehicles on Urban Parking Demand: An Agent-Based Simulation Approach."
73 Dia and Javanshour, "Autonomous Shared Mobility-On-Demand: Melbourne Pilot Simulation Study."
74 Segal, Ma, and Kockelman, "Making The Most of Curb Spaces in a World of Shared Autonomous Vehicles: A Case Study of Austin, Texas."
75 Lee, "Seattle Plan: Ease Public Parking Crunch by Tapping Unused Spaces in Private Lots and Buildings."

ROADWAY CAPACITY

Potential increases in roadway capacity come from the technological innovations related to autonomous travel. First, it is believed that these vehicles should be able to safely travel closer together than conventional vehicles.[76] Second, cooperative adaptive cruise control, at a 90% market penetration rate, is predicted to increase lanes' effective capacities by 80%.[77] Third, it has also been predicted that autonomous vehicles will travel through intersections much more efficiently than conventional vehicles. Thus, intersection delays could be all but eliminated, further improving roadway capacity.[78]

There have been several studies that have worked understand to what degree capacity may improve with the implementation of autonomous technology. Perhaps the most important aspect of this technology would be the ability for vehicles to communicate with each other. One study found that platoons of connected and automated vehicles traveling at 45mph would increase roadway capacity by 500%.[79] Another, which looked at increased highway capacity, determined that smart vehicle sensors alone could increase highway capacity by 43%, but when combined with vehicle to vehicle communication capacity would increase by 273%.[80] A summary of these findings can be found in Figure 2.11.

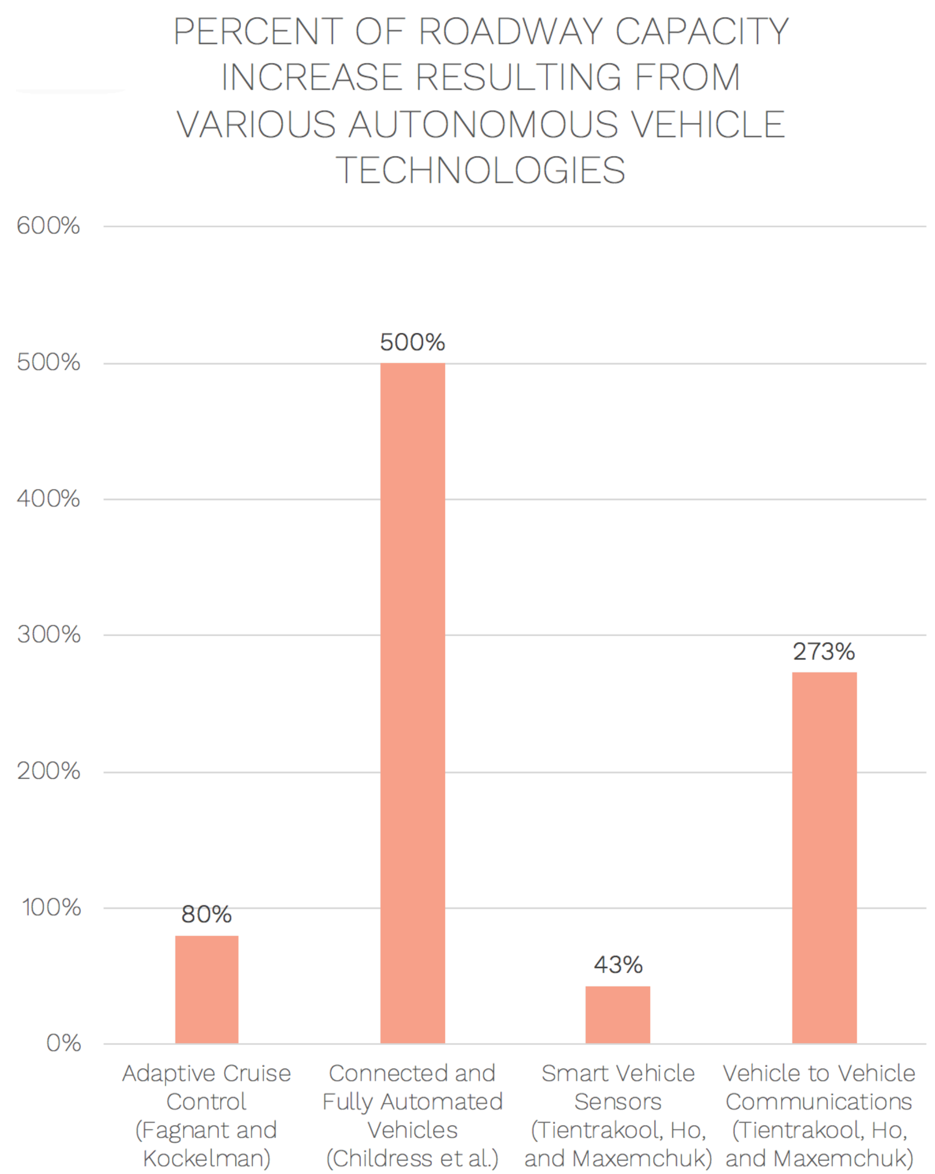


Figure 2.11: Summery of Roadway Capacity Studies

76 Lioris et al., "Platoons of Connected Vehicles Can Double Throughput in Urban Roads."
77 Fagnant and Kockelman, "Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations."
78 Lioris et al., "Platoons of Connected Vehicles Can Double Throughput in Urban Roads."
79 Childress et al., "Using an Activity-Based Model to Explore the Potential Impacts of Automated Vehicles."
80 Tientrakool, Ho, and Maxemchuk, "Highway Capacity Benefits from Using Vehicle-to-Vehicle Communication and Sensors for Collision Avoidance."

IMPACTS ON THE BUILT ENVIRONMENT

Perhaps one of the most significant effects of autonomous vehicle technology, especially for the purpose of this study, is its potential to dramatically reshape the built environment. In regard to urban form, urban designers have hailed autonomous vehicles as potentially "one of the most transformative and disruptive technologies ever introduced."[81] This impact on urban from is expected to have far reaching effects, both within the right-of-way and beyond. A reduction in the number of vehicles on the road, increased roadway capacity, a reduction in parking infrastructure, and other impacts of a system of shared autonomous vehicles all contribute to this effect on urban form.

In the past, transportation planning has largely worked to serve the "simplistic goal of moving motor vehicles at high speeds with limited impedance" and because of this "streets have been designed and prioritized for movement of cars, with other road users treated as an afterthought, if at all."[82] Again, autonomous vehicle technology provides an opportunity for planners and urban designers to rethink the traditional understanding of right-of-way design. In regard to the right-of-way, there are three key aspects of this technology that will present opportunities for thinking about how this space is designed and used. These are: the ability to reduce the number of vehicle travel lanes, the elimination of on street parking, and the capacity to reduce the width of travel lanes.

As discussed previously, it is widely believed that autonomous vehicles will have the ability to significantly increase the capacity of urban roads. Should this be the case there would be opportunities to remove lanes of traffic and dedicate this space to other uses. This type of road diet has been explored with the use of traditional vehicles, and transportation planners typically utilize average daily traffic thresholds in order to determine when these transformations are possible. For example, an average daily traffic threshold of twenty-thousand vehicles per day is used when determining whether or not it is possible to reduce a four-lane street down to two lanes.[83] It is expected that the improved efficiency of autonomous vehicles will result in an exponential increase of these determining thresholds, meaning that the majority of urban streets would become candidates for road diets. In addition to removing lanes of traffic, autonomous vehicles will also allow for existing travel lanes to be reduced in size. There are two main reasons for this transformation. First, it is expected that the size and shape of cars may also shift during this transformation. Large passenger vehicles may be replaced with smaller purpose-built vehicles that take up less space on the road.[84] Second, autonomous vehicles will do a better job at staying in their lanes compared

81 Snyder, "Street Design Implications of Autonomous Vehicles."
82 Schlossberg et al., "Rethinking the Street in an Era of Driverless Cars," 2.
83 Snyder, "Street Design Implications of Autonomous Vehicles."
84 Burns, Jordan, and Scarborough, "Transforming Personal Mobility."

to those driven by humans.[85] With this in mind, the width of the majority of urban roads could be reduced to ten-feet, and those outside of major transportation or freight networks could be reduced to as small as eight-feet in width.

The elimination of on street parking will also have a significant impact on right-of-way allocation and design. Parking takes up substantial amounts of urban land, and should autonomous vehicles require less parking, this would provide urban designers with opportunities to rethink traditional urban form. Many of the previously citied studies have suggested that a potential reduction in vehicles would have cascading effects on urban parking. In the United States it is estimated that there are as many as eight parking spaces per car, and a reduction in vehicles would reduce this demand.[86] Furthermore, the remote storage of autonomous vehicles would also work to reduce demand for on street parking, as these vehicles would return to off-street storage facilities when not in use. The previously cited literature suggests several recommendations for the potential reuse of this space. One paper suggests that unused parking space should "shift to better uses" such as "parks and retail establishments, offices, wider sidewalks, bus parking, and bike lanes."[87] Another suggests that prior research informs us that no matter the use, "this space must be pro-actively managed in order to lock in benefits."[88] Altogether, these three key effects of autonomous technology provide an opportunity to "reclaim one of our largest public assets to create higher value, better quality streets designed to move people, not just vehicles."[89]

Outside of the right-of-way, autonomous vehicles are expected to have additional impacts on the built environment. Parking continues to play a major role in this space. Because the potential reduction of parking spaces is expected to be so great, the consequences of a transition to a shared autonomous fleet will also spill over into off-street parking facilities. It has been suggested that a portion of the land dedicated to surface parking lots or parking structures could be re-purposed for higher-value activities, such as urban parks or affordable housing.[90] Although a total shift to autonomous mobility is years away, developers have already begun to consider how their properties may adapt to a future without parking. AvalonBay Communities Inc., one of the nation's largest apartment developers, is one of those who have begun to consider this future. AvalonBay, along with architecture firm Gensler, is currently planning a residential complex in downtown Los Angeles with what at first glance may appear to be a traditional parking structure for nearly 1,000 vehicles. However, this parking facility has been specifically designed to eventually serve other uses. Part of this planning includes building the structure with level floors so that it may be used as additional office space, a gym, a theater, and "perhaps

85 Hand, "Redefining Urban Mobility: Four Ways Shared Autonomous Vehicles Will Reshape Our Cities."
86 Flemming et al., "Automated Vehicles: The Coming of the Next Disruptive Technology."
87 Fagnant, Kockelman, and Bansal, "Operations of Shared Autonomous Vehicle Fleet for Austin, Texas, Market," 103.
88 Martinez and Viegas, "Assessing the Impacts of Deploying a Shared Self-Driving Urban Mobility System: An Agent-Based Model Applied to the City of Lisbon, Portugal,"
89 Hand, "Redefining Urban Mobility: Four Ways Shared Autonomous Vehicles Will Reshape Our Cities," 49.
90 Yigitcanlar, Currie, and Kamruzzaman, "Here's How Driverless Vehicles Will Utterly Transform How Our Cities Look."

other recreational uses when cars can park themselves two or three deep in tighter spaces" (see Figure 2.12)[91]

In addition to parking facilities, it has been suggested that the basic structure of off-street development will need to adapt to an autonomous future. Due to the fact that many people commute via personal automobiles, "many buildings and developments have increasingly turned their back on the public right-of-way to face and serve tenants and visitors who are entering from a parking garage or parking lot."[92] Commercial developments often feature large setbacks, where expansive surface lofts make it difficult for pedestrians, bicyclists, and transit users to easily approach building entrances. Even in situations without large building setbacks, some developments have closed street-facing building entrances in favor of a parking-centric entrance, eliminating the possibility of an active street façade. While it is possible that developers may instinctively respond to autonomous technology and adjust their current practices accordingly, it may also be necessary for local governments to adopt zoning or design regulations which require buildings to introduce elements that work to activate the streetscape and serve the public realm with people in mind, especially users who are being dropped-off or picked-up by shared autonomous vehicles.

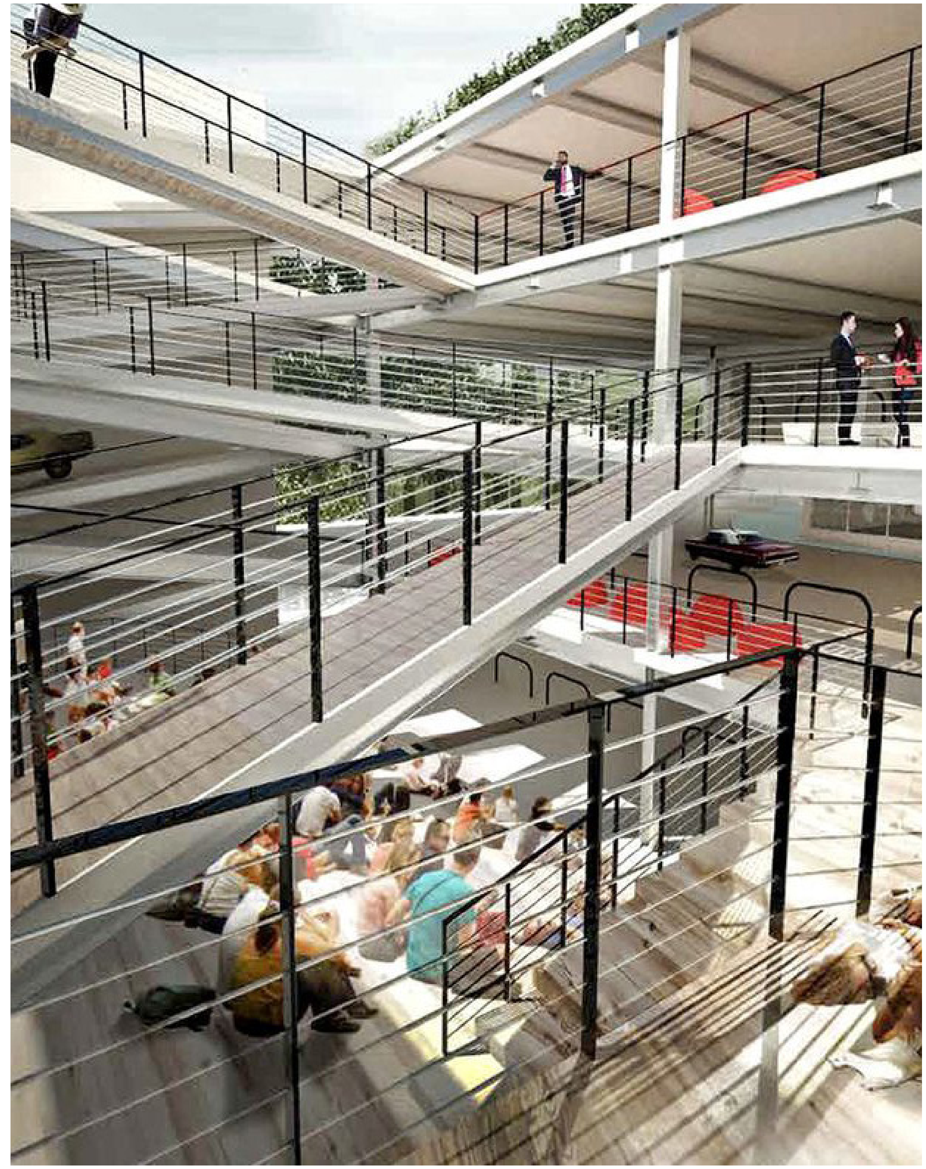


Figure 2.12: Gensler's Rendering of a Re-purposed Parking Structure (Source: Los Angeles Times 2017)

91 Vincent, "When Car Ownership Fades, This Parking Garage Will Be Ready for Its next Life."
92 Hand, "Redefining Urban Mobility: Four Ways Shared Autonomous Vehicles Will Reshape Our Cities," 50.

Finally, there are a number of other land use considerations that, while beyond the scope of this study, are worth mentioning. These include transforming gas stations into new uses, as most fully autonomous vehicles are expected to be electric, transitioning suburban parking garages into additional housing stock, and preparing for a potential increase in urban sprawl. This potential increase in urban sprawl is one issue that is particularly worthy of additional exploration, especially at the policy level, considering that the convenience of autonomous travel "might make the economics and practicality of sprawl more attractive."[93]

Altogether, when you begin to consider the extraordinary impacts of a shared autonomous system, such as significant decreases in the number of vehicles on the road and parking demand, combined with a substantial increase in roadway capacity, it is possible to see how such a major shift in urban mobility may pave the way to completely rethink the vast amounts of land dedicated to automobiles. In order to begin to imagine want kind of changes a shared autonomous vehicle society could actually create, the next section of this thesis will begin to explore the role of design in such a transition.

93 Yigitcanlar, Currie, and Kamruzzaman, "Here's How Driverless Vehicles Will Utterly Transform How Our Cities Look."

DESIGNING FOR AN AUTONOMOUS FUTURE

WHY DESIGN MATTERS

Among all of the possibilities that currently surround the use of autonomous vehicles, perhaps one of the most exciting is how these vehicles may work to reshape the built environment. As previously stated, a shift to a shared autonomous fleet will provide a unique and important opportunity to completely rethink the massive amount of urban land dedicated to vehicles, and the time to begin considering the role of design in this process is now. This next revolution in urban mobility provides the opportunity for design and design thinking to fulfill two important roles. First, design can work to inspire. Providing both the public and policy makers with a clear understanding of the true potential of this transformation is critical. Brian Jencek, the director of planning at the global architecture and design firm HOK, recently spoke about this issue and stated that "we (as designers) haven't spent enough time showing people what cities could look like if they're not designed around the car." This statement was part of a larger discussion in which he stressed the importance of the need to look forward, consider how autonomous vehicle technology will reshape different paradigms of urban design, and set goals for the future.[94] Some design explorations of autonomous futures have been criticized as overly optimistic, however, perhaps this level of optimism is necessary.[95] In a way, these conceptual explorations can act as a provocation by working to challenge the ways in which we have typically thought about designing our public spaces and who we design for.

Second, design can work as a guiding force. Too often in the past large shifts in mobility were undertaken without truly considering their design implications or the potential adverse effects on urban inhabitants. Function and efficiency were often prioritized over anything else, often at a cost to pedestrians and the environment. This was often the result of important transportation decisions being made from a single perspective. Including urban designers and design thinking into these decisions making processes has the potential to bring a new and perhaps more holistic perspective to the table. Ideally, when planning for the future designers would have the ability to introduce guidelines or frameworks in order to "take advantage of this opportunity to reshape our urban areas in ways that promote safe, sustainable, and people-centered environments."[96]

The rest of this chapter will focus on these two ideas by exploring the limited amount of literature dedicated to establishing guidelines for autonomous design, as well as a selection of conceptual design explorations focused on investigating an autonomous future.

94 Sisson, "Thanks to Autonomous Vehicles, We Could Have These Utopian, Tree-Filled Streets."
95 Florida, "Driverless Cars Are Not a Panacea."
96 Chapin et al., "Envisioning Florida's Future : Transportation and Land Use in an Automated Vehicle World,"

DESIGN FRAMEWORKS

Due to the fact that autonomous vehicle technology is relatively new and rapidly advancing, the amount of literature dedicated to establishing design frameworks for this technology is fairly limited. However, with that being said there are several highly cited and well-constructed reports that tackle this issue. One of the most robust of these was recently released by the National Association of City Transportation Officials (NACTO). This comprehensive report, titled *Blueprint for Autonomous Urbanism* works to tackle this subject from multiple perspectives. First, rather than acting as just a design guide, which is what NACTO is known for producing, this document works to graphically portray principles and policies for autonomous urbanism. There are six major principles that work to structure the entire report. These include: Safety is the Top Priority, Provide Mobility for the Whole City, Rebalance the Right-of-Way, Manage Streets in Real Time, Move More with Fewer Vehicles, and Public Benefit Guides Private Action.[97] Nested below each of these principles are policy ideals and actions that the organization believes may serve as an "aspirational framework for the deployment of automated vehicles."[98]

The guide goes on to make recommendations regarding how a variety of systems might fit into this overall structure. This includes suggestions for a variety of street typology schemes, data handling procedures, mobility frameworks, designing for safety, and curbside management. To date, this is perhaps the most thorough guide to dealing with autonomous transit within the urban design sphere. This particular document will be used as a guide for making design decisions in the next chapter of this thesis, and at the time the contents of this blueprint, including the principles and policies for autonomous urbanism, will be explored in greater detail.

One other document that addressed the role of design in this transition was produced by Florida State University's Department of Urban & Regional Planning for the Florida Department of Transportation. This report, *Envisioning Florida's Future: Transportation and Land Use in an Automated Vehicle Automated Vehicle World*, was the end result of a brainstorming session between planners, engineers, public officials, and autonomous vehicle-industry professionals at the 2015 Florida Automated Vehicles Summit. These small table discussions focused on six major topics related to designing for autonomous vehicles. The authors go on to summarize the findings for each of these topics, and then recommend design and policy recommendations for each. These six major discussion topics are discussing in more detail below.[99]

97 National Association of City Transportation Officials, "Blueprint for Autonomous Urbanism."
98 National Association of City Transportation Officials, 8.
99 Chapin et al., "Envisioning Florida's Future : Transportation and Land Use in an Automated Vehicle World."

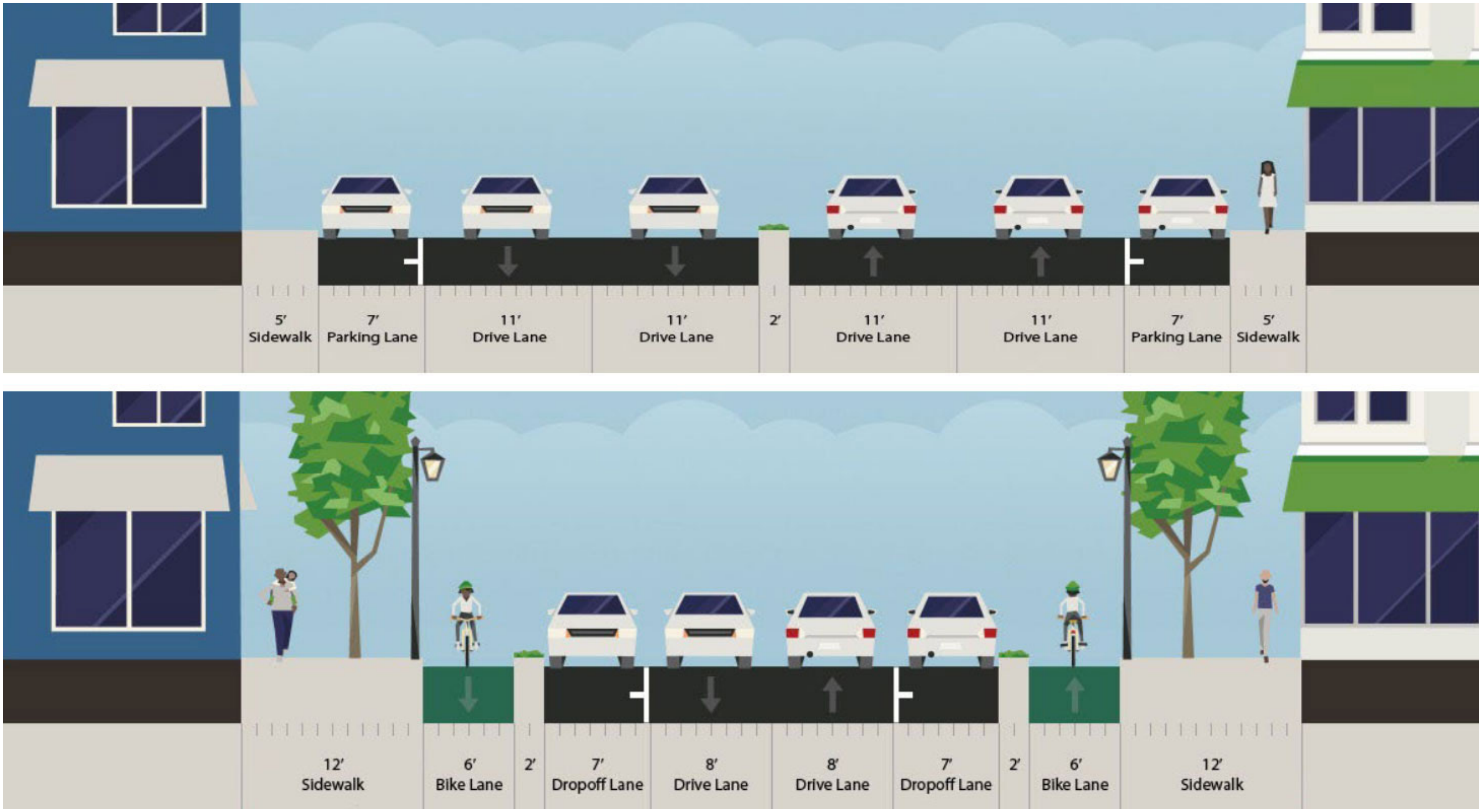


Figure 3.1: Common Auto-Centric Right-of-Way vs. Autonomous Vehicle Right-of-Way (Source: Chapin et al., 2016)

Right-of-Ways: Within this section the authors of this report lay out in detail a of number of specific design recommendations for the right-of-way. These include: reducing lane widths, reducing the number of lanes of traffic, and utilizing smaller medians. Each of these recommendations is based on assumed travel characteristics of autonomous vehicles, primarily the fact that they are expected to travel much more efficiently and safely. A visual representation of these recommendations is shown in Figure 3.1.

Drop Off Areas: Due to the fact that shared autonomous vehicles will no longer need to park on the street, as they can continue on to pick up a new passenger or return to their base, street parking would be eliminated and there would be a new need for expanded passenger and cargo pick-up and drop-off spaces. The authors acknowledge that these new loading zones will become a staple of urban spaces and recommend that each be tailored to the surrounding urban conditions. Chapin and colleagues also suggest the need for the creation of safe and comfortable spaces to be incorporated into these spaces for riders as they wait for their vehicle.

Signage and Signals: In this section of the report the authors go on to advocate for nearly the complete removal of all street signs and signals. This idea is based on the theory that traffic instructions will largely be programed into the vehicles memory or would be picked up using the smart technologies discussed in the previous chapter (see Figure 3.2). The report does however suggest that some signage remain, such as wayfinding for pedestrians and bicycles. The authors suggest that classic street signs should be "replaced by creative pedestrian way-finding or other features that make streetscapes more appealing and attractive to pedestrians" in order to "create more attractive urban spaces and communities."[100]

Bike and Pedestrian Infrastructure: This section of the report largely focus on the requirement of re-purposing right-of-way space gained by reducing travel lanes and parking spaces in manner that works to improve and/or create spaces for bicyclists and pedestrians. In the case of bicycle lanes, the authors, while not providing specific details, recommend special attention be paid to the siting of these facilities in order to avoid conflicts with pick-up and drop-off zones.

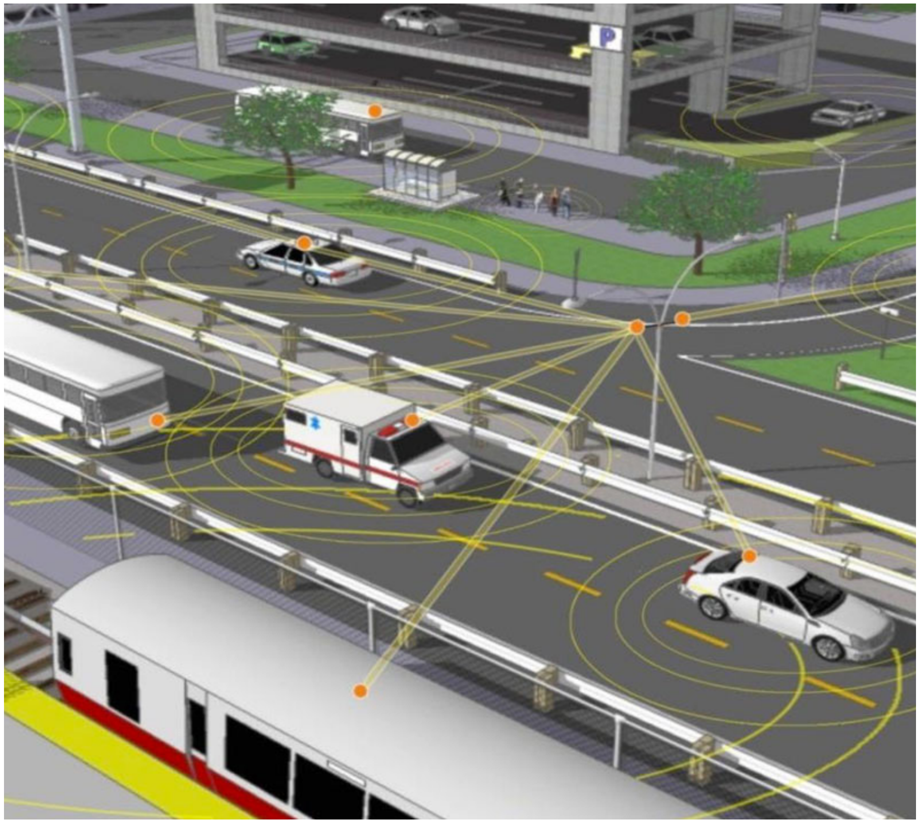


Figure 3.2: Autonomous Vehicles Utilizing Smart Technologies & Traveling Without the Need for Traffic Signs or Signals (Source: Chapin et al., 2016)

100 Chapin et al, 15.

Parking: Here, the authors focus on two primary aspects of autonomous vehicle parking. First, they recommend that existing parking design guidelines be reconsidered, as these vehicles will be able to park much closer together without the need to open their doors once parked. Second, the authors recommend a strategy of introducing large autonomous parking facilities on the peripheries of urban areas. This specific recommendation is one that has potential equity issues associated with it. The sites of these facilities need to be chosen carefully in order to ensure that they do not adversely impact minority communities.

Redevelopment Opportunities: This final section focuses on possible redevelopment opportunities outside of the right-of-way, considering both the transformation of urban centers and the eliminations of typical site design requirements. The authors believe that there will be considerable opportunities for infill development in urban centers thanks to the relocation of parking facilities. One suggested preferred alternative would be to utilize these spaces as parks and recreational spaces for urban inhabitants (see Figure 3.3). The second point is more of a policy recommendation than a design proposal. The authors suggest that parking requirements and other building regulations related to the use of automobiles be fully eliminated or reconsidered.

The authors conclude the report by stating that they believe autonomous vehicles will drastically change the design and function of the built environment and believe that this guide can function as a starting point to begin thinking about these issues.[101] These author's also stress the importance of beginning to think about these issues now, in order to capitalize on what they believe is a rare opportunity to improve the form and function of the built environment.

Figure 3.3: Conceptual Redesign of a Typical Strip Mall (Source: Chapin et al., 2016)

101 Chapin et al.

The final report that deals with the convergence of autonomous technology and urban design was produced by an engineering firm and an urban design firm, both of which are based in the United Kingdom. This report, titled *Making Better Places: Autonomous vehicles and Future Opportunities*, focuses on the potential that autonomous travel has to completely reshape the built environment. The report is structured around rethinking four different spaces that are prevalent throughout the UK: city centers, suburban spaces, motorways, and rural areas. This report falls someone on the line between a design framework and a design case study. For each of the aforementioned spaces the authors include a conceptual rendering as well as a list of design actions taken in the proposed redesign (see Figure 3.4 & Figure 3.5). The authors state that these conceptual renderings each depict a "feasible future case," and they are used "to show the spaces as they could look and feel if we reach a point where autonomous vehicles are the norm."[102] Where this report falls short of a full design framework is the lack of explanation behind their design decisions. The majority of the discussion that follows each design focuses mostly on what decisions were made, and not why they were made. However, there is still a significant amount of important design information to be found in this report, and their design decisions could be worth considering when rethinking how public space may be completely rethought after a total switch to autonomous mobility.

102 Skinner and Bidwell, "Making Better Places: Autonomous Vehicles and Future Opportunities," 19.

- More space for urban retail, commercial and leisure activity
- Safe interaction between cyclists, pedestrians and AVs
- Edge of centre car parks become larger AV servicing and storage hubs
- AVs able to access hard-to-reach places, especially for mobility impaired passengers
- Much reduced congestion and smoother traffic flow
- Better quality of townscape with more space for pedestrian activity

Figure 3.4: Conceptual Redesign of a Typical Strip Mall (Source: Chapin et al., 2016)

Crash barriers, sign gantries and lane markings are no longer required

Flexible, fluid lanes cater for tidal flows, freight and live work on carriageways

AVs move in connected platoons for maximum safety and route efficiency

Priority lanes can be created for high occupancy AVs and/or premium users

Safety is enhanced by on-board sensors to monitor road obstructions

Improved water runoff, flood management and ecology benefits for the motorway corridor

New uses alongside the motorway could include long distance cycle routes, light industry and energy capture

Motorway lighting – and associated light pollution – dramatically reduced

Figure 3.5: Motorway Conceptual Redesign (Source: Skinner and Bidwell, 2017)

CONCEPTUAL DESIGN CASE STUDIES

In addition to the reports that focused on establishing design frameworks, there have been some autonomous mobility conceptual design proposals put forward by a variety of design firms. These range from the fantastical to the more realistic. While some of the proposals are less likely than others to play out in the real world, they are all worth exploring as a way to expand the scope of what could be possible in the face of an autonomous vehicle revolution.

Firm: HOK
Project: Roadways for Human & Environmental Health

When rethinking how public space within the right-of-way might be transformed through the adoption of autonomous vehicles, the global architecture and design firm HOK focused on one key concept, health. The firm's main intent was to transform the right-of-way from a space previously dominated by automobiles to one that offers solutions to many of the environmental and health problems that cities are currently facing. Their design goals included cutting air pollution, reducing the urban heat island effect, utilizing landscape elements that filter water and pollution, and providing urban inhabitants with green spaces where they may find quiet spaces for relaxation. One of the principle designers on the project, Brian Jencek, acknowledged that their concept renderings were missing key components that would "make these sketches more relevant and realistic, such as where emergency vehicles would go."[103] However, Jeneck would go on to explain that the key purpose of this exploration was to get people thinking and to start a dialog about the what our streets could become.

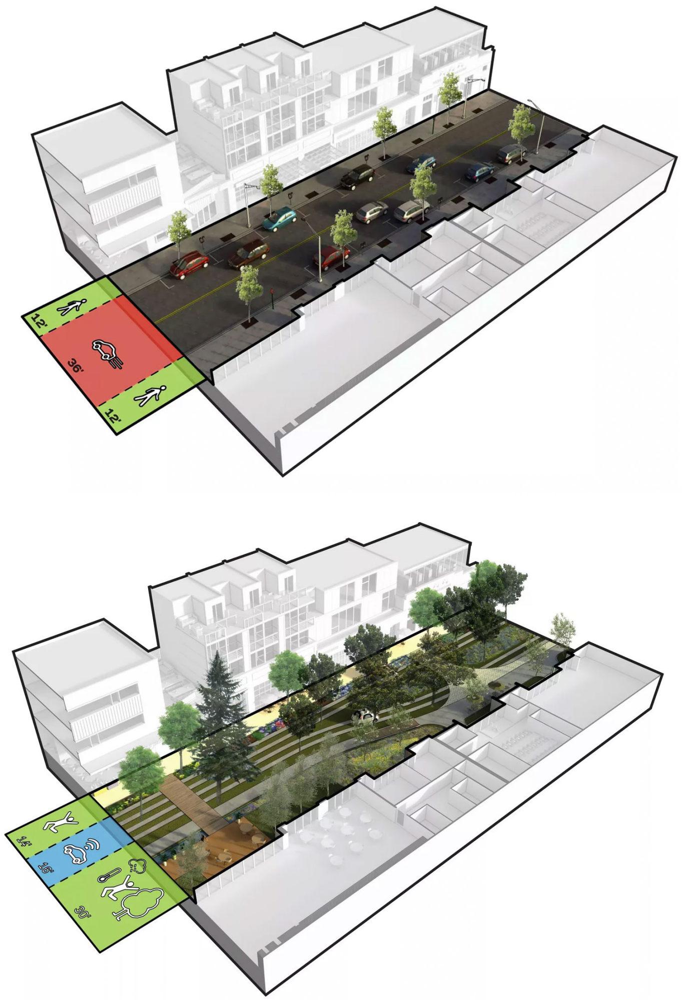


Figure 3.6: Current Roadway Dimensions vs HOK's Proposed Walkable Forrest (Source: Curbed, 2017)

103 Sisson, "Thanks to Autonomous Vehicles, We Could Have These Utopian, Tree-Filled Streets."

Figure 3.7: HOK's conceptual design for the Autonomous Vehicle Age (Source: Curbed, 2017)

Firm: Bjarke Ingels Group (BIG)

Project: Urban Future: Plasti-City

BIG was one of the first design firms to propose a radical reimagining of a cityscape resulting from the full adoption of highly connected shared autonomous vehicles in 2010. Their proposal is centered around utilizing Ray Kurzweil's model of the exponential growth of technology to predict the future of the automobile. They imagine a future in which driverless vehicles and pedestrians share a city whose pavement has transformed into a "reprogrammable surface replacing the fixed elements of driveway, sidewalk or square; a digital street surface completely re-animating a familiar city."[104] This responsive digital surface would work to harmonize the flows of autonomous vehicles, bicycles, and pedestrians in an entirely fluid and flexible manner (see Figure 3.8). Autonomous vehicles would connect to and receive instructions from the surface in order to safely move through urban spaces. The designers believe that this surface would work to "replace the static city cast in concrete with a future city that dynamically transforms and adapts to the life between the buildings."[105]

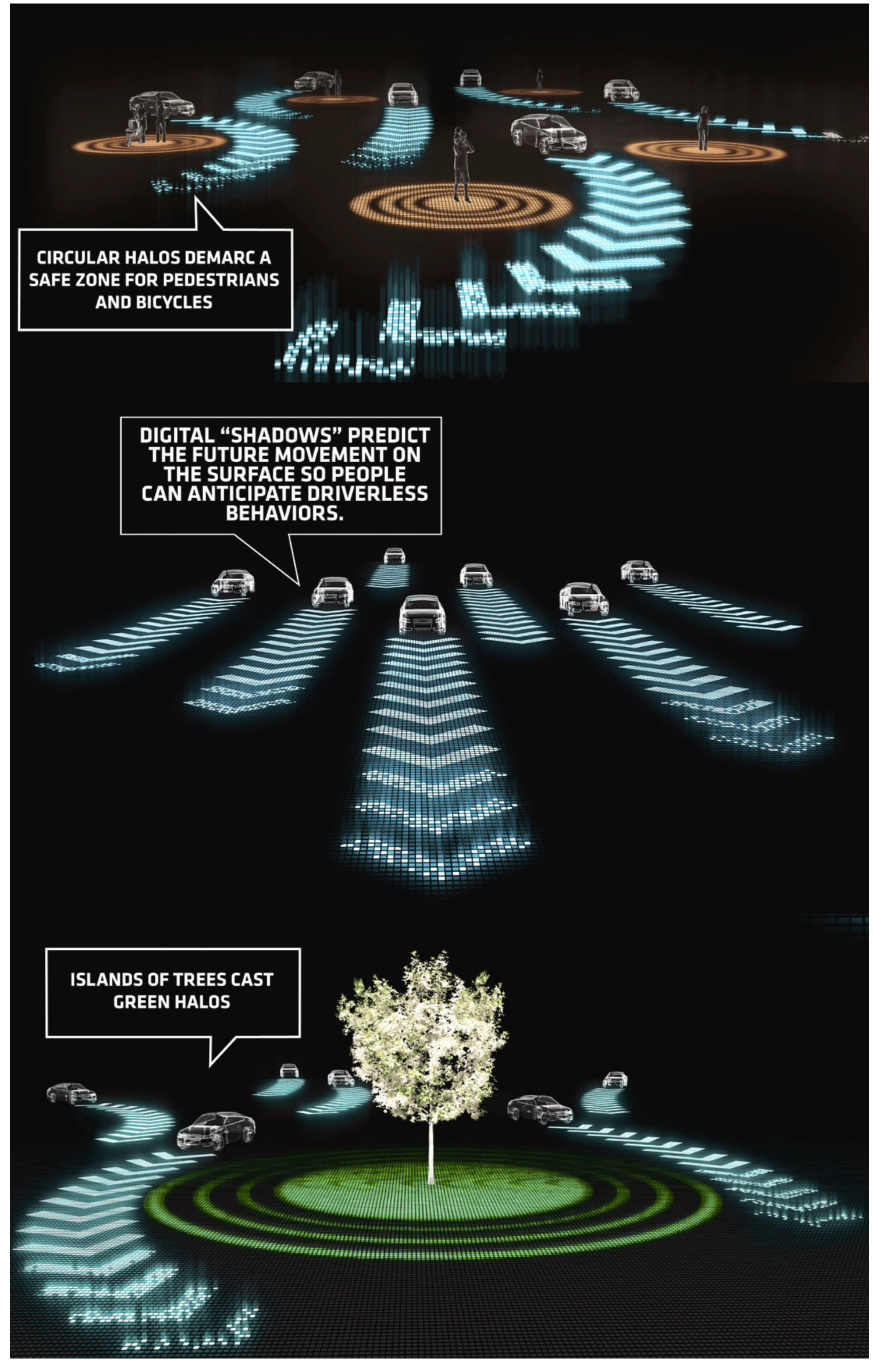


Figure 3.8: BIG's Proposed Digital Street Surface (Source: ArchDaily, 2010)

104 Jordana, "BIG's Proposal for the Audi Urban Future Award."
105 Jordana.

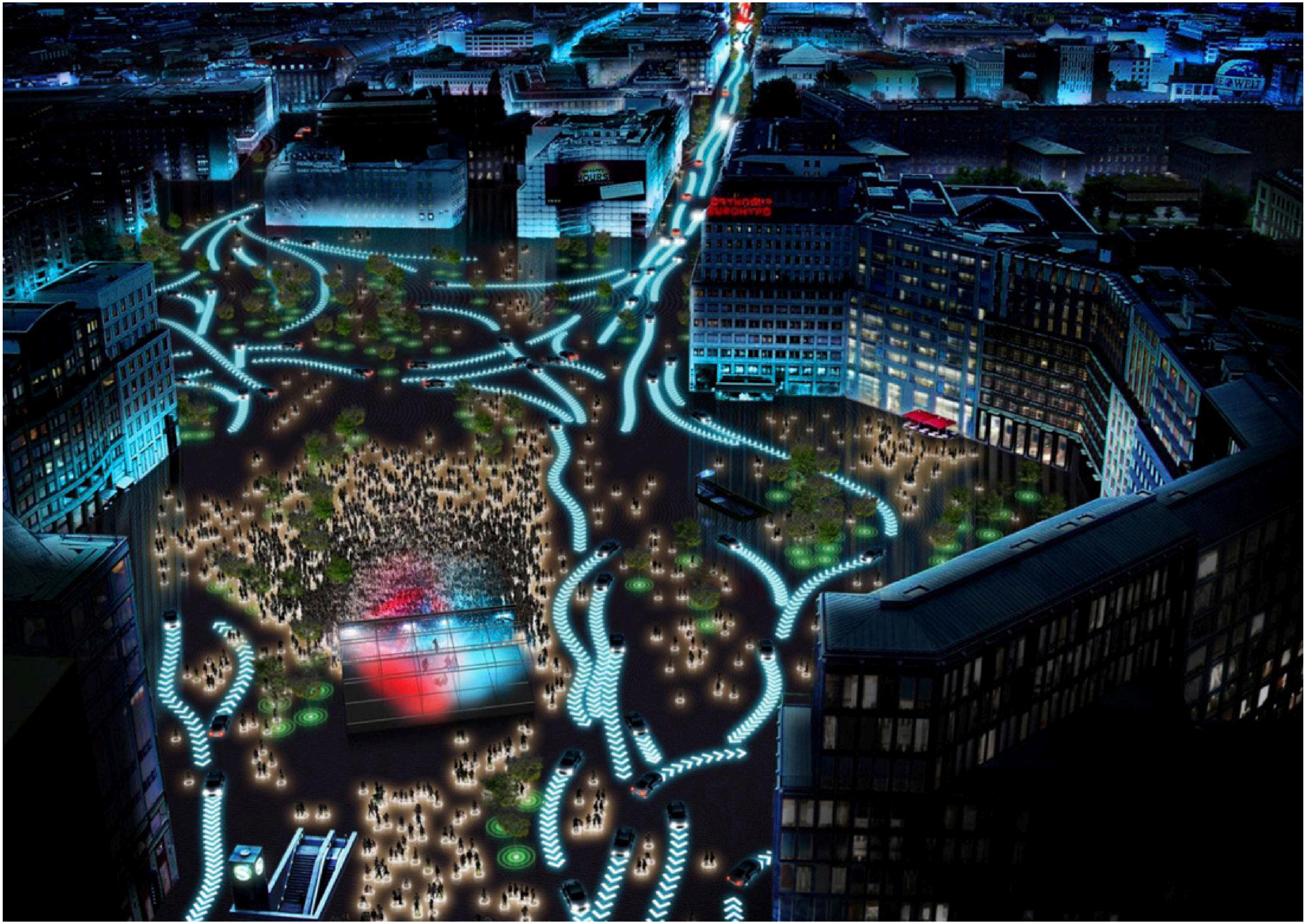


Figure 3.9: BIG's Proposal for an Autonomous Future (Source: ArchDaily, 2010)

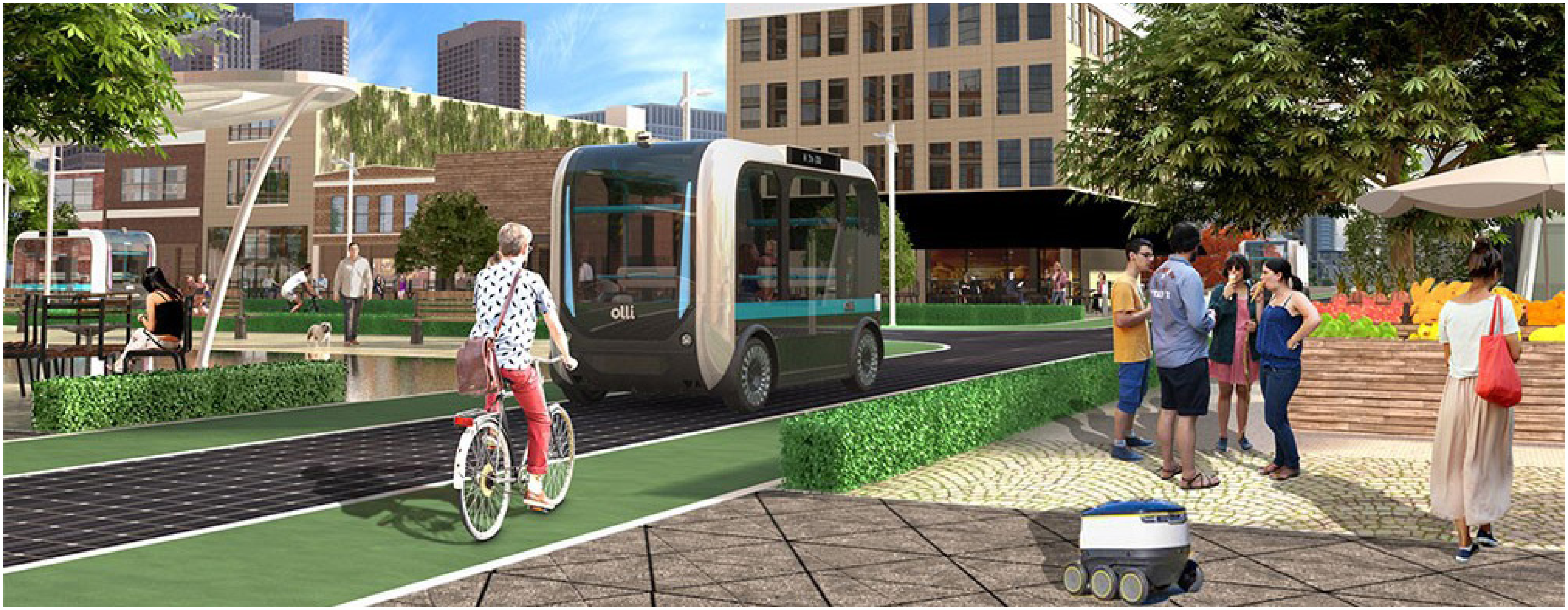


Figure 3.10: Greg Kristo's Reimagining of Randolph Street in Chicago (Source: Stantec, 2018)

Designer: Greg Kristo
Project: Chicago's Autonomous Future

Inspired by Masdar City, a car-free city in Abu Dhabi, architectural designer Greg Kristo chose to reimagine what a street in his hometown of Chicago might look like should we prioritize people over cars. For this exploration he chose Randolph Street, a four-lane arterial with parking on both sides that travels through one of Chicago's booming neighborhoods in the West Loop, as his case study. Kristo states that "nothing will be as disruptive to our urban fabric as autonomous vehicles," and he sees this disruption as an opportunity to "help us in our quest to design more pedestrian-friendly cities."[106] Kristo's overall concept includes massively increasing pedestrian space while reducing vehicular traffic to two lanes, introducing environmentally friendly design elements such as solar panels and greenspaces, and implementing a well thought out system of movement for non-vehicular travel that includes easy to access bike lanes and LED equipped pedestrian streetscapes and crosswalks (see Figure 3.11).

106 Kristo, "Why Study Autonomous Vehicles and the City?"

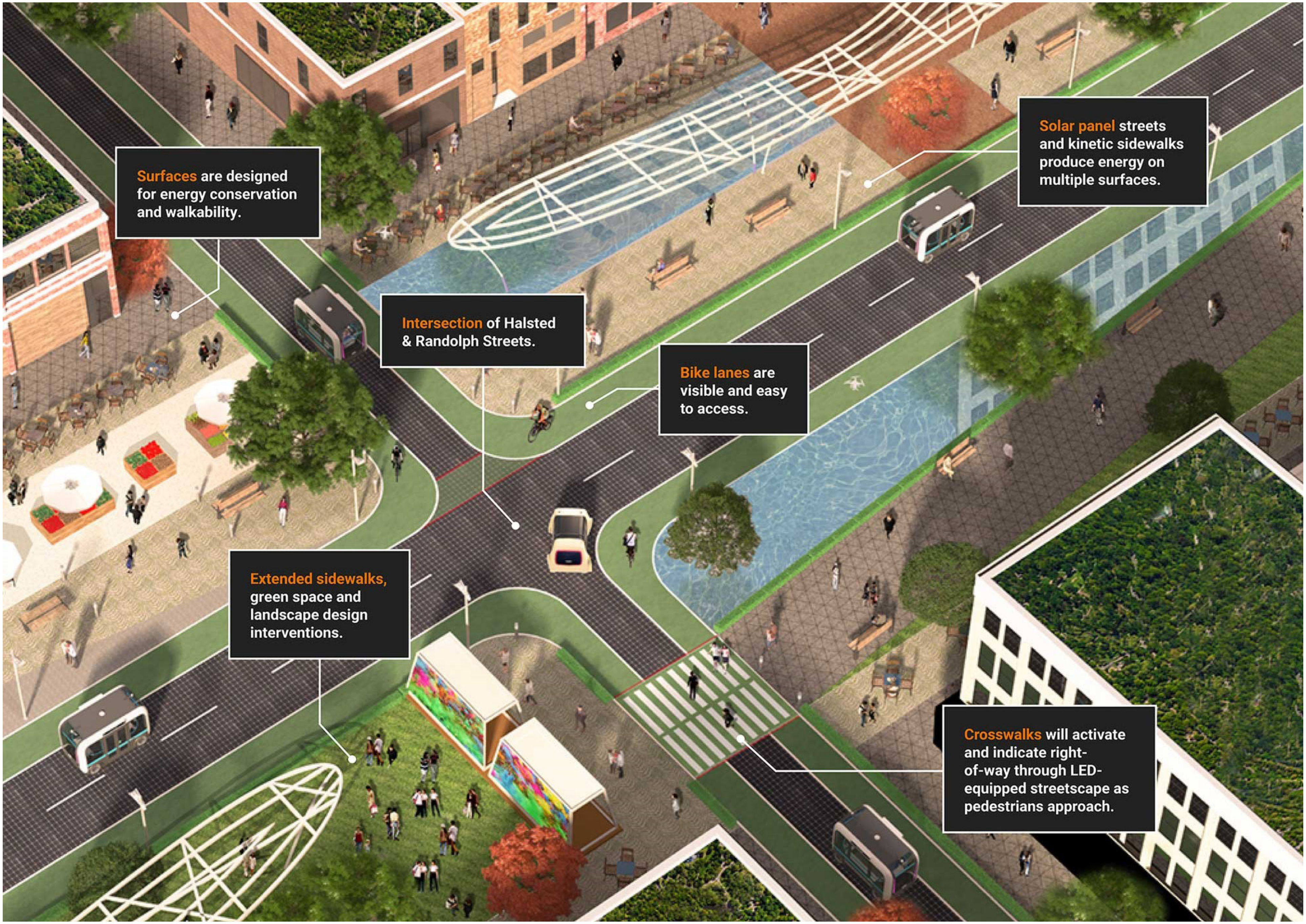


Figure 3.11: Randolph Street Design Elements (Source: Stantec, 2018)

Figure 3.12: FXCollaborative's Proposal for Reclaiming Public Space (Source: ArchDaily, 2017)

Firm: FXCollaborative
Project: Public Square

In 2017 Blank Space issued a challenge for designers to submit actionable solutions for a driverless future in New York City. The winner of the *Driverless Future Challenge* was FXCollaborative's entry *Public Square*. For their entry, the firm proposed a plug-and-play system of interlocking 8'x 8' squares which work to replace redundant public parking spaces with "integrated infrastructure, green spaces, play equipment, retail opportunities and urban furniture" (see Figure 3.13). Different combinations of these squares would work to create "endless varieties of public programs and amenities."[107] With this proposal, the designers recognized that change may come at a gradual pace, which is why they choose a system that could be introduced incrementally through a series of small interventions, all of which come together to form large modular networks of pedestrian friendly spaces. Furthermore, the plug-and-play nature of the system would allow streetscapes to adapt to new environments as the city around them changes. Winning this competition means that the designers will have the chance to make their visions a reality, as they will be working with fabrication facilities at Brooklyn's New Lab to begin testing prototypes of this system in real world spaces.

107 Bari, "The Driverless Future Challenge's Winning Entry Uses Plug-and-Play System to Reclaim Public Space for Pedestrians."

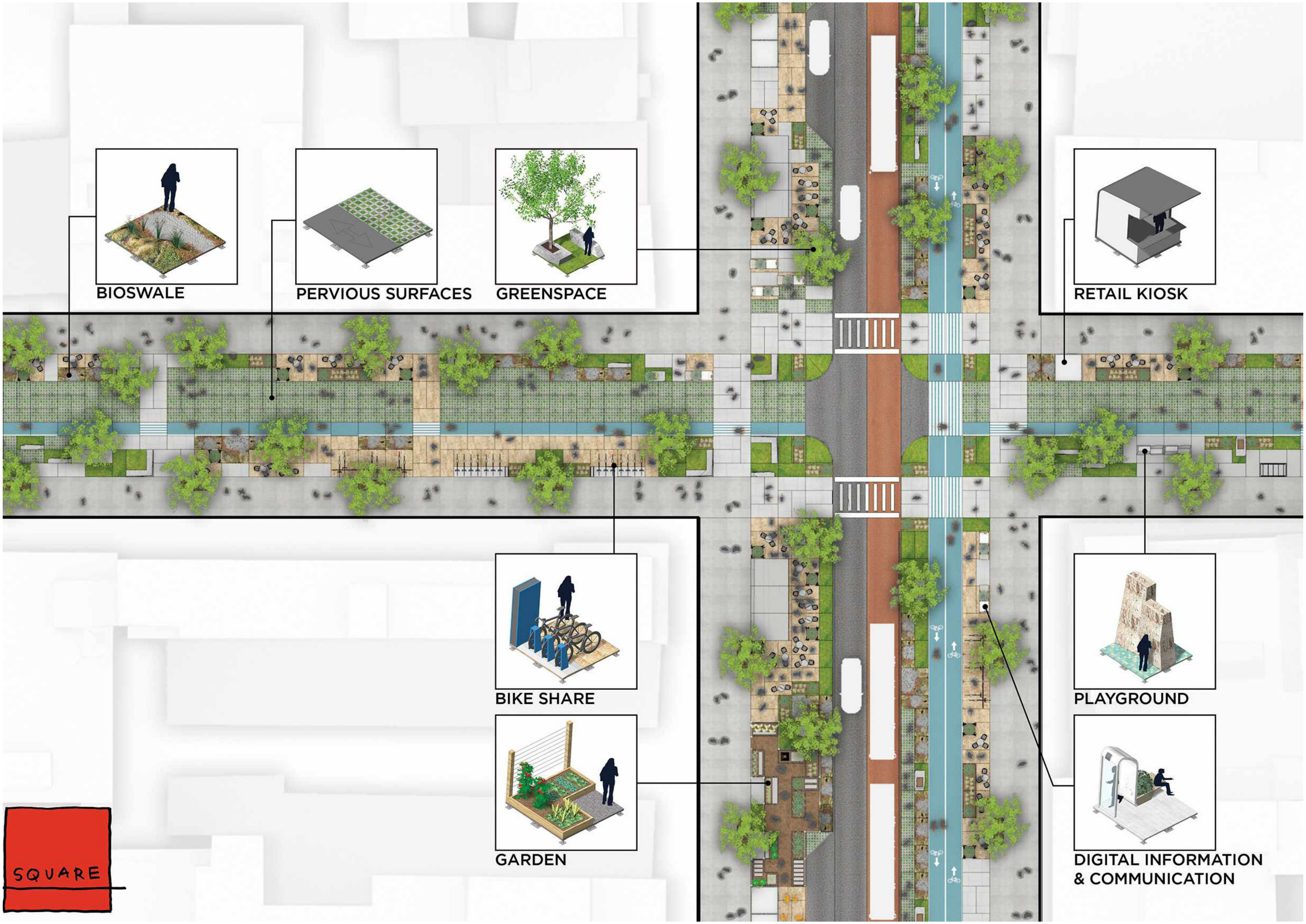


Figure 3.13: FXCollaborative's Plug-and-Play System (Source: ArchDaily, 2017)

CASE STUDY TAKEAWAYS

The preceding design case studies work to highlight a range of proposals put forth by design professionals. As previously stated, one of the goals of this research is to emphasize the role of design as both a tool to inspire and to challenge the typical notion of how streets are used and who we design for. These design case studies work to accomplish that goal. Some of the more radical proposals, such as HOK's Roadways for Human & Environmental Health and BIG's Plasti-City, push the limits of right-of-way design by introducing streetscape elements unlike anything proposed today. The final two case studies, Greg Kristo's Reimagining of Randolph Street and FXCollaborative's Public Square, although more rooted in reality, still work to challenge traditional right-of-way design by prioritizing the human experience over vehicular travel. All of these case studies have the potential to inspire, and to perhaps nudge consumers in the direction of accepting a shared autonomous vehicle system, by graphically representing the advantages of these potential futures.

Furthermore, early on in the design process of this thesis, these conceptual proposals worked to provide a base understanding of how designers were beginning to approach a future of autonomous travel. While not all of these proposals played a direct role in informing design decisions within the Seattle case study, they did assist in the establishment of this study's design objectives, which are explored in the next chapter of this thesis.

SEATTLE CASE STUDY

As previously stated, the overall objective of this thesis, and the focus of this chapter, is a creative exploration of a future scenario in which there has been a total shift in mobility and autonomous vehicles have superseded traditional cars. This chapter begins by establishing a basic methodology for the site selection, site analysis, and the conceptual design process. Next, the chosen neighborhoods are introduced, and a site analysis of these locations is conducted. This analysis focuses on essential land use data as well as current resident behavior. Following this, a baseline future scenario is established based on how autonomous vehicles may operate in a shared system. Next, the *Blueprint for Autonomous Urbanism,* the foundational framework utilized in order to guide the design decision making process, is described in greater detail. Then, the study's design objectives are established. Finally, six right-of-way design proposals are presented. Each proposal includes a brief overview of the current conditions for these sites, as well as any predictions for how these spaces may transform while this technology advances. This is followed by introducing the proposed conceptual designs and establishing the reasons for which specific decisions were made.

METHODOLOGY

NEIGHBORHOOD & SITE SELECTION

In order to explore future scenarios in which the right-of-way has been transformed through the full adoption of autonomous technology, existing street classifications established by City of Seattle were utilized in order to explore how these scenarios might play out across varying street typologies. The City of Seattle's new right-of-way improvement manual *Streets Illustrated* works to improve upon existing street classifications established by the American Association of State Highway and Transportation Officials by further refining these classifications using a process that emphasizes varying levels of mobility and direct access to property.[108] Ultimately, the city established twelve functional street types that can be found throughout Seattle (see Figure 4.1).

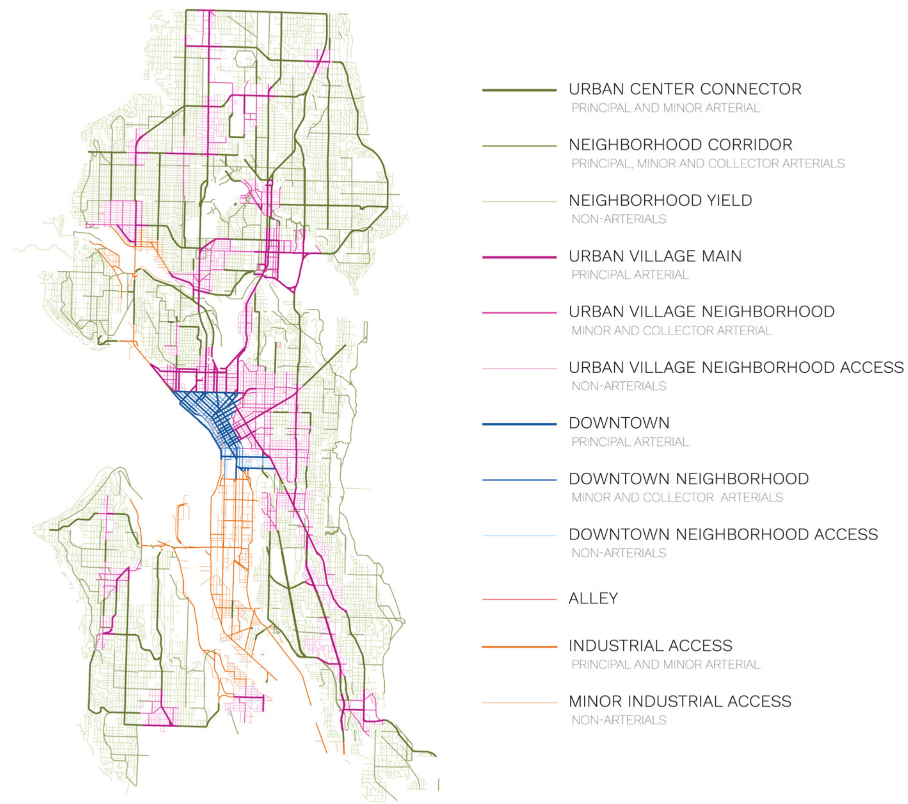


Figure 4.1: Seattle Street Type Classifications (Data Source: data.seattle.gov)

108 City of Seattle, "Streets Illustrated."

Rather than exploring street typologies throughout the Seattle area, existing neighborhood boundaries within the city were chosen in order to investigate these potential changes at a smaller and more recognizable scale. Scaling down the area of investigation also allowed for more detailed site analysis. Perhaps the largest determining factor when considering which neighborhoods should be considered for this exploration was the variety of street types found within their boundaries. In order to determine which neighborhoods were suitable for this study, geographical information systems (GIS) software (ArcMap) was used. Two shapefiles obtained from the City of Seattle's open data portal, Street Network Database and Neighborhoods, were used in this investigation. The Street Network Database shapefile includes all of the improved, travel pathway infrastructure within the city. This file includes a column which allows this data to be categorized by the newly established street types. The Neighborhoods shapefile includes the unofficial delineation of neighborhood boundaries established and used by the office of the city clerk. This shapefile includes both larger, broad neighborhood districts, as well as smaller, localized neighborhoods. ArcMap was then used, through various selection and clipping procedures, to determine the variety of street types found within these unofficial neighborhood delineations (see Figure 4.2).

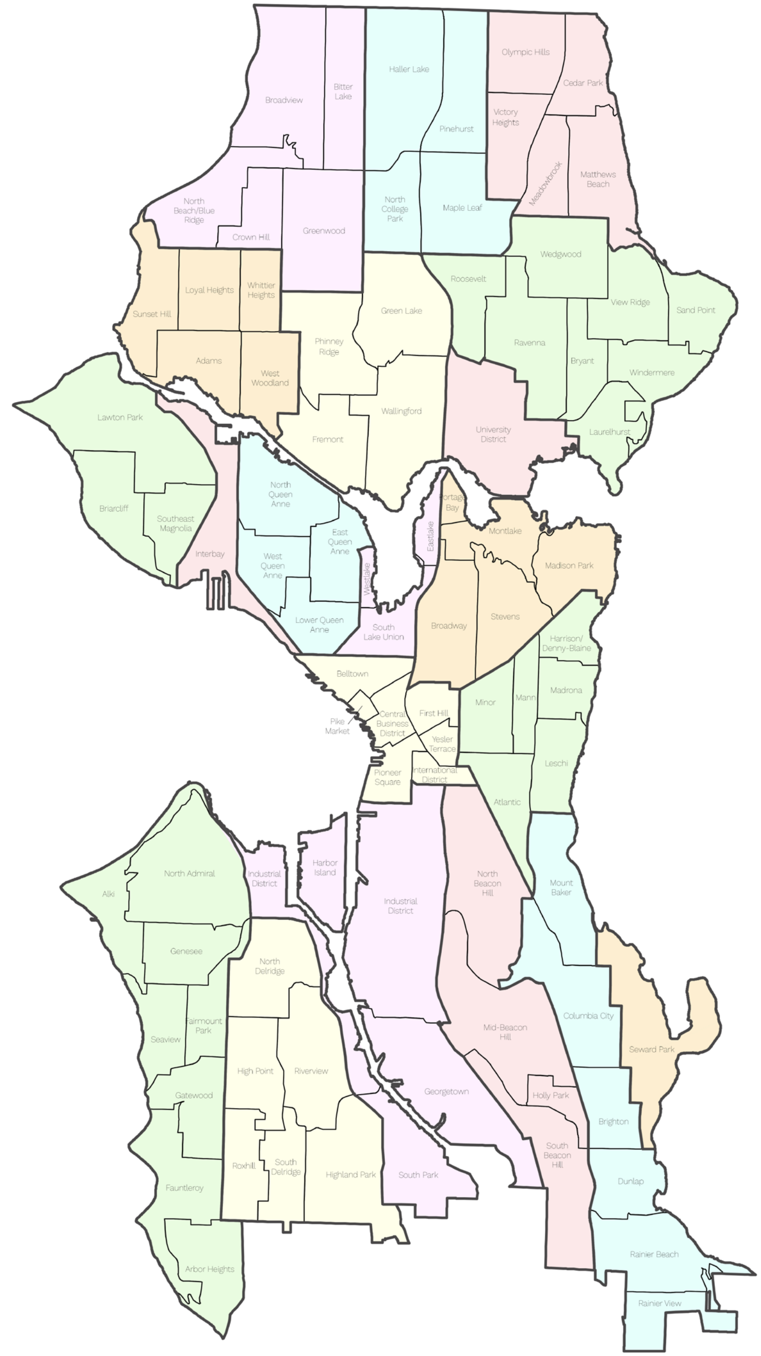


Figure 4.2: Seattle Neighborhood Boundaries (Data Source: data.seattle.gov)

In addition to the variety of street types found within the neighborhood delineations, other factors were also considered when determining which neighborhoods should be considered for this study. This included looking for neighborhoods with varying character, building typologies, and public transit. This was done in order to ensure that these right-of-way explorations, while localized in nature, could be seen as models that may be applied to locations with similar conditions throughout the City of Seattle as well as other urbanized areas.

Once a boundary of exploration was established it was necessary to determine which street types within this boundary would be explored, and where these right-of-way explorations would take place within this boundary. The primary determining factor is choosing which street types would be selected, and the locations for these explorations, was based around the notion of creating a set of design proposals that fairly accurately represented typical neighborhood typologies and street topologies established in the *Streets Illustrated* manual. Again, this was done in the hope that while these explorations represented specific local places, the interventions could be seen as potentially applicable to similar locations within other urban neighborhoods. The six chosen neighborhood and street typology combinations are described in Table 4.1. In the case of the single family residential neighborhood / neighborhood yield street type, more than one location was chosen in order to explore varying aspects of this combination.

	Neighborhood Type	Street Typology
1	Single-Family Residential	Alley
2	Single-Family Residential	Neighborhood Yield
3	Single-Family Residential	Neighborhood Yield
4	Multi-Family Residential	Urban Center Connector
5	Commercial District	Urban Village Main
6	Mixed-Use	Urban Village Connector

Table 4.1 - Case Study Neighborhood and Street Typology Combinations

The goal of this research was not to explore every street or neighborhood typology found within a typical city, or even all of those found in the chosen neighborhoods, but to choose a limited number and explore them in a more in-depth manner. These specific neighborhood and street typology combinations were in part chosen based on feedback from design professionals and city employees received during studio critiques.

SITE ANALYSIS

Once neighborhood boundaries were established additional site analysis was performed in order to better understand the study area and its inhabitants. This was done in order to both confirm this as an applicable neighborhood, as well as work to understand how a transition to autonomous mobility may impact this space. This work was largely conducted utilizing ArcMap.

CENSUS DATA

Census data was used in order to understand the travel behavior of the neighborhoods inhabitants. Two different topics were investigated, and data was studied at the census tract level. To begin, shapefile data containing local census tract boundaries was obtained from the United States Census Bureau. These census tracts did not perfectly align with established neighborhood boundaries, and only those for which the majority of the census tract lies inside the neighborhood boundary were included in this analysis. Next, census information from the American Community Survey was obtained through the bureau's American Fact Finder tool. Information was obtained regarding the number of vehicles available per household and the means of transportation for workers 16 years and over. ArcMap was then used to join these figures with the census tract shape files in order to obtain visual representations of this data.

PARKING & RIGHT-OF-WAY

Because parking, both on and off the street, will play a major role in a transition to autonomous mobility, GIS data obtained from the City of Seattle's open data portal was used to better understand the role of parking within the chosen neighborhood boundaries. Two shapefiles were used for this investigation, Parking Categories and Public Garage or Parking Lot. The Parking Categories shapefile calculates parking attributes at the blockface level within the City of Seattle. This data includes types of parking categories for each block, as well as the total number of parking spaces. The Public Garage or Parking Lot shapefile, as the title implies, includes point data for all public parking locations in the city. Additional attribute information also includes total number of spaces per location. Both of these shapefiles were clipped within ArcMap using the chosen neighborhood boundaries. This data was then used to visually represent a current understanding of parking infrastructure within the study area.

The amount of right-of-way within the study area was calculated using the Right of Way shapefile obtained through Seattle's Open Data Portal. This shapefile includes polygon data for all land utilized for right-of-way within the city. This shapefile was clipped using ArcMap to the neighborhood boundaries, and area calculations were performed in order to determine and represent the area of land dedicated to this use within the study area.

RIGHT-OF-WAY EXPLORATIONS

Once right-of-way sites were chosen within the study area the first step to begin exploring how these spaces may be reimagined after a total shift to autonomous mobility was to establish a base understanding of these spaces and how they currently function. The bulk of this work was performed in ArcMap using GIS shapefiles from the City of Seattle's Open

Data Portal. The files utilized were the Right of Way polygon shape file, the Pavement Edge polyline file, and the Lane View polyline file. As previously stated, the Right of Way file provides coverage of land dedicated to the right of way. The Pavement Edge file delineates the edges of streets / curb lines, while the Lane View file provides information regarding traffic lanes such as lane type and width. These files were used simultaneously in order to understand the overall extent of the right-of-way, as well as how the space is divided between uses. There were however some gaps in this information that needed to be filled in using other means. Certain streets lacked Lane View data, and sidewalk data was not available for any of the locations. In these instances, Google Maps/Street View was used to measure these spaces. This provided a general understanding of the missing data, which combined with a general knowledge of street design / layout filled in the missing gaps.

This right-of-way data was then exported from ArcMap and imported into SketchUp, a 3D modeling computer program. SketchUp was then used to create 3D representations of existing conditions. Additional site details, such as building size and type, street trees / vegetation, and other various right-of-way elements were recorded using in-person site visits and Google Maps/Street View and included these models. These models were then used as base to begin exploring design possibilities for each site location.

WINTER 2018 THESIS DESIGN STUDIO

Throughout the winter quarter of 2018 the landscape architecture thesis design studio, taught by instructor Julie Parrett, provided the opportunity to begin to explore how the *Blueprint for Autonomous Urbanism* could be applied to the chosen site locations, as well as the opportunity to investigate design possibilities that fall outside the scope of the document. More specifically, this studio time was largely dedicated to exploring various design interventions that ultimately resulted in several conceptual alternatives for each site location. Each conceptual alternative typically included a variety of elements that all came together to form a unique design narrative. One on one desk critiques with the instructor helped guide the design process and clarify these themes. Studio work was presented twice throughout the quarter, once during a mid-quarter review, and again during the end-of-quarter / mid-thesis review. These reviews provided the opportunity to share the work and receive constructive feedback and guiding advice from other university faculty, design professionals, and employees of the City of Seattle's Office of Planning & Community Development. This feedback was often incorporated into later iterations of these narratives and helped to guide final design decisions.

FINAL RIGHT-OF-WAY DESIGNS

The final stage of design for each of the right-of-way investigations began by first establishing design objectives that would apply to each site location, unlike the winter design studio, in which design proposals were based on several disparate narratives for each location. This decision was made in an effort to approach these final reimaginations of the right-of-way in a more cohesive and consistent manner across the study area. These design objects were considered alongside the policies and principles established in the *Blueprint for Autonomous Urbanism* in order to make final design decisions for each location.

In addition to the blueprint for autonomous urbanism, several other design guides were consulted throughout the design process. These include NACTO's *Urban Street Stormwater Guide*, *Global Street Design Guide*, *Urban Bikeway Design Guide*, *and Transit Street Design Guide*. The City of Seattle's *Streets Illustrated* guide was also consulted.

Due to the fact that the final designs envision a future in which autonomous mobility has fully superseded traditional forms of transportation, it is likely that these locations will have undergone other changes in this time. These changes would most likely take the form of increased development, and these changes are represented in the final representations. Three key resources were consulted in order to make informed decisions regarding how these changes may occur. These include the *Seattle 2035 Comprehensive Plan*, Seattle's Mandatory Housing Affordability zoning proposals, and the *Seattle 2035 Urban Village Study*.

Final design representations, as well as existing condition comparisons, were modeled using Sketchup and the previously imported right-of-way data. Adobe creative suite was then used to render these illustrations.

NEIGHBORHOOD INTRODUCTION & ANALYSIS

For this study, the neighborhoods of Broadway and Stevens, both within the larger neighborhood of Capitol Hill, were chosen (see Figure 4.3). While these two neighborhoods were chosen for several reasons, the principal motivation was working to ensure that there was a fairly wide variety of street and neighborhood types to explore within the chosen study area. As seen in Figure 4.4, seven of the twelve street topologies established in the *Streets Illustrated* manual are found within the Broadway and Stevens neighborhoods. Due to the fact the streets typologies established in *Streets Illustrated* manual are partially based on direct access to specific property types, it was assumed that a variety of neighborhoods typologies would be found within this boundary. However, in person site visits, as well as a general familiarity of these neighborhoods, ensured that there were a variety of neighborhood typologies within Broadway and Stevens. In addition to this primary motivation, these neighborhoods were also chosen based on their overall recognizability for those familiar with the City of Seattle, and the fact that major transit and bicycle networks run through them.

Figure 4.3: Case Study Neighborhood Selection (Data Source: data.seattle.gov)

STREET TYPOLOGIES

BASED ON SEATTLE RIGHTS-OF-WAY IMPROVEMENT MANUAL

URBAN CENTER CONNECTOR
PRINCIPAL AND MINOR ARTERIAL

NEIGHBORHOOD CORRIDOR
PRINCIPAL, MINOR AND COLLECTOR ARTERIALS

NEIGHBORHOOD YIELD
NON-ARTERIALS

URBAN VILLAGE MAIN
PRINCIPAL ARTERIAL

URBAN VILLAGE NEIGHBORHOOD
MINOR AND COLLECTOR ARTERIAL

URBAN VILLAGE NEIGHBORHOOD ACCESS
NON-ARTERIALS

ALLEY

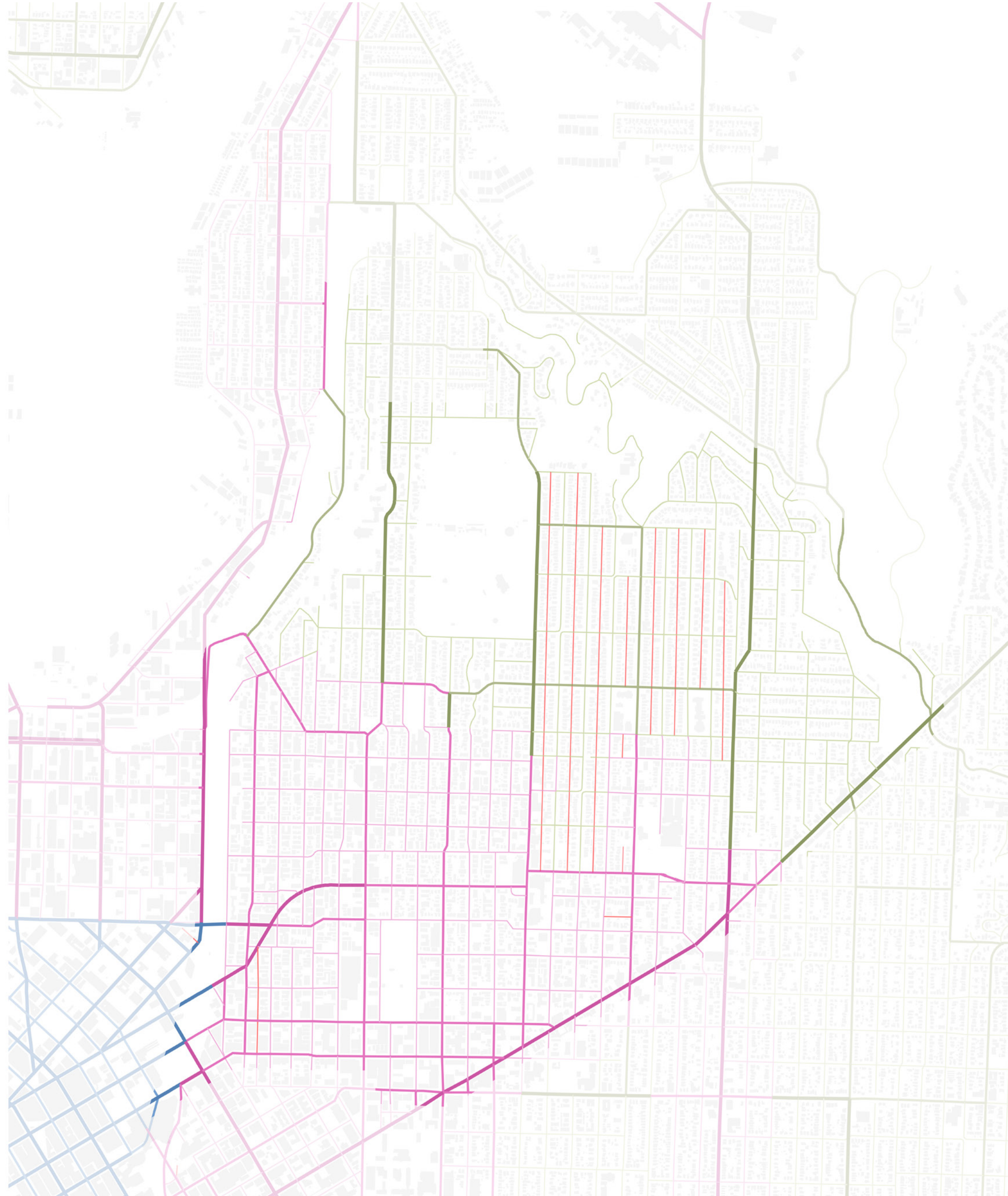


Figure 4.4: Neighborhood Street Typologies (Data Source: data.seattle.gov)

Neighborhood Analysis begins by first exploring the behaviors of the current residents of the Broadway and Stevens Neighborhoods through census data. One thing to note before exploring these findings is that fact that a portion of the Broadway and Stevens neighborhoods fall into the Capitol Hill / First Hill Urban Village. Within the city of Seattle these urban villages are part of the city's solution to creating sustainable places and accommodating future growth. They are designed to be "self-sustaining hubs with their own identity and a balance of mixed uses of commercial and community services," as well as a variety of housing stock, all within walking distance.[109] The majority of census tracks 74.01, 74.02, and 75 fall within this urban village

First, looking at the means of transportation to work for those living within census blocks within the chosen neighborhoods begins to establish both a desire for automobile travel, as well as other means of transportation (see Figure 4.5). As can be seen in the figure, the majority of the residents of these neighborhoods drive alone to work. However, it is also significant that half of these residents either take public transportation or walk. Higher proportions of residents within the census tracks that fall within the urban village (where non-personal vehicular modes of transportation are prioritized) walk or take public transportation to work compared to those census tracks outside of the urban village boundary.

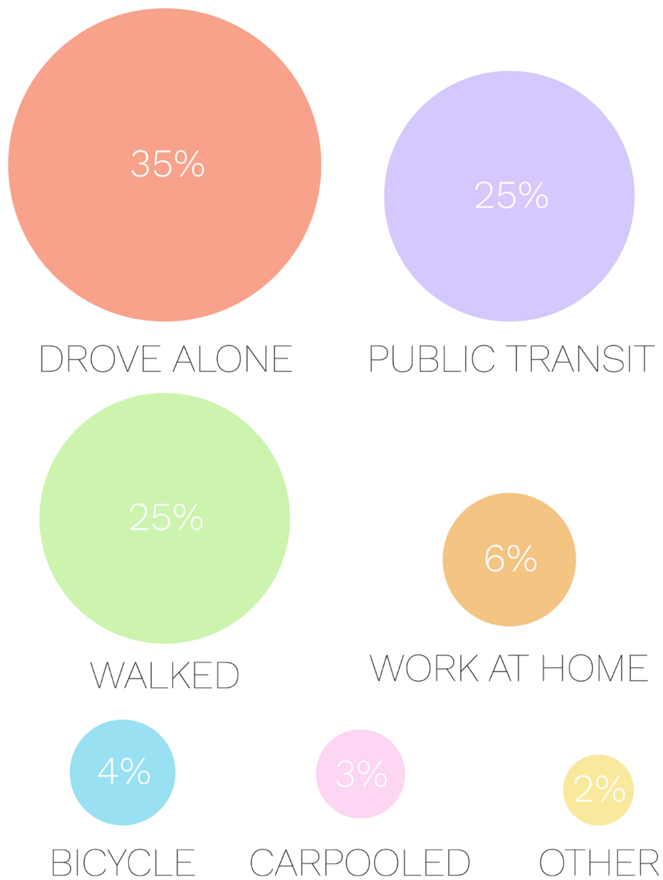
Next, the number of vehicles available per household was studied in order to gauge the total number of vehicles available within the study area. As can be seen in Figure 4.6, the majority of households have access to one or more vehicles. This finding is interesting for two reasons. First, the fact that the majority of households have access to one or more vehicles, but only 35% of people drive alone to work, means that a significant proportion of these vehicles are used primarily for trips outside of commuting to work. Second, is also interesting that the majority of households within census blocks that fall within the urban village boundary similarly have access to one or more vehicles. As previously stated, within urban villages non-personal vehicular modes of transportation are prioritized. While prioritizing non-personal vehicular travel for trips to work seems to be working, the majority of these residents (for one reason or another) still prefer having access to an automobile. In fact, between 2010 and 2013 car registrations increased a faster pace than population growth within the Capitol Hill / First Hill Urban Village.[110] While further research would be needed to confirm this hypothesis, a desire to have access to an automobile that is only used occasionally could potentially make many residents of these neighborhoods ideal candidates as users of a shared autonomous vehicle system.

109 Tsenkova, "The Urban Village Strategy in Seattle," 3.
110 Balk, "The Surprising Places Where Car Ownership Is up in Seattle."

MEANS OF TRANSPORTATION TO WORK

WORKERS 16 YEARS AND OVER

PROPORTIONALLY SIZED BY NUMBER OF WORKERS



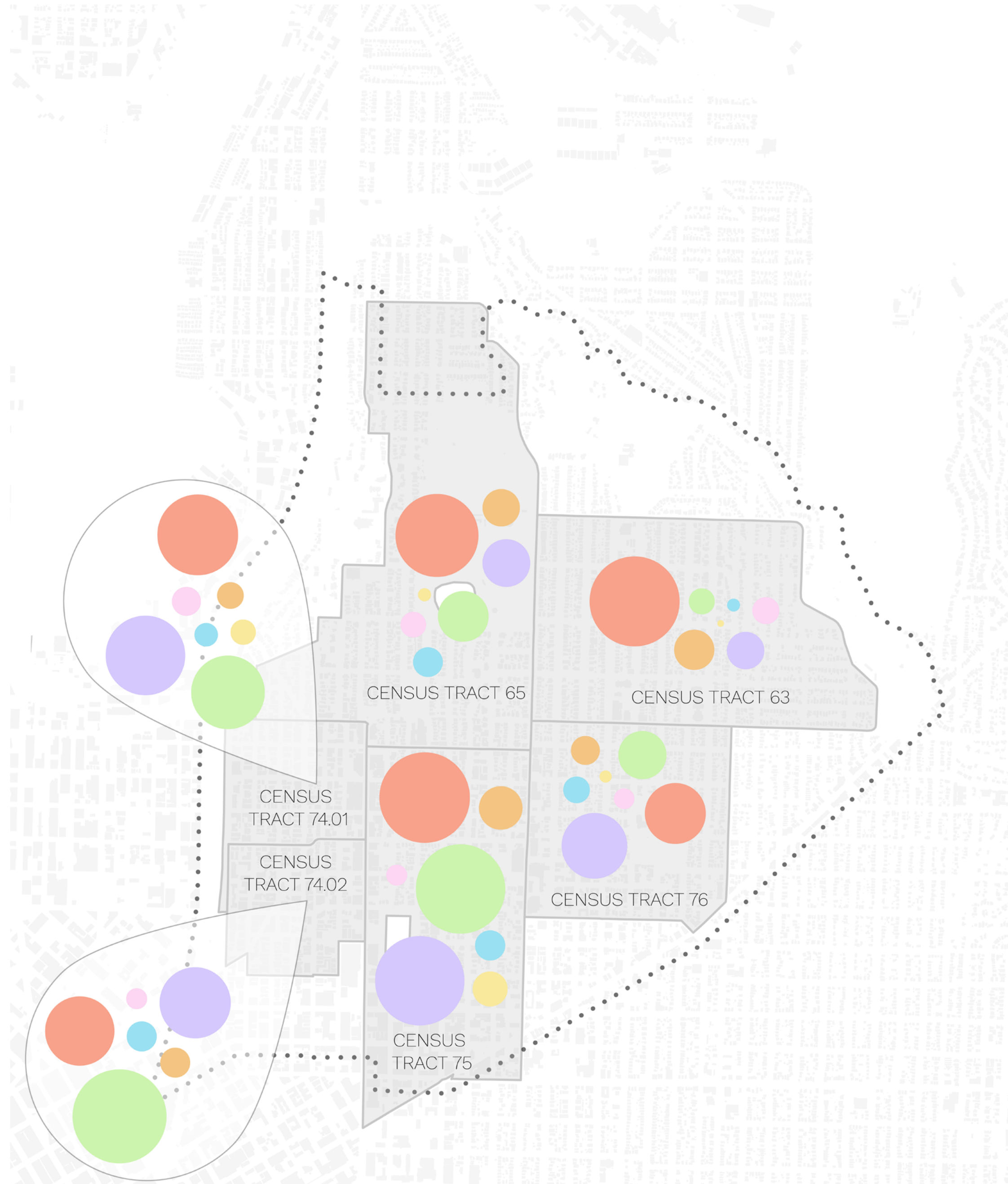


Figure 4.5: Neighborhood Transportation Statistics (Data Source: data.seattle.gov)

NUMBER OF VEHICLES AVAILABLE

PER HOUSING UNIT

PROPORTIONALLY SIZED BY NUMBER OF HOUSEHOLDS

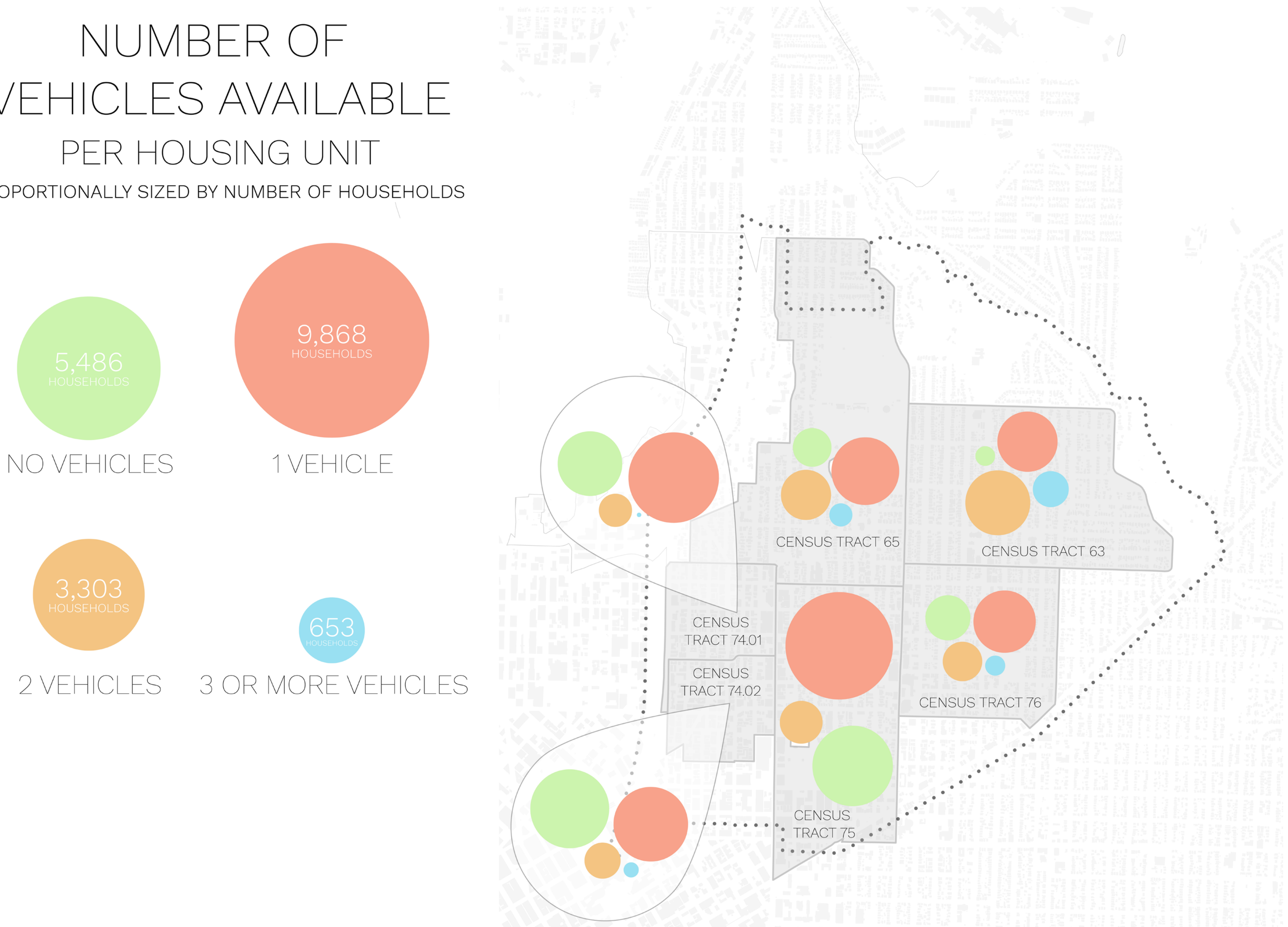


Figure 4.6: Household Vehicle Data (Data Source: data.seattle.gov)

Moving on from the behaviors of current residents, the next portion of the site analysis focuses on the right-of-way. This begins by first exploring the percentage of land dedicated to this function. As seen in Figure 4.7, a significant portion of land (32%) within these neighborhoods is being utilized as right-of-way. This is important to note because it shows the potential for how much land may be reconfigured after a switch to autonomous mobility. Next, an exploration of street parking spaces was conducted. As previously stated, the potential to completely eliminate street parking will have a significant impact on right-of-way design when the shift to a shared autonomous system occurs. Figure 4.8 shows the characteristics and the extent of the space dedicated to street parking with the Broadway and Stevens neighborhoods. With each street parking space taking an estimated one-hundred and forty square feet of space (as discovered in the metadata of the Parking Categories shapefile), the total space within these neighborhoods is approximately 42 acres, or 10% of the right-of-way. Again, this is a significant figure as it begins to paint a picture of how much land within these neighborhoods may be repurposed for higher-value activities.

Finally, the last piece of site analysis considers the number of public parking spaces found within off-street surface lots and parking garages within the study area (see Figure 4.9). Although this thesis primarily explores changes within the right-of-way, it is important to consider where shared autonomous vehicles may locate themselves when they are not being used. This exploration of public parking spaces begins to paint a picture of locations within these neighborhoods in which these vehicles may be stored. Given the significant decrease in the need for parking infrastructure as explored in chapter two, not all of these parking facilities would be needed under a shared autonomous system. Storing vehicles locally is important for two main reasons. First, there an equity concern related to the storage of autonomous vehicles should their storage locations be sited within low-income neighborhoods. Second, it is important to consider local storage options in order to ensure there is not a significant increase in vehicle miles traveled due to these vehicles traveling long distances empty. In addition to public parking spaces, existing private parking facilities may be considered as storage locations.

LAND DEDICATED TO THE RIGHT-OF-WAY

WITHIN BROADWAY & STEVENS NEIGHBORHOODS

417

ACRES

32%

OF TOTAL LAND AREA

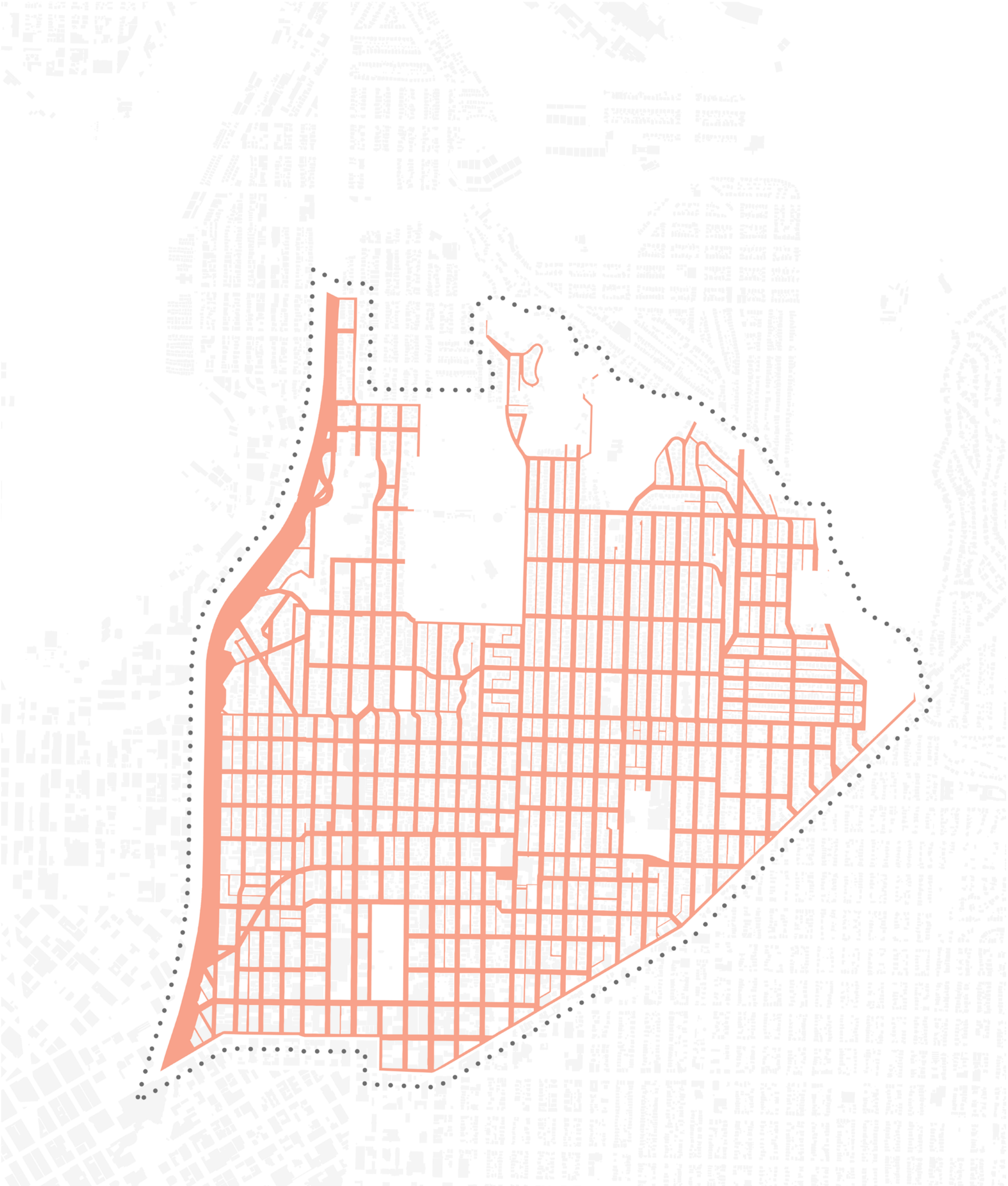
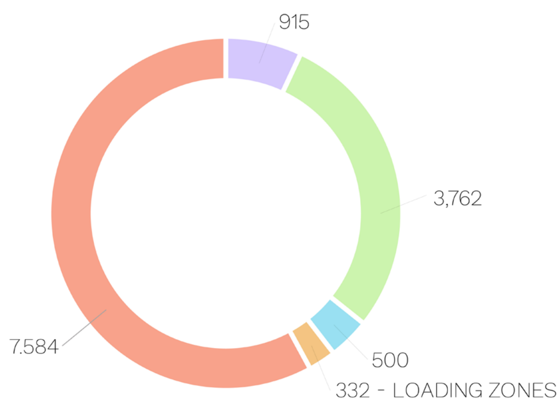


Figure 4.7: Neighborhood Right-of-Way Statistics (Data Source: data.seattle.gov)

STREET PARKING CATEGORIES & NUMBER OF SPACES

WITHIN BROADWAY & STEVENS NEIGHBORHOODS

- UNRESTRICTED PARKING
- PAID PARKING
- ZONED PARKING
- TIME LIMITED PARKING
- NO PARKING



13,093 TOTAL PARKING SPACES = **42** ACRES **10%** OF RIGHT-OF-WAY

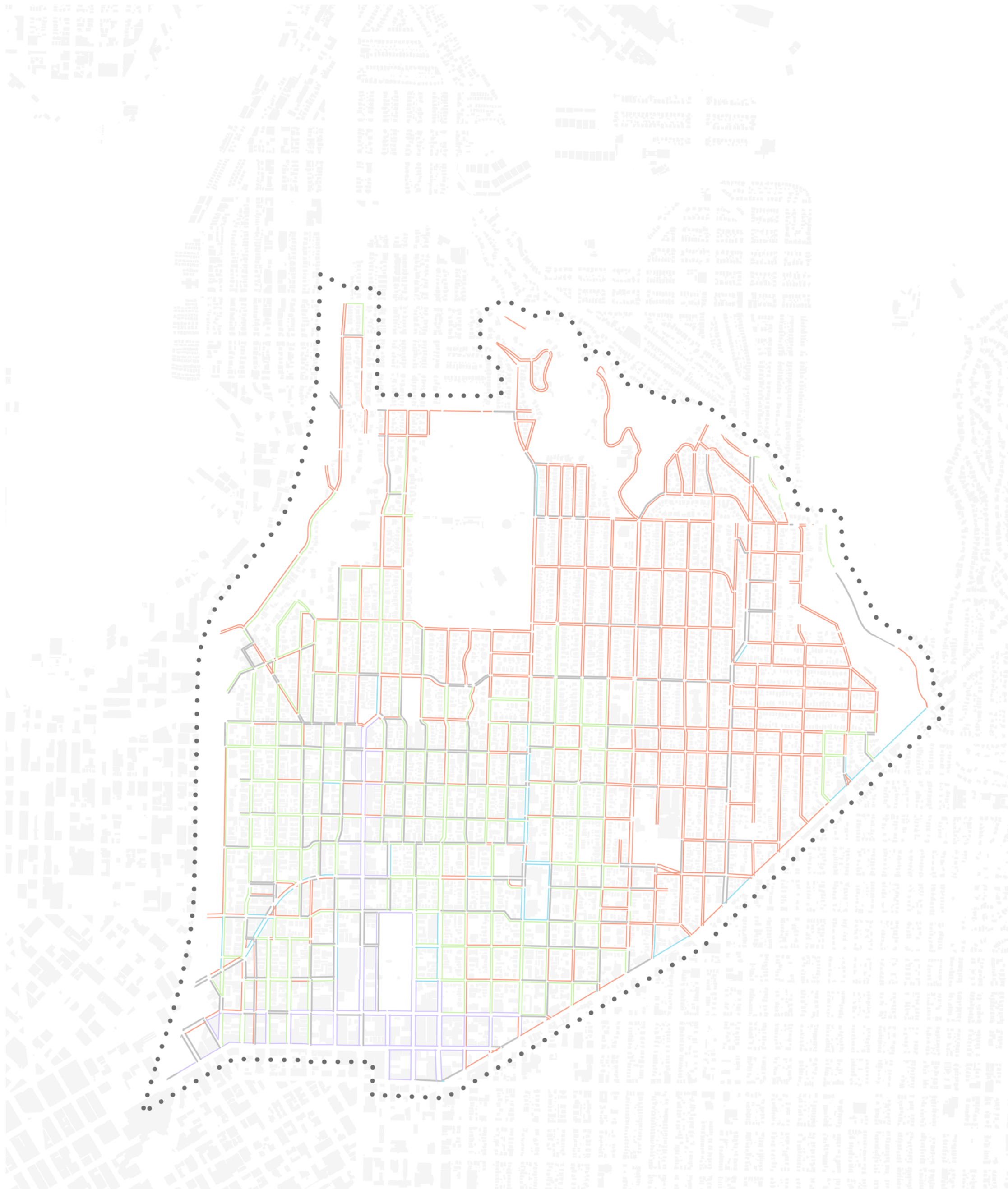


Figure 4.8: Neighborhood Street Parking Statistics (Data Source: data.seattle.gov)

PUBLIC PARKING: SURFACE LOTS & GARAGES

WITHIN BROADWAY & STEVENS NEIGHBORHOODS

PROPORTIONALLY SIZED BY NUMBER OF SPACES

2,969 TOTAL SPACES

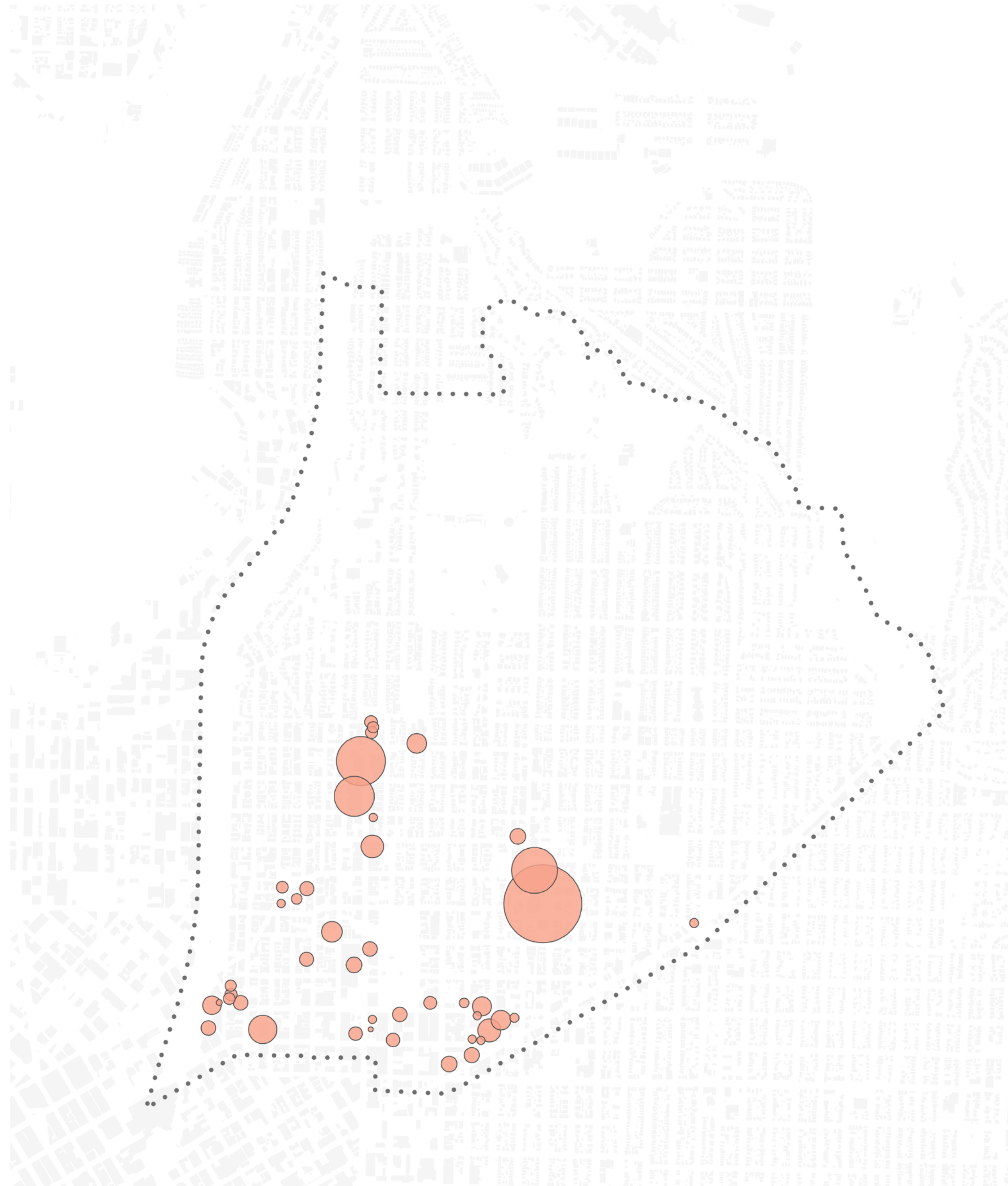


Figure 4.9: Parking Lots & Garages (Data Source: data.seattle.gov)

ESTABLISHING A BASELINE SCENARIO

As previously discussed, two of the more challenging questions to answer when it comes to predicting the future of autonomous mobility are when will this transition occur, and who will own these vehicles? The section of this thesis which focused on exploring these two topics provided a range of interesting insights, but as was discovered there is no easy way to determine any exact future outcomes with a significant level of certainty. The following sections of the thesis did however provide interesting insights as to how a system of shared autonomous vehicles may function in an urban environment. With all of this in mind, it does not seem to make sense to attempt to make any finalized or overly detailed predictions regarding when and exactly how this transition will occur, such as a specific year the shift will occur or the number of people who will partake in vehicle sharing, as there are currently too many unknown variables. Instead, this design case study will proceed under the basis of seven broad but informed assumptions regarding how the autonomous revolution may occur. The fundamental assumptions that will guide this case study are outlined below.

- A major shift in urban mobility has occurred, and autonomous vehicles have completely superseded traditional modes of travel. Either through government regulation, consumer choice, or market pressure, the decision has been made that human driven vehicles no longer have a place on public roads.

- The vast majority of consumers have chosen to partake in shared autonomous vehicle programs. While there may be some who choose to continue to own their own vehicle, perhaps driven by a special need, these individuals will be the exception, not the rule. These shared vehicle systems will resemble the car sharing programs that are prevalent today, but at a much larger scale. They may include subscription based models as well as on-demand models. More than likely two potential modes of sharing will exist. Individuals may either choose to pay a higher premium to ride by themselves or with their family, and others may choose to share rides with friends, coworkers, or even strangers and as a result pay a lower cost fare. These two choices will not be mutually exclusive, and consumers may switch back and forth between them based on need.

• There has been a significant reduction in the number of vehicles on the road. As discovered in chapter two, the predicted share of shared autonomous vehicles required to meet the demands of an urban population is approximately 12% of current vehicle numbers. While this exact number is not assumed for this study, is it indicative of how substantial this reduction may be.

• The demand for parking will also be significantly reduced. This will be the combined result of the significant reduction in the number of vehicles on the road and the increased usage of these vehicles. Whereas cars today currently sit unused 95% of the time, these shared vehicles will be utilized in a much more efficient manner.[111] In this scenario in can be assumed that the need for street parking will be fully eliminated and instead there will be a focus on providing passenger and cargo pick-up and drop-off points along the right-of-way. When autonomous vehicles are not in demand, they will travel to specially designated facilities until they are needed, as discussed in the site analysis portion of this chapter.

• Autonomous vehicles have not eliminated the need for or the use of public transit. In fact, this system of shared vehicles will actually work the increase transit ridership by working to bridge the "existing gaps at the edges of transit systems" known as the last mile.[112] Providing door-to-door access from homes to transit hubs will work solve one of the main challenges facing increasing transit ridership today.

• There will be a significant increase in roadway capacity due to the fact that autonomous vehicles will be able to travel closer together and move through intersections more efficiently. This increase in capacity will provide opportunities to rethink the number of lanes dedicated to vehicular transit.

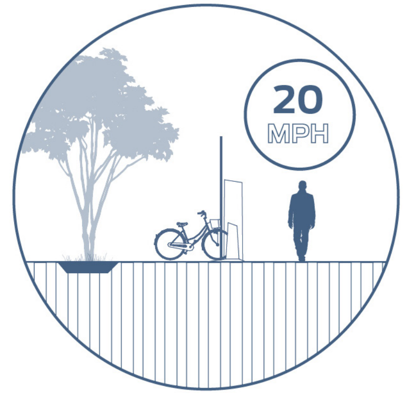
• There will be an influx of new vehicle types. Depending on how people choose to travel, either by themselves or with a group, where they are going, and what their personal needs are, a variety of purpose-built vehicles will be needed. This will range from small vehicles transporting single users short distances, to larger shuttle-like vehicles used for multiple rider sharing, and specially designed transport vehicles for making deliveries in an urban setting.

111 Morris, "Today's Cars Are Parked 95% of the Time."
112 Berman, "An Open Network of Autonomous Vehicles Could Solve the 'Last Mile' Problem."

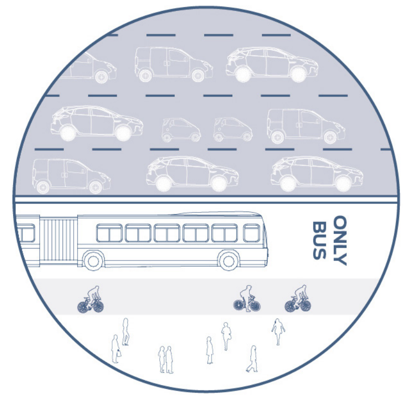
BLUEPRINT FOR AUTONOMOUS URBANISM

The main guiding framework used to assist in the process of making design and right-of-way allocation decisions for this study was the National Association of City Transportation Official's *Blueprint for Autonomous Urbanism*. As discussed in chapter three, there are six major principles that work to structure the entire report including: Safety is the Top Priority, Provide Mobility for the Whole City, Rebalance the Right-of-Way, Manage Streets in Real Time, Move More with Fewer Vehicles, and Public Benefit Guides Private Action.[113] While this entire framework will prove worthwhile when planning for a shift to autonomous mobility, some of these principles focus more on the policy aspects of this shift, and are not as applicable to this thesis. With that being said, three of these principles, as seen in Figure 4.10, and their associated policies are directly applicable to this study. These principles, as well as their applicable associated policies, are discussed in greater detail below.

Safety is the Top Priority: This principle focuses on ensuring the safety of all right-of-way users, with special attention being paid to pedestrians and cyclists. There are two policies listed under this principle that focus on right of way design and operation: *20 Is Plenty* and *Set Operating Principles that Prioritize People*. *20 Is Plenty* suggests that speed limits throughout urban areas be set appropriately in order to ensure the safety of



Safety is the Top Priority



Rebalance the Right-of-Way

Move More with Fewer Vehicles:

Figure 4.10: Autonomous Design Principles (Source: NACTO, 2017)

113 National Association of City Transportation Officials, "Blueprint for Autonomous Urbanism."

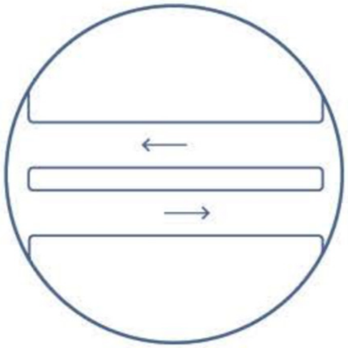
pedestrians and cyclists. NACTO suggests "twenty mph for most urban roads, twenty-five mph in very limited circumstances, with lower speeds (ten-fifteen mph) in downtown and neighborhood zones."[114] *Set Operating Principles that Prioritize People* focuses on the need to establish additional principles for the operation of autonomous vehicles and the design of city streets that also ensure the safety of all users.

Rebalance the Right-of-Way: This principle establishes the need to reconsider how space within the right-of-way is allocated. This principle lists three basic policies. First, *Stop Expanding Roads* suggests that municipalities begin to prepare for a shift to autonomous mobility now by updating any existing transportation plans in a manner that no longer considers expanding existing travel lanes. Second, *Take a Lane for Transit* advocates for transit-only travel lanes for critical corridors of high-volume transit where right-of-way space provides. This policy mostly applies to roads with wide right-of-way allocation, often in the downtown core. Finally, and perhaps most importantly, *Pavement for the People* advocates for underutilized spaces created through a shift to shared autonomous travel be programmed in a manner that prioritizes people in an effort to "create valuable public spaces in neighborhoods and downtowns alike."[115]

Move More with Fewer Vehicles: The primary focus of this principle is ensuring that streets are designed in a manner that provide and promote opportunities for travel via mass transit. Shared autonomous vehicles should not be seen as a substitute for publicly operated transit systems. Instead the adoption of these vehicles should promote the use of these systems through the creation of spaces that incentivize mass transit travel, and by working to serve as a means of last mile connections for major transit systems. One other important policy of this principle is *Prepare for a Future without Parking*. This policy suggests that planners begin to consider how a shift to autonomous mobility may impact parking demand, both on and off the street, and plan for the eventual reconsideration of this space.

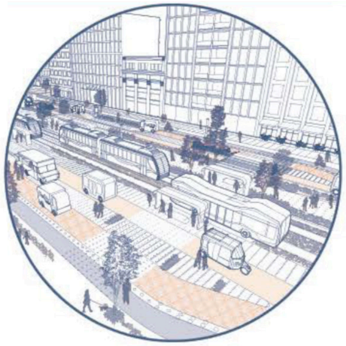
In addition to these broad principles and policies, the *Blueprint for Autonomous Urbanism* also goes on to suggest several specific street design recommendations based on the dynamics of the future street, each of which was considered when making right-of-way design and allocation decisions in the final design proposals. Figure 4.11 provides an overview of these recommendations. Lastly, this document goes on to provide additional specific design recommendations based on street typology types. The street typologies presented in this report range from large multi-way boulevards to small residential roads. While not all of these recommendations were applicable to the chosen right-of-ways in this study many of them where, and in these incidences these recommendations and their application are described in further detail in the final design proposals.

114 National Association of City Transportation Officials, 16.
115 National Association of City Transportation Officials, 16.



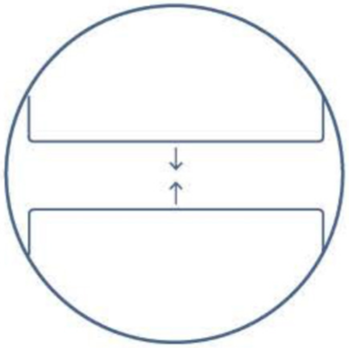
One Lane Each Way

Outside of highways, streets could be limited to a single lane of vehicle traffic in each direction, excluding dedicated transit lanes. Residential streets can be designed as "yield" streets to limit through traffic. Major streets should provide high-capacity bus or rail service. AV-only lanes should be discouraged.



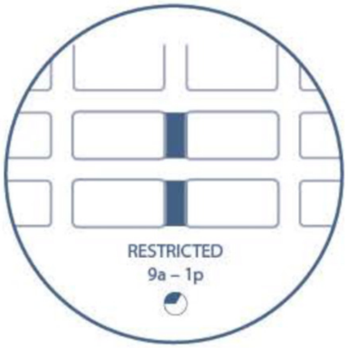
Surfaces Over Striping

In the long term, lanes should not be demarcated by markings, but instead be relatively flush with the sidewalk and median, with elements like bollards, accessible textured pavers, or other surface cues to demarcate uses in place of striping.



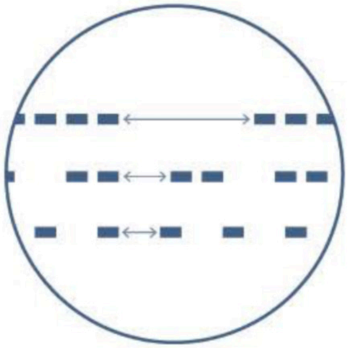
Lane Width

Lane widths can be kept to a minimum. In most urban environments, lanes of 10' or less suffice with controlled lane guidance, and streets without large transit vehicles can be even smaller if adjacent flexible space is available.



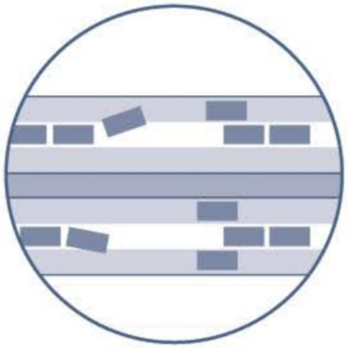
Time of Day Management

Streets could be managed actively according to different demand during different times of day. Certain thresholds of pedestrian activity may trigger closures, temporary 10 mph operation, or ensure re-routing to other parts of the network.



Manage Traffic Gaps

Cities should avoid creating robo-route arterials with endless platoons of traffic. With more passenger consolidation into multi-use vehicles and sufficient spacing between vehicles and platoons, pedestrians could have safer, more frequent crossing opportunities than traditional signalization can provide, achieving both safety and operational goals.



Manage Streets by Mode

Shared spaces, rather than separation, could define street operations in the future, especially on lower capacity streets. Motor vehicle traffic would be allowed at low speeds on many streets, diminishing some of the challenges of preserving freight access while dramatically expanding public space. As with truck routes today, some vehicle types could be forbidden from certain streets.

Figure 4.11: Dynamics of the Future Street (Source: NACTO, 2017)

DESIGN OBJECTIVES

One important thing to note about the *Blueprint for Autonomous Urbanism* is that, as the document itself states, it is “not a design guide” but rather a blueprint that works to lay “the groundwork and sets a vision for city streets in the automated future”.[116] Given this, there is flexibility in how this blueprint and how its established principles are applied to site, leaving room for individual design decisions. As stated in the methodology section, it was decided that instead of designing each individual location around an independent narrative or theme, a set of design objectives would be established. By doing so, design decisions made across the study area come together to form a cohesive and consistent set of final right-of-way conceptual design proposals. While the designs for each space work to fulfill these design objectives, they do so in a manner that responds to the unique characterizes of each individual location. For the final explorations, two specific design objectives were established:

1: Improving the pedestrian experience within the right-of-way

2: Providing spaces for ecological function within an urban context

These design objectives were chosen for two primary reasons. First, they were selected as a reaction to what has occurred within the right-of-way as a result of the mass adoption of personal automobiles. As previously stated, transportation planning decisions in the past typically prioritized vehicular travel, often at a cost to pedestrians and the environment. Provided with the opportunity to rebalance the right-of-way, it felt appropriate to prioritize what was often ignored in the past. Second, the design case studies in chapter three also helped to confirm these two objectives as a meaningful approach, as each of these case studies featured design elements which focused on these two objectives.

116 National Association of City Transportation Officials, 8.

CONCEPTUAL DESIGN PROPOSALS

The final product of this thesis is six conceptual design proposals which explore the future of autonomous mobility and right-of-way design for the sites listed in Figure 4.12. Each of the following sections include a brief site introduction and growth predictions for the location. Finally, the proposed conceptual designs, and the motivations for why specific design decisions were made, are introduced. As previously stated, while these conceptual design proposals are localized in nature, these six street and neighborhood typology combinations were chosen in a hope that these proposals may be seen as models that may be applied to similar locations within other urban neighborhoods.

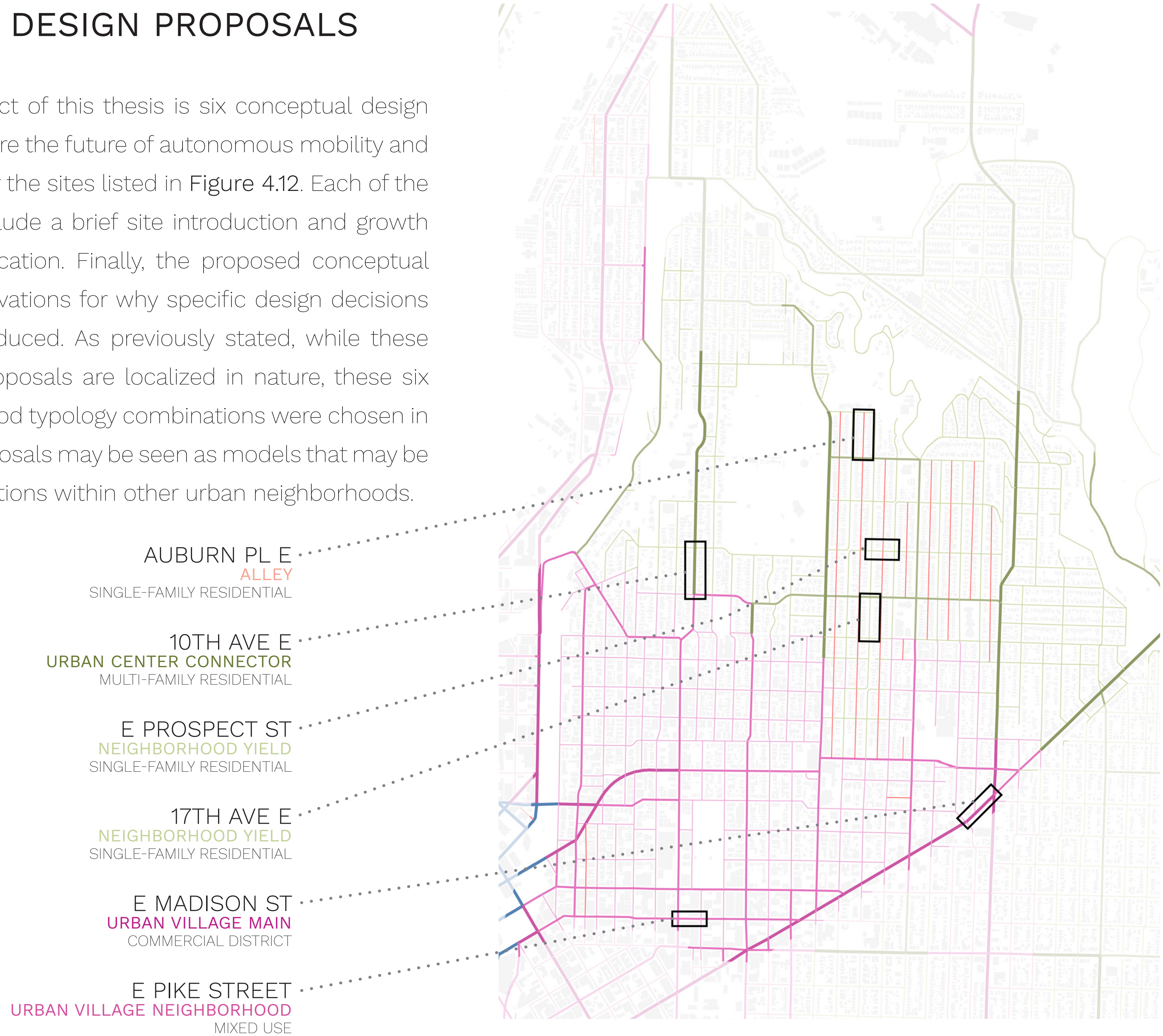


Figure 4.12: Seattle Case Study: Site Locations, Street Classifications, and Neighborhood Typologies

AUBURN PL E

BETWEEN E GARFIELD ST & E GALER ST

ALLEY

SINGLE-FAMILY RESIDENTIAL

Figure 4.13: Auburn Pl E Existing Conditions (Source: Google Street View)

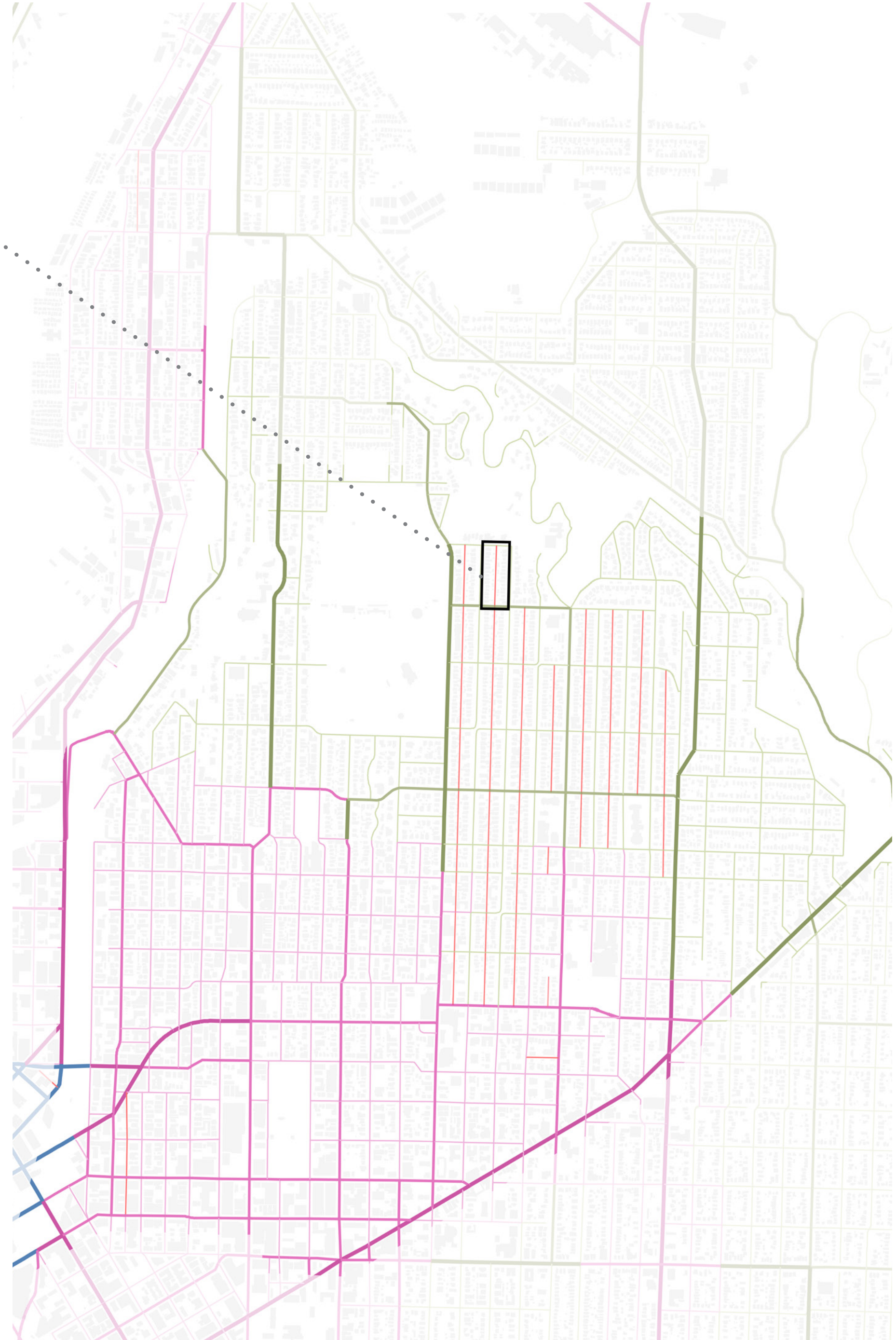


Figure 4.14: Site Location: Auburn Pl E

EXISTING SITE CONDITIONS

Auburn Pl E is an alley that runs through a single family residential neighborhood within the Stevens Neighborhood of Capitol Hill. This alley, and many others like it in this neighborhood, runs north-south between single family homes. It is primarily utilized as a means of accessing the parking structures that line the length of the space. Many of these structures, as well as other auto-oriented elements, have begun to encroach upon the right-of-way. Due to this, this alley and others like it have begun to lose their sense of publicness, as their primary function is serving to vehicular needs or the local residents.

GROWTH PREDICTIONS

The neighborhood surrounding Auburn Pl E is currently zoned as Single Family 5000.[117] At this point in time there is no indication that this space may begin to shift towards a greater density of housing. Nevertheless, should this space experience residential housing growth it would not significantly impact of the proposed design changes, as they are meant to serve as a model that could be applicable for a variety of residential neighborhoods.

117 City of Seattle, "Generalized Zoning Map."

Figure 4.15: Auburn Pl E Design Proposal

① **Bicycle Path:** Although bicycle travel will be welcomed on most streets after a shift to autonomous mobility, this dedicated bicycle path provides an opportunity for cyclists to take an alternative, and perhaps more relaxed, route. At six feet wide this path, which will likely not be too heavily traveled, provides adequate space for passing or travel in both directions, but also provides an opportunity for cyclists to ride two abreast when traffic is limited.[118]

② **Additional Backyard Space:** Because vehicular travel will be restricted in this alley, there will no longer be a need for the large parking structures that take up a significant amount of private space. Once removed this land can be utilized in new ways, such as providing opportunities for increased planting, additional outdoor recreational space, or as a space for smaller storage structures.

③ **Pollinator Planting Path:** In addition to providing opportunities for cyclists and pedestrians to move through this reclaimed space, this alley could also function as a corridor for crucial pollinator species. Urban growth tends to disrupt the movement of native pollinator spaces by fragmenting their habitat, and this corridor would work to bridge the gap between these spaces.[119]

④ **Pedestrian Path:** As with cyclists, space for pedestrians within the right-of-way will be significantly improved thanks to the full adoption of autonomous vehicles. However, there may be some who desire an alternative path to move through these urban spaces, and the dedicated pedestrian path would provide just that. This path would provide a more scenic route for those moving through this neighborhood and could function as a more direct route for local residents to move between houses. Opportunities to pause, such as small benches would be provided, and a path constructed of permeable pavers would reduce storm-water runoff in this space.[120]

Transforming this alley from a space that was once fully dedicated to vehicular travel to one aimed at improving movement for cyclists, pedestrians, and pollinator species is one of the more drastic outcomes of a transition to autonomous mobility (as seen in Figure 4.17). A system of shared autonomous vehicles would eliminate the need for private parking structures and creates the opportunity to fully restrict vehicular travel in this space. The *Blueprint for Autonomous Urbanism*, as well as the other design frameworks, do not have any specific recommendations for alleys. With this in mind design decisions were primarily based on meeting the two major objectives of this exploration, improving pedestrian experience and ecological function. One important aspect of this design proposal to note is that it is primarily aimed at residential neighborhoods. Alleyways within commercial and mixed used spaces have a variety of different needs and regulations, and fully restricting vehicular travel in these spaces may be always be practical.

118 National Association of City Transportation Officials, "Urban Bikeway Design Guide."
119 Nijhuis, "Tiny Pollinators Need Wildlife Corridors Too."
120 National Association of City Transportation Officials, "Urban Street Stormwater Guide."

Figure 4.16: Auburn Pl E Existing Conditions Section

Figure 4.17: Auburn Pl E Design Proposal Section

E PROSPECT ST

BETWEEN 17TH AVE E & 18TH AVE E

NEIGHBORHOOD YIELD

SINGLE-FAMILY RESIDENTIAL

Figure 4.18: E Prospect St Existing Conditions (Source: Google Street View)

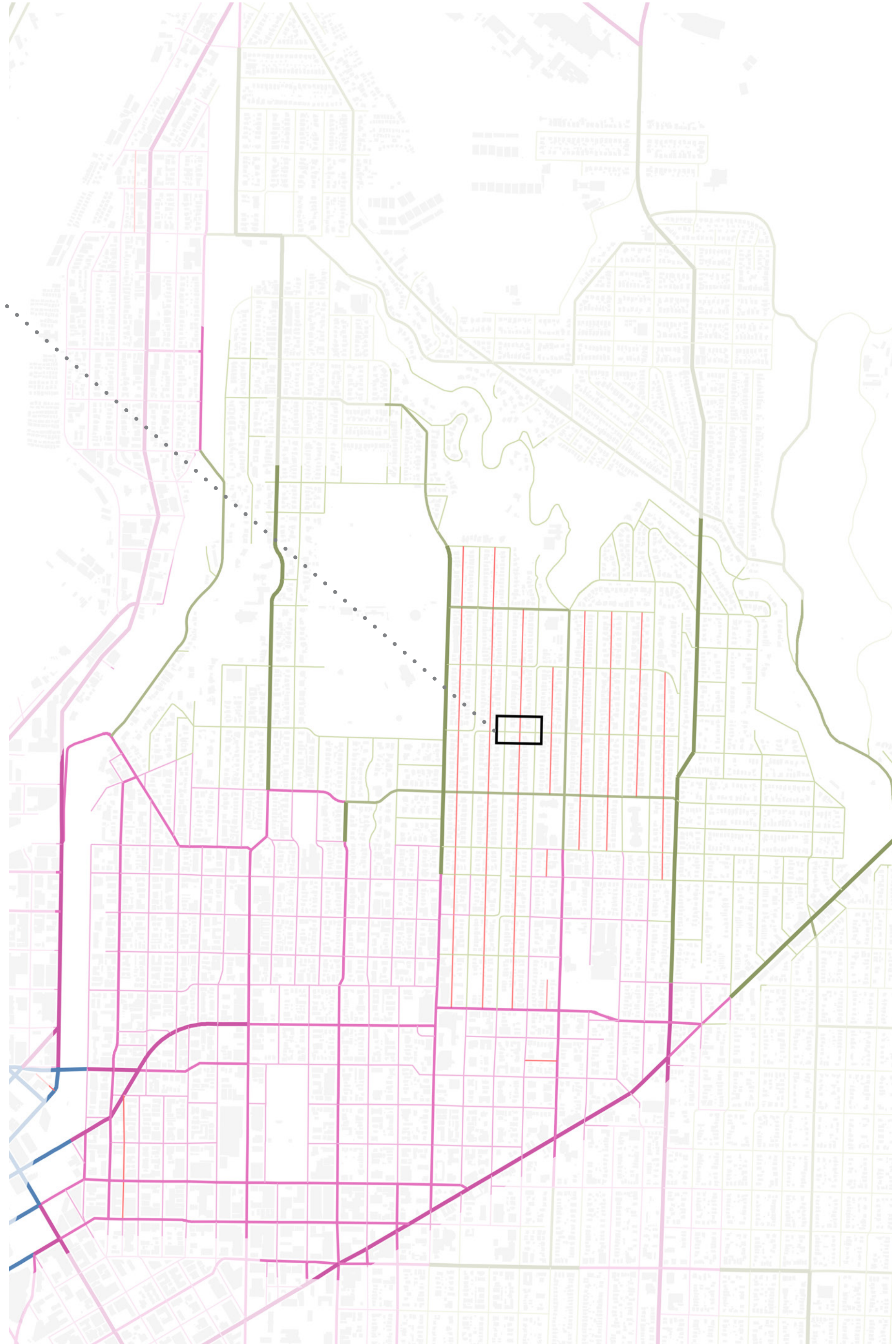


Figure 4.19: Site Location: E Prospect St

EXISTING SITE CONDITIONS

Prospect is an east-west neighborhood yield, or non-arterial, street in the Stevens Neighborhood of Capitol Hill. This street is within a single family, low-rise neighborhood. One of the most interesting things about this street, and a large reason it was chosen for this study, is its steep evaluation. Between 18th Ave E and 17th Ave E, Prospect Street is at a 10.5% grade. This type of steep grade is fairly representative of many of the east-west streets in this neighborhood, as they tend to run up and over hills, while north-south streets are fairly level running along the hillside. One other characteristic of this street, as well as most of the east-west streets in the Broadway and Steven neighborhoods, is that it runs along the short side of the city block. The blocks in this neighborhood tend to be over twice as long as they are wide. This results in few properties actually facing this street. Instead of places where people might congregate, these short sides of the blocks tend to be spaces which people move through but do not typically stop.

GROWTH PREDICTIONS

As previously stated, Prospect Street is within a single family residential neighborhood. This area is currently zoned as Single Family 5000, indicating a maximum lot size of five-thousand square-feet.[121] Although there is a potential for drastic changes to occur within this neighborhood between now and the full adoption of autonomous vehicles, there are currently no changes in the works within this section of the neighborhood. There are no mentions of potential up-zoning in the Seattle 2035 Draft Comprehensive plan, this portion of the neighborhood is not within an urban village, and finally the location does not fall into one of the proposed HALA mandatory housing affordability rezones. With all of this being said, for the purpose of this study this space will continue to retain its single-family character.

121 City of Seattle, "Generalized Zoning Map."

Figure 4.20: E Prospect St Design Proposal

① **Pedestrian Hill Climb:** One of the largest design moves made within this space is the introduction of a pedestrian hill climb. As previously stated these east-west streets tend to be places people move through but do not spend any significant amount of stationary time in. With that in mind the design element works to provide pedestrians with a more stimulating experience as they move through the space. Outside of the space dedicated to vehicles, the *Blueprint for Autonomous Urbanism* recommends creating spaces for play and introducing increased green space along residential streets, and this space works to achieve both by encouraging exploration within the heavily planted space.[122]

② **Sidewalk & Stairs:** This element works to break up the rather strenuous treks up and down these steep hills and provides opportunities for pedestrians to comfortably stop along their journey. Unfortunately, given the grade of the street and the space to work with, it was not possible to create an accessible path along this street.

③ **Loading Zone:** One of the primary objectives of the *Blueprint for Autonomous Urbanism* is to properly manage passenger and cargo pick-up and drop-off zones along the street. In this case, because of the fact that few houses face this street, there is only a limited need for these zones and they were designed accordingly. At twenty-feet, these zones are shorter in length than those found on busier streets. Furthermore, they are limited to one side of the street and are placed at three spaces along each block.

④ **Travel Lane:** For neighborhood yield streets, the *Blueprint for Autonomous Urbanism* recommends limiting traffic to one lane, reducing lane width, limiting speeds to ten miles-per-hour, and only permitting local traffic and deliveries.[123] With this in mind the previous sixteen feet of travel lanes was reduced to ten.

⑤ **Bioretention Swale:** For residential streets the *Blueprint for Autonomous Urbanism* generally recommends introducing enhanced green spaces, such as additional trees, planters, and green stormwater infrastructure, however it does not go into any specifics related to the design of these elements. In this case another NACTO publication, the *Urban Street Stormwater Guide*, was consulted in order to determine what type of stormwater element would be best suited for this space. Given that there is a significant amount of space to work with, and a desire to limit the use of bulky curbs, a biorientation swale was chosen. According to the guide, this type of stormwater management is better suited for lower traffic contexts and can provide greater flexibility for planting a variety of street trees and plants along the bottom and on the sides of the slope.[124]

⑥ **Sidewalk:** A typical sidewalk in kept along one edge for the street for those who may not wish to travel up or down stairs, or who may have mobility issues.

122 National Association of City Transportation Officials, "Blueprint for Autonomous Urbanism."
123 National Association of City Transportation Officials.
124 National Association of City Transportation Officials, "Urban Street Stormwater Guide."

⑦ **Planting Strip:** A small planting strip was included along the north edge of the sidewalk. This was integrated in order to provide a level of separation between the sidewalk and the edges of the houses that often extend fairly close to the right-of-way, and to enhance the pedestrian experience.

As seen in Figure 4.21 & Figure 4.22 a considerable number of changes have been proposed along Prospect Street. In addition to shrinking the space dedicated to vehicular travel and parking, part of the reason this proposal was able to include a significant amount of space dedicated to improving pedestrian experience and ecological function was the fairly wide right-of-way. At fifty-six feet wide, the size of this right-of-way is comparable to some of the higher-volume streets this thesis will explore. Perhaps one of the most noticeable differences in these two sections is the significant increase in planting and greenspace. Although the street currently features ten-foot planting strips, they are awfully underutilized. In this space autonomous mobility provides the opportunity to Increase planting and introduce green stormwater elements, eliminate parking, decrease the size of vehicular travel lanes, and improve pedestrian travel paths. All of this works together to create an entirely new and almost unrecognizable experience compared to what exists today.

Figure 4.21: E Prospect Street Existing Conditions Section (Facing West)

Figure 4.22: E Prospect Street Design Proposal Section (Facing West)

17TH AVE E

BETWEEN E ALOHA ST & E ROY ST

NEIGHBORHOOD YIELD

SINGLE-FAMILY RESIDENTIAL

Figure 4.23: 17th Ave E Existing Conditions (Source: Google Street View)

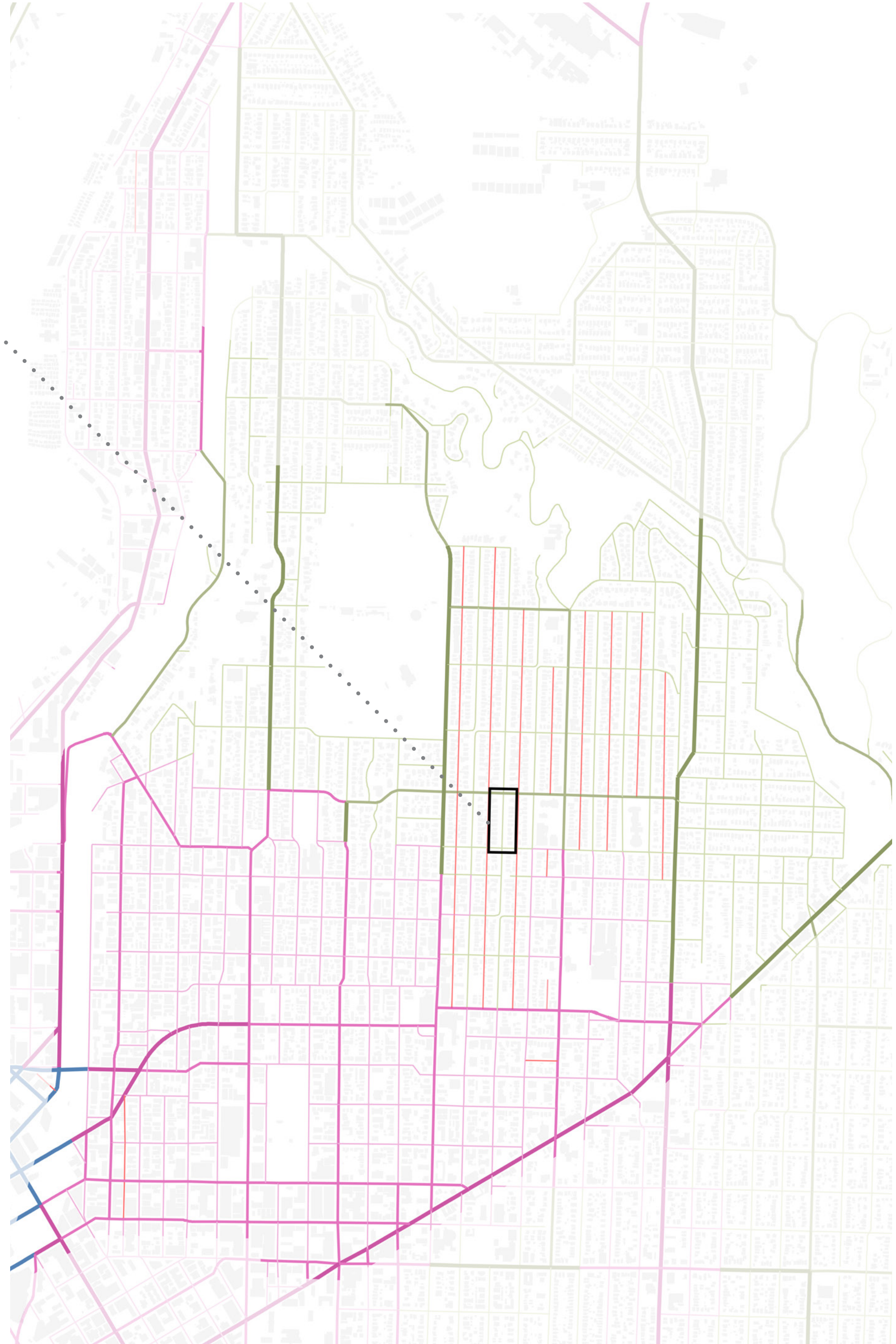


Figure 4.24: Site Location: 17th Ave E

EXISTING SITE CONDITIONS

17th Ave E is a neighborhood yield street that, like the other streets explored thus far, runs through a single family residential district in the Stevens Neighborhood of Capitol Hill. There are two primary differences between 17^{th} Ave E and E Prospect St, which is why two neighborhood yield streets are being explored in this case study. First, this street is relatively flat as it runs along the side of a hill. This lack of grade provides opportunities for change that are quite different from the steep grade of Prospect St. Second, 17th Ave E runs along the long side of the block. This particular street is just over six-hundred feet long, and all of the houses along the block face the street. At this point in time the majority of the right-of-way is dedicated to vehicular travel. Although parking is zoned on this street, site visits have revealed that for the most part a majority of parking spaces are typically occupied.

GROWTH PREDICTIONS

As with E Prospect St, 17^{th} Ave E is currently zoned as Single Family 5000, indicating lots with a maximum size of 5000 Ft^2 which contain detached houses with a single dwelling unit.[125] Also like E Prospect St, there are currently no regulations in place, or proposed zoning changes, that would suggest any major change in the character of this neighborhood occurring in the near future. Again, because the exact timeline of autonomous vehicle adoption is currently unknown, there is the potential for residential housing growth within this space to occur, but the for purpose of this exploration it is assumed that 17^{th} Ave E will retain its single-family character.

125 City of Seattle, "Generalized Zoning Map."

Figure 4.25: 17th Ave E Design Proposal

① **Stormwater Curb Extension:** As previously stated, the *Blueprint for Autonomous Urbanism* generally recommends incorporating green infrastructure into the redesign of residential streets. In this case, a stormwater curb extension fulfills that recommendation while serving multiple functions. First, the stormwater curb extensions at the ends of 17th Ave E work to collect run off from the impervious surface of the street. Due to the fact that the area of this impervious surface has been greatly reduced, this type of green stormwater infrastructure should be sufficient for this space. In accordance with the *Urban Street Stormwater Guide*, planting near the ends of the bioretention swale have been kept low in order to ensure clear sightlines for autonomous vehicles and pedestrians.[126] Second, this type of curb extension narrows the crossing distance for pedestrians at these intersections, prioritizing the pedestrian experience over vehicular travel.

② **Flexible Community Space:** With street parking eliminated and vehicular passage limited to local traffic, the right-of-way may take on a new function of creating flexible community space. The *Blueprint for Autonomous Urbanism* recommends creating spaces that can function as central meeting hubs for the community, and as extensions of the front yard.[127] On 17th Ave E spaces have been provided for gathering, play, and other activities such as community gardening.

③ **Loading Zones:** The loading zones along 17th Ave E serve three primary functions. First, they provide a space for autonomous vehicles to yield to one another should two vehicles be traveling in different directions down the street. Second, they provide easy access for local residents to be picked up and dropped off by shared autonomous vehicles. Third and finally, they provide a space for local deliveries and refuse pickup. These loading zones span the entire length of 17th Ave E, but alternate along each edge of the street. This provides convenient access for local residents while breaking up the space dedicated to this function.

④ **Travel Lane:** As previously mentioned, along residential streets autonomous vehicle travel will be limited to local traffic and deliveries, and speeds will be limited to 10 miles-per-hour. This works to provide a space in which pedestrians and cyclists can feel comfortable moving freely within.

⑤ **Sidewalk:** In addition to creating flexible community space, eliminating street parking provides for the opportunity to widen the sidewalks and incorporate additional elements, such as seating or play, into this space.

Eliminating street parking and severely limiting vehicular traffic has the potential to completely transform the form and function of residential streets. Studies have shown that increased vehicular travel along residential streets is associated with noteworthy negative externalities. These include reduced quality of life, limited social connection, a decrease in the perception of safety, and a reduction of street-based recreational activities.[128] Shared autonomous travel provides the opportunity to reclaim the right-of-way for local residents in an effort to combat these externalities and reestablish residential streets as spaces for play and community gathering.

126 National Association of City Transportation Officials, "Urban Street Stormwater Guide."
127 National Association of City Transportation Officials, "Blueprint for Autonomous Urbanism."
128 Hart, "Driven To Excess : A Study of Motor Vehicle Impacts on Three Streets in Bristol UK."

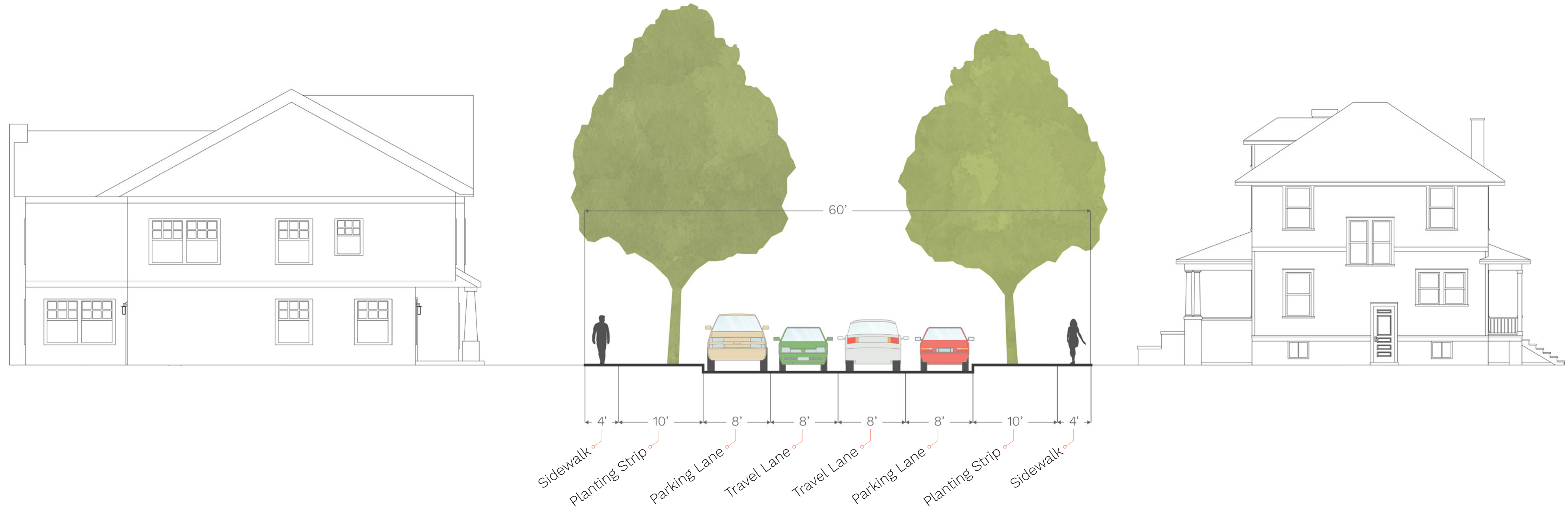


Figure 4.26: 17th Ave E Existing Conditions Section (Facing North)

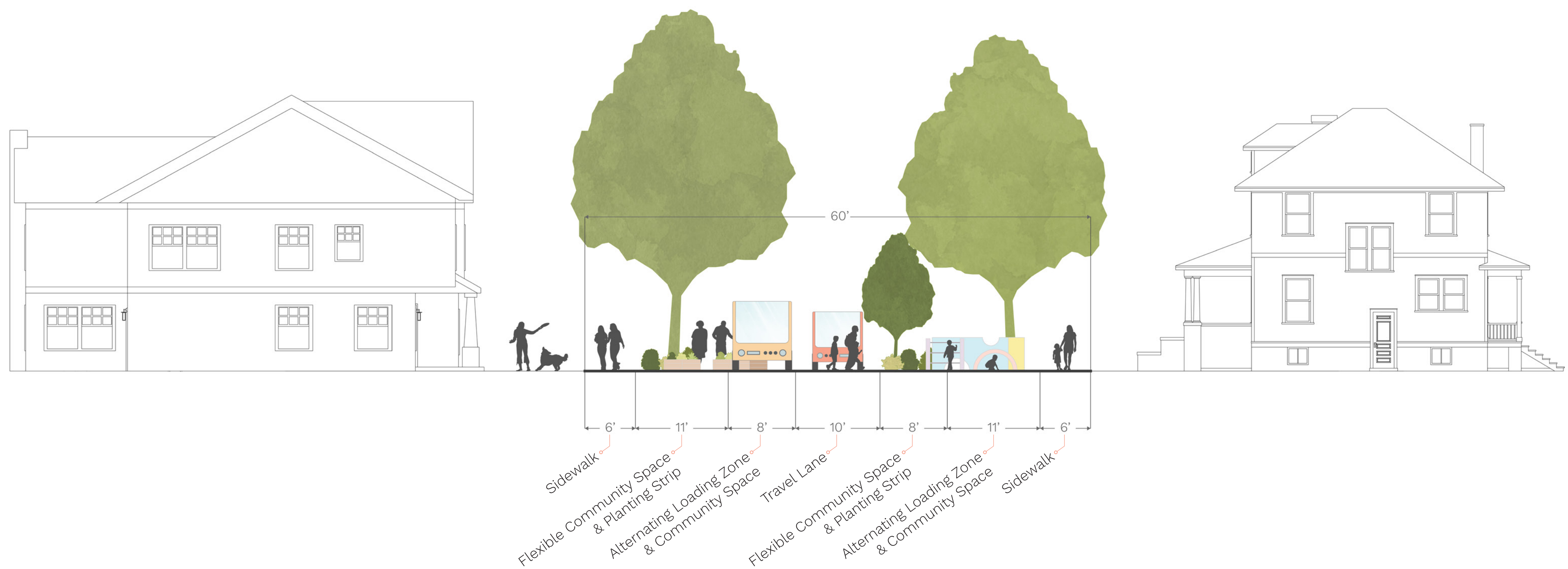


Figure 4.27: 17th Ave E Design Proposal Section (Facing North)

10TH AVE E

BETWEEN E PROSPECT ST & E ALOHA STREET

URBAN CENTER CONNECTOR

MULTI-FAMILY RESIDENTIAL

Figure 4.28: 10th Ave E Existing Conditions (Source: Google Street View)

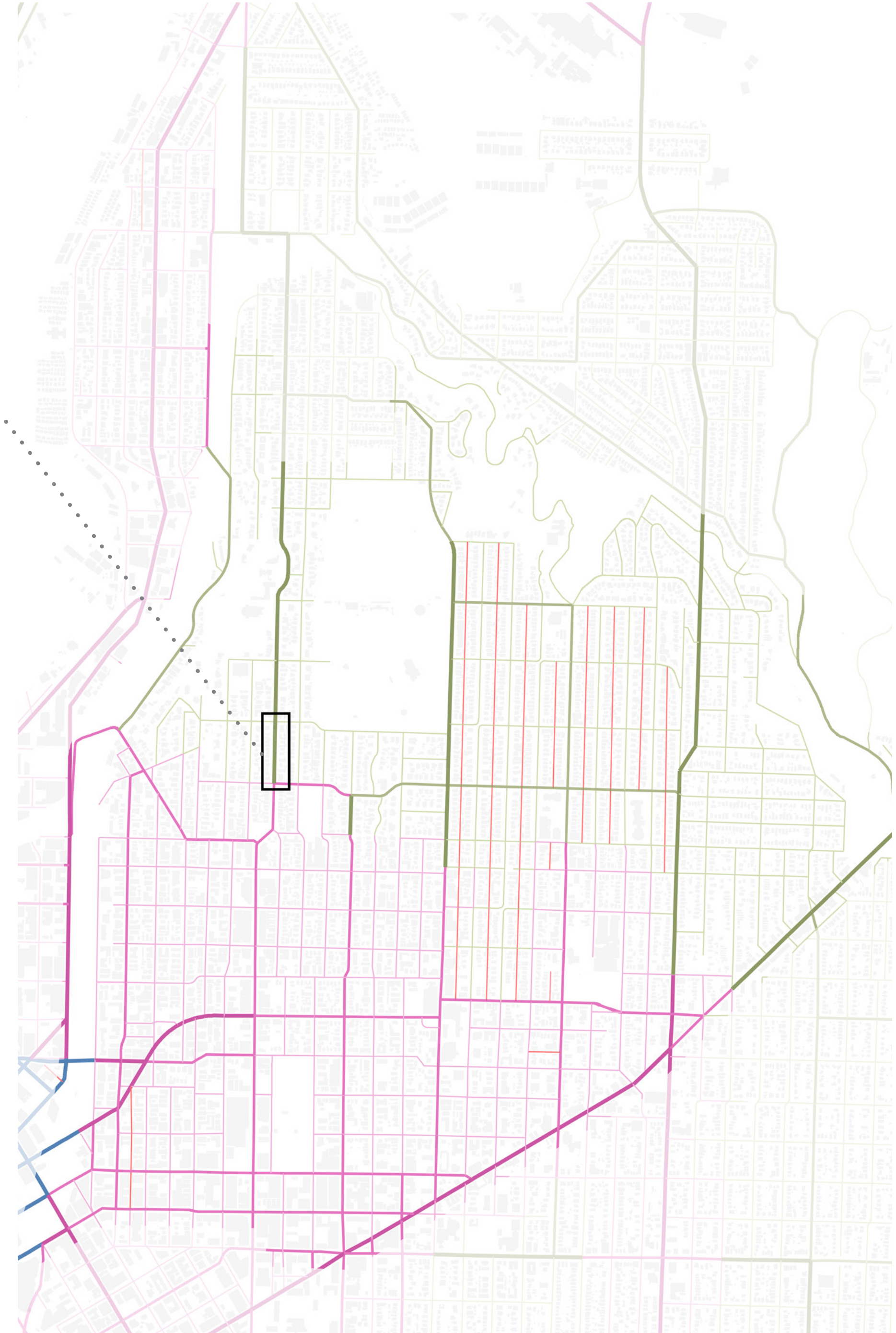


Figure 4.29: Site Location: 10th Ave E

EXISTING SITE CONDITIONS

10th Ave E is classified as an Urban Center Connector street and is located in the Broadway neighborhood of Capitol Hill. The Seattle Streets illustrated manual defines Urban Center Connectors as streets that are either part of the freight network or transit network, and link outside neighborhoods to urban villages within the city.[129] 10th Ave E serves as part of the transit and bicycle network in the city. There is a bus line which runs down the street and connects to the Capitol Hill urban village, and the wide travel lanes feature sharrows, lane markings indicating that the street is a shared lane environment for bicycles and automobiles. This portion of 10th Ave E falls within a Low Rise 3 zoning district. This zoning designation is meant to accommodate residential growth by providing a variety of multifamily housing types.[130] As it currently stands, there is a mix of single and multifamily housing types along the street. These include cottage housing, townhouses, and apartments.

GROWTH PREDICTIONS

It is likely that as the City of Seattle continues to grow this street will grow with it. Site visits reveled a significant amount of new multifamily housing currently being constructed along 10th Ave E, replacing the underutilized single-family homes. The Low Rise 3 zoning designation currently allows for apartment buildings to reach a max height of forty feet, and many of the newly constructed buildings are taking advantage of this limit. For the purpose of this study it is assumed that between now and the full adoption of autonomous vehicles 10th Ave E will undergo a complete transformation to multifamily housing types. It is also assumed that height limits will be marginally relaxed, allowing for this space to meet the growing demand for housing in a neighborhood adjacent to an urban village.

129 City of Seattle, "Streets Illustrated."
130 City of Seattle, "Generalized Zoning Map."

Figure 4.30: 10th Ave E Design Proposal

① **Transit Stop & Bicycle Share:** As previously stated 10th Ave E serves as an important component of the city's transit system, connecting neighboring residents to the Capitol Hill urban village via bus. The re-envisioning of this street prioritizes mass transit, as part of the *Blueprint for Autonomous Urbanism's* principles of providing mobility for the whole city and moving more with fewer vehicles.[131] Due to the limited width of the right-of-way along 10th Ave E transit stops are introduced in the form of boarding bulb stops. This type of stop utilizes a cub extension that aligns with the existing travel lane. This type of transit stop has been shown to improve the speed and reliability of mass transit by decreasing the amount of time lost to merging in and out of traffic.[132] Furthermore, utilizing a boarding bulb stop provides the opportunity to provide other amenities in this area, which are currently lacking along 10th Ave E due to the limited amount of pedestrian space. These include waiting shelters and opportunities for mode switching via spaces dedicated to bicycle sharing. These types of amenities work to incentivize travel by mass transit.

② **Loading Zones:** As always, curb management is a key component of autonomous travel. For this type of street, the *Blueprint for Autonomous Urbanism* recommends passenger and freight loading and unloading take place in curb lane so "as to not disrupt passing vehicles and bicyclists."[133] Thirty-five-foot loading zones are staggered along the street, providing significant access for local residential land uses.

③ **Pedestrian Crossings:** Another key component of autonomous travel is safe and frequent pedestrian crossings. NACTO recommends frequent and formal mid-block pedestrian crossings in order to accommodate pedestrian desire and strike a balance between vehicular and pedestrian travel.[134] On one hand pedestrians should feel comfortable safely crossing the street and should be able to do so with relative ease. On the other hand, pedestrians should not have free reign in this environment, as it may bring traffic to a standstill. Recurrent and clearly marked pedestrian crossings, combined with sufficient gaps in autonomous vehicle traffic, would work to solve this concern. Per NACTO guidelines, pedestrian crossings are placed every one-hundred-feet along 10th Ave E.

④ **Dedicated Bicycle Lanes**: The sharrows currently used to indicating that shared lane environment for bicycles and automobiles are in many ways insufficient. The NACTO *Urban Bikeway Design Guide* states that sharrows are "not a facility type and should not be considered a substitute for bike lanes, cycle tracks, or other separation treatments where these types of facilities are otherwise warranted or space permits."[135] While there previously may not have been room for this type of facility, a shift to autonomous mobility can provide this opportunity

131 National Association of City Transportation Officials, "Blueprint for Autonomous Urbanism."
132 National Association of City Transportation Officials, "Transit Street Design Guide."
133 National Association of City Transportation Officials, "Blueprint for Autonomous Urbanism," 33.
134 National Association of City Transportation Officials.
135 National Association of City Transportation Officials, "Urban Bikeway Design Guide," 133.

through the elimination of street parking and the narrowing of lane widths. Given that this span of 10th Ave E is a part of the city's dedicated bicycle network, this type of facility seems warranted. Other steps were taken to ensure the successful implementation of this bicycle lane. Per NACTO guidelines, a distinguishing color was used to draw attention to the unique function of the lane for both pedestrians and autonomous vehicles.[136] This type of treatment aligns with the *Blueprint for Autonomous Urbanism's* principle of surfaces over striping. Finally, this facility was sited in a manner in which bicycle movement will not be interrupted by vehicular traffic. Both mass transit and shared autonomous vehicles stop outside of the bicycle lane, without ever crossing it.

⑤ **Bioretention Planters:** These planters were included in this space in order fulfill the NACTO principle of introducing green infrastructure and to meet one of the overall objectives of this design exploration, designing for urban ecological function. Siting these planters is the space between the flexible pedestrian areas and the loading zones takes advantage of space that otherwise may have been underutilized.

⑥ **Flexible Pedestrian Space:** One of the most important aspects of this transformation was the introduction of space dedicated to pedestrians. One of the major principles of the *Blueprint for Autonomous Urbanism* is working to rebalance the right-of-way, and this includes creating pavement for the people by repurposing underutilized space. Previously, pedestrians were confined to a rather narrow eight-foot shared sidewalk and planting strip. This design proposal includes a dedicated six-foot sidewalk and well as nine-feet of flexible pedestrian space (see Figure 4.32). This pedestrian space has the potential to function as a sort of urban living room for residents living in adjacent multifamily housing structures. The exact function of these spaces can fluctuate between larger gathering areas and smaller spaces dedicated to providing refuge. All of these spaces are surrounded by a variety of plantings in order to create small pocket enclosures, which have been shown provide restorative benefits to urban inhabitants by providing them access to natural elements.[137]

136 National Association of City Transportation Officials.
137 Kaplan, Kaplan, and Ryan, *With People in Mind : Design and Management of Everyday Nature.*

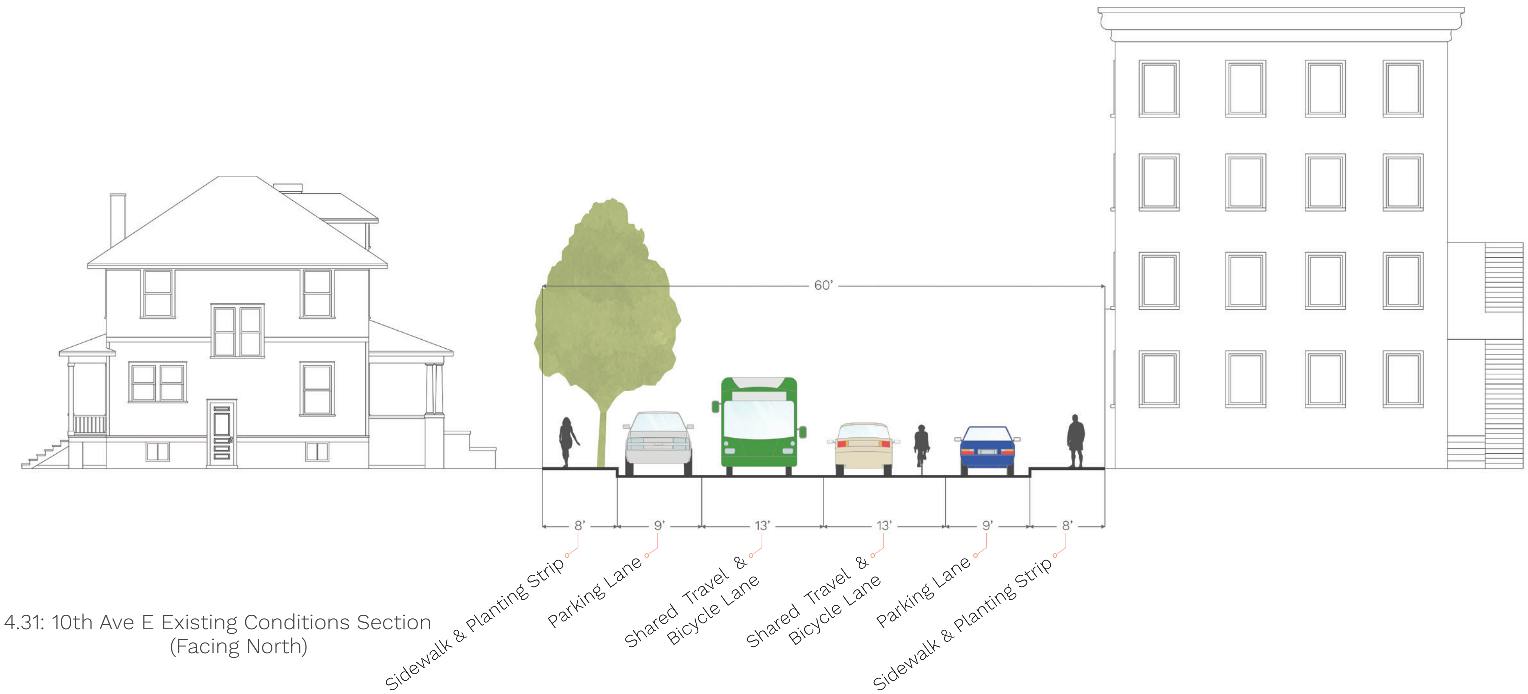


Figure 4.31: 10th Ave E Existing Conditions Section (Facing North)

Figure 4.32: 10th Ave E Design Proposal Section (Facing North)

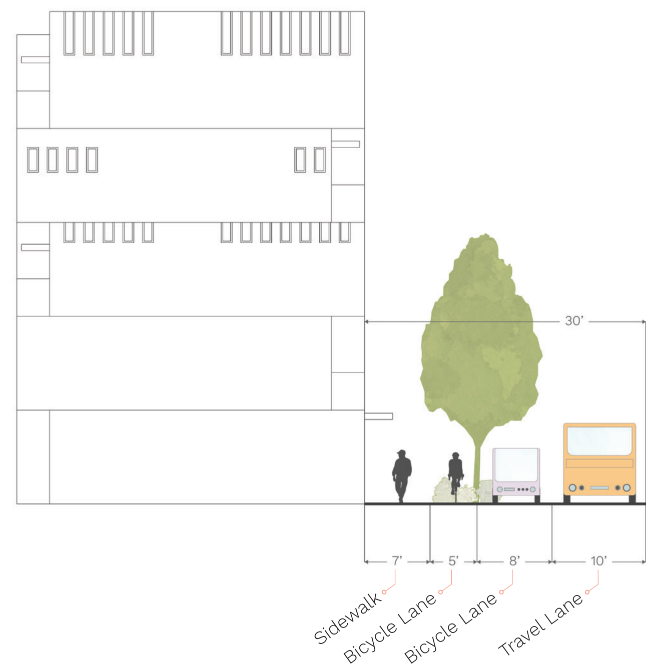


Figure 4.33: 10th Ave E Design Proposal Section at Loading Zone

E PIKE STREET

BETWEEN BROADWAY & 10TH AVE

URBAN VILLAGE NEIGHBORHOOD

COMMERCIAL DISTRICT

Figure 4.34: E Pike St Existing Conditions (Source: Google Street View)

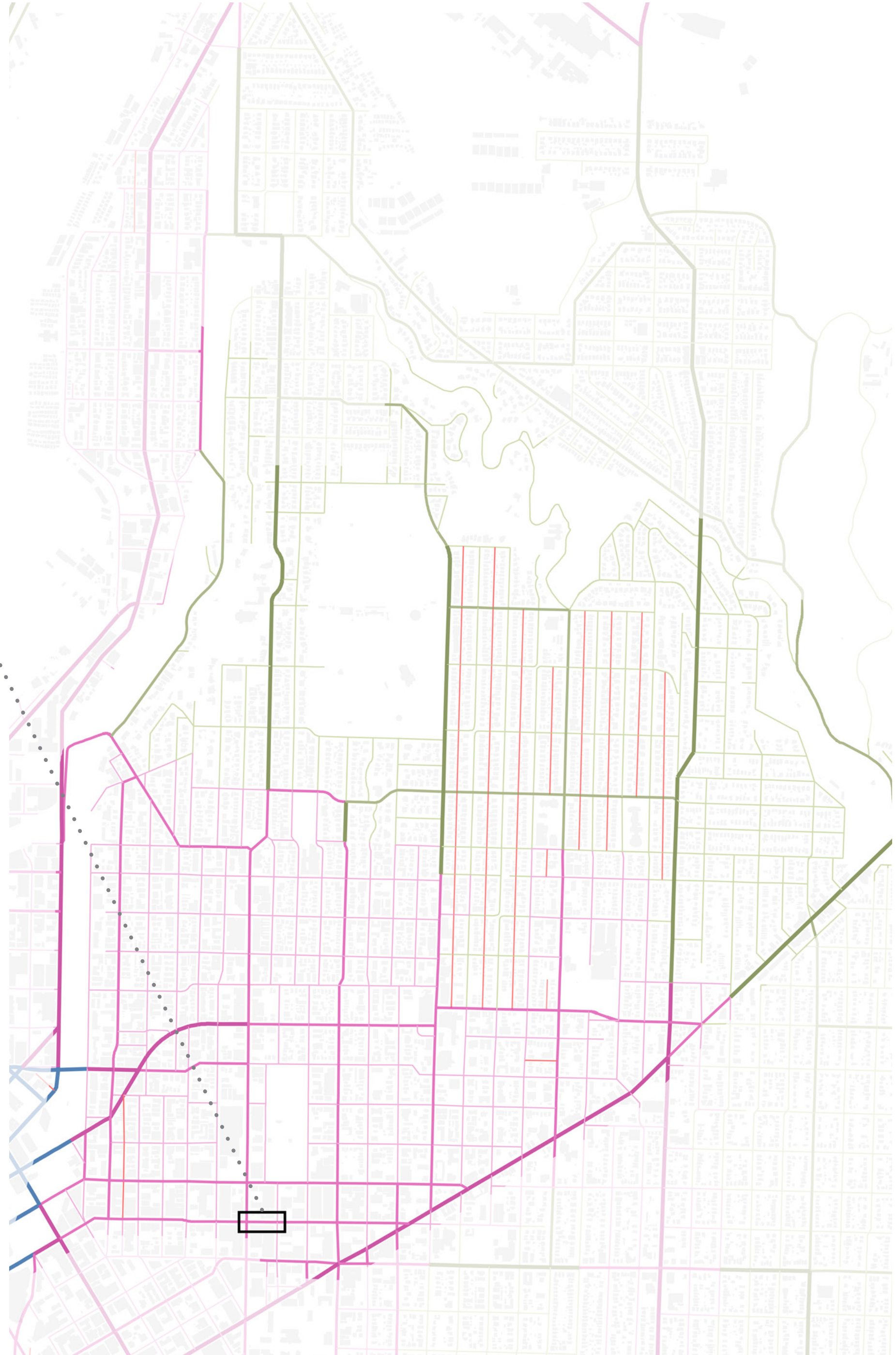


Figure 4.35: Site Location: E Pike St

EXISTING SITE CONDITIONS

E Pike is an Urban Village Neighborhood Street that runs through the center of the Capital Hill urban village. This location is known as one of the city's primary retail, nightlife and entertainment districts.[138] This neighborhood is currently Zoned as NC3P-65, signifying a Neighborhood Commercial District with sixty-five-foot height limits. The P designation within this zoning classification indicates that this space should encourage an "intensely pedestrian-oriented, retail shopping district where non-auto modes of transportation, both to and within the district, are strongly favored."[139] Although this neighborhood is zoned to allow buildings with sixty-five-foot height limits, this specific span of E Pike St is far from being fully built out. All of the buildings are two or three stories tall, and one prominent corner lot currently features a gas station. It is worth nothing that while this span of the street hasn't seen any major growth, a significant portion of this neighborhood has recently undergone substantial growth transformations.

GROWTH PREDICTIONS

For the purpose of this study, it is assumed that this span of E Pike St, like much of the surrounding neighborhood already has, will experience considerable growth. Either through retrofitting existing buildings, or by replacing existing structures with new construction, buildings heights are expected to reach the sixty-five-foot height limit. There is also a chance that limits on building heights in this neighborhood may be increased. The city's Mandatory Housing Affordability policy, which works to ensure that growth brings affordability by increasing development capacity and enacting affordable housing requirements, has recommended that building heights in this neighborhood be increased to seventy-five-feet.[140]

138 Whiting, "Capitol Hill."
139 City of Seattle, "Generalized Zoning Map."
140 City of Seattle, "Final MHA HALA Preferred Alternative Map."

Figure 4.36: E Pike Street Design Proposal

① **Flexible Pedestrian Space:** Pedestrian space along this section of Pike is currently limited to a small six-foot sidewalk and four-foot planting strip. As with the other design proposals, eliminating street parking and narrowing lanes provides an opportunity to completely rethink the space dedicated to pedestrians, and expands this space by an additional four-feet. In this case, how this space is activated varies from what has been shown thus far, as the primary function of this street is commercial. The elements that have been incorporated into this design proposal work to meet the commercial character of the neighborhood, and these human scale design features include sidewalk cafes, public art, and other street furniture and planting elements that provide opportunities for pedestrians to pause and gather along the street.

② **Planting Strip:** Planting strips, instead of street parking, provide a valuable buffer between the pedestrian space and travel lanes. Furthermore, these planting strips also work to break up and frame the loading zones.

Time-of-Day Curbside Management: Like other spaces, curbside management along E Pike St is key to a properly functioning shared autonomous system, however here it is handled slightly differently. One of the proposals the *Blueprint for Autonomous Urbanism* puts forward for this type of street is the use of time-flexible curbside zones. As with other streets, these loading zones will primarily function as a space for passenger and cargo loading and unloading, however additional functions can be considered over the course of a day, week, or even year.[141] What this rendering is showing is an example of how these loading zones might transform over the course of a day.

3.1 Morning – In the morning these zones will primarily be utilized as a space for passenger loading and unloading as people begin their day.

3.2 Mid-day – Once the morning rush hour has ended additional uses of these spaces may be considered. In this case a temporary market stall utilizes a portion of the zone, while retaining some space for loading and unloading.

3.3 Evening – After the afternoon rush hour it may be possible to completely rethink the use of some of these loading zones. Here a food truck and additional outdoor seating occupy a space that may be underutilized at this time of day.

3.4 Night – Late at night and in the early morning, when pedestrian and passenger movement is at its lowest, these spaces would primarily function as cargo loading zones. Automated delivery vehicles would take advantage of this time to deliver a large amount of cargos. Nearby Storage lockers would provide a space for consumer goods to be stored and picked up by local residents at their leisure.

141 National Association of City Transportation Officials, "Blueprint for Autonomous Urbanism."

What is shown in these examples is only a small portion of what might be possible through the use of time-of-day curbside management. Ultimately how these spaces are programed will be highly dependent on the level of traffic in the area and how the surrounding land is used. Wherever time-of-day curbside management is utilized, interventions should respond to the character of the surrounding neighborhood.

④ **Time-of-Day Managed Travel Lanes:** E Pike street would feature one travel lane for each direction of traffic, and in certain cases these travel lanes could also be managed according to varying levels of demand. The *Blueprint for Autonomous Urbanism* suggests that "certain thresholds of pedestrian activity may trigger closures" on streets such as E Pike.[142] This type of street closure, which has been previously tested along E Pike St, would be more easily achievable by utilizing Autonomous vehicles. Smart Technologies could be utilized to easily reroute these vehicles to other parts of the network.

⑤ **Functional Median:** Reducing vehicular traffic to one lane in each direction provides the opportunity to transform a space in the right of way that once functioned as a left-hand turn lane into one that can work to improve ecological function along E Pike St. In this case a bioretention planter was chosen to treat stormwater runoff. This method was chosen due to the high-volume of runoff that is likely to occur in this highly urbanized space. This type of vertical walled, flat bottomed retention planter "offers greater capacity within the cross-section for stormwater detention and infiltration than bioretention swales" and are more adaptable within a highly urbanized context.[143] In addition to their ecological benefits, the *Blueprint for Autonomous Urbanism* also recommends the use of functional medians on neighborhood main streets due to their ability to "beautify neighborhoods while also providing a refuge for pedestrians crossing the street.

Figure 4.38 depicts what the E Pike St might look like should a portion of the street be closed to vehicular traffic through the use of time-of-day managed travel lanes. As previously stated, street closures along this section of E Pike is something that the Seattle Department of Transportation formerly studied. Over the course of three summers, from 2015-17, a pilot "People Street" program was conducted within the Capitol Hill Urban Village.[144] While this type of street closure is often difficult to organize and implement, autonomous vehicles would make implementing a program like this easier and less costly.

142 National Association of City Transportation Officials, 25.
143 National Association of City Transportation Officials, "Urban Street Stormwater Guide," 78.
144 Cetron, "On Capitol Hill, Seattle's People Streets May Have Come to an End."

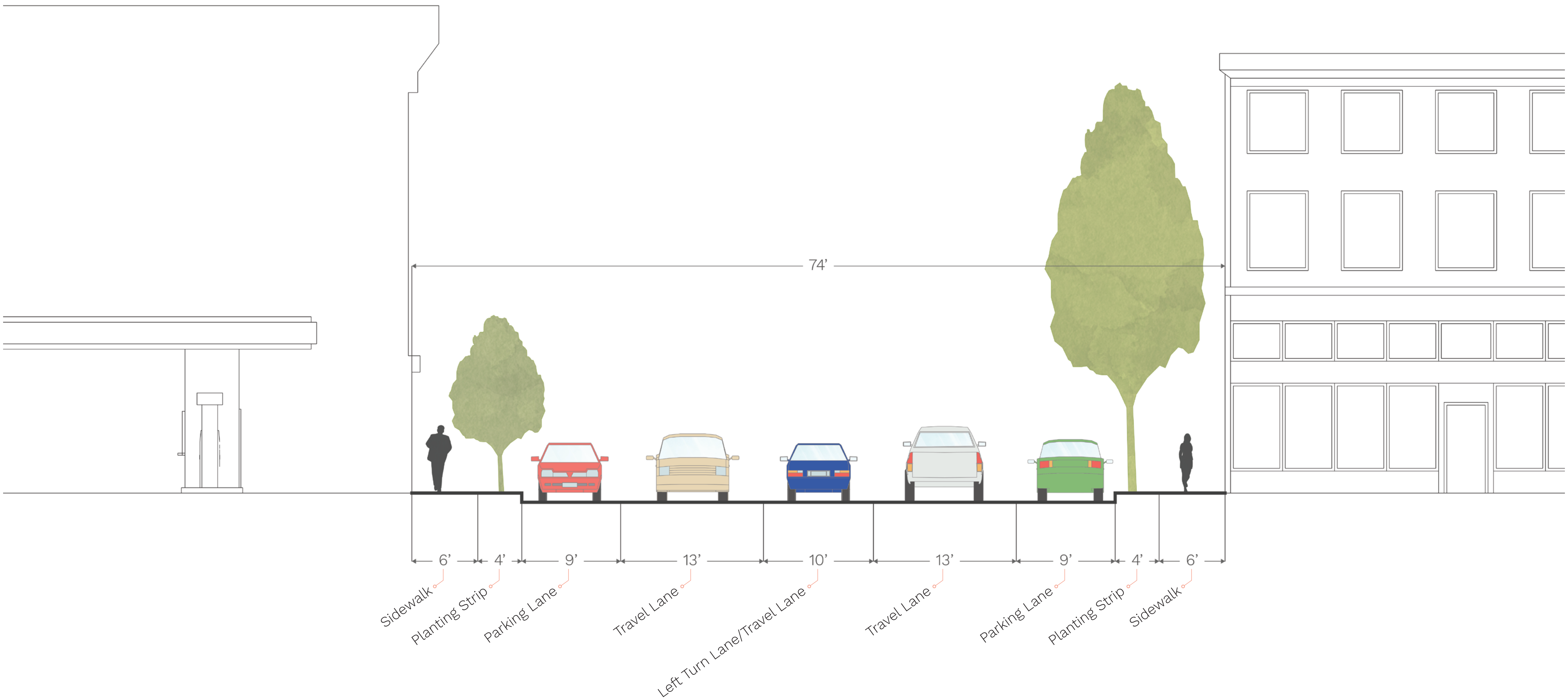


Figure 4.37: E Pike Street Existing Conditions Section (Facing East)

Figure 4.38: E Pike Street Design Proposal Section (Facing East)

E MADISON ST

BETWEEN 22ND AVE & 23RD AVE

URBAN VILLAGE MAIN

MIXED-USE

Figure 4.39: E Madison St Existing Conditions (Source: Google Street View)

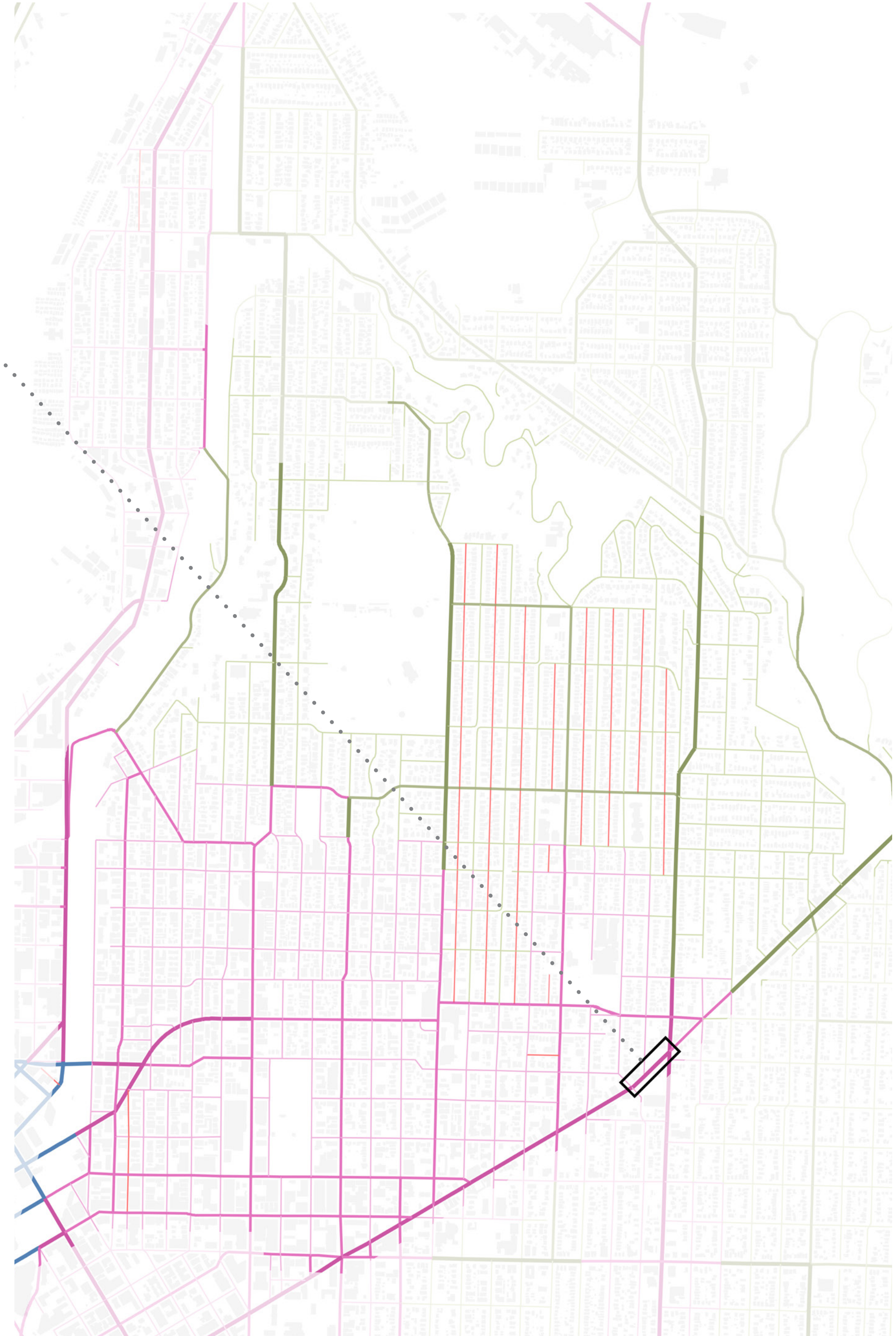


Figure 4.40: Site Location: E Madison St

EXISTING SITE CONDITIONS

E Madison is an Urban Village Main St that runs through the Stevens neighborhood and falls within the Capitol Hill urban village. This street type is meant to function as the spine of Seattle's urban villages and centers. The Seattle Streets Illustrated manual provides a fairly accurate description of this street when describing the primary function of this typology. It states that these streets should provide residents and workers with "daily essentials and visitors with a range of services" while also working "to accommodate the movement of people and goods through the urban center."[145] Essentially, this mixed-use district lacks the distinct commercial character of streets such as E Pike, and there is a greater balance between the commercial and residential character of the neighborhood. Like E Pike St, E Madison is also zoned as Zoned as NC3P-65 and there are opportunities for development. While there are a couple of large new developments along this span of Madison, there are also several plots which are currently occupied by single story/ single-use buildings. One thing that makes Madison unique as an Urban Village Main street is how narrow the right-of-way is. While the Streets Illustrated Manual shows a typical urban village main street with a ninety-three-foot right-of-way, this portion of Madison is only sixty-eight-feet across.[146]

GROWTH PREDICTIONS

Growth predictions for E Madison St are very similar to those for E pike. They both fall under the same zoning designation, and the Housing Affordability policy is also recommending that height limits be increased to seventy-five-feet along this stretch of Madison. For the purpose of this study it is assumed that while autonomous technology advances this portion of Madison will continue to grow. The single-use/single-story buildings will be replaced with new mixed-use developments similar to the segments of the street that were recently developed. In fact, permits have already been issued to replace the single-story structure in Figure 4.39 with a new sixty-five-foot/six-story mixed use development.

145 City of Seattle, "Streets Illustrated."
146 City of Seattle.

Figure 4.41: E Madison Street Design Proposal

① **Right Turn Drop Off:** One thing the *Blueprint for Autonomous Urbanism* recommends for major corridors such as E Madison, is providing passenger loading zones around a right-turn corner, where possible.[147] There are two main benefits to this simple move. First, it works to reduce congestion along the major corridor, as passing vehicles will not have to wait as the vehicle pulls in and out of the loading zone. Second, it provides an opportunity for sections of the main right-of-way that would be used as a loading zone to be utilized for higher-value activities.

② **Flexible Pedestrian Space:** As with many of the transformations seen thus far, space gained from the reduction of travel lanes and the elimination of street parking can be utilized in order to provide much needed pedestrian space. Although this stretch is E Madison features retail establishments, it is not as heavily trafficked by pedestrians visiting commercial locations, and there are a significant number of housing units above these retail businesses. With that being said, this additional pedestrian space should be programmed in a manner that best reflects the character of the space, and perhaps what is most appropriate is a mix of what was proposed along both E Pike St and 10th Ave E. This being a mix of spaces that function as extensions of retail establishments, such as outdoor cafes, as well as spaces for local residents to pause and gather.

③ **Transit Stop & Bicycle Share:** Much like 10th Ave E, Madison street also features transit stops that utilize boarding bulb stops. Again, these spaces provide an opportunity for additional transit elements, such as shelters and spaces dedicated to bicycle sharing, that can work to incentivize travel via mass transit.

④ **Safe & Short Crossings:** On heavily traffic routes such as E Madison, the *Blueprint for Autonomous Urbanism recommends* "safe and short crossings" in order to ensure that crossing a major street is no longer considered a problematic or time-consuming task.[148] As with other streets, and per the NACTO guidelines, the maximum distance between any of these crossings is one-hundred-feet.

⑤ **Bioretention Planters:** These bioretention planters perform three main functions in this space, one of which aids in the creation of the short pedestrian crossings. Placing the Planters at the ends of the loading zones works to ensure that pedestrians cross at the shortest distance possible on this street. This method creates a space in which pedestrians cross twenty-feet of vehicular space, compared to forty-eight-feet today. Second, placing these planters at the edges of the loading zones works to break up the space dedicated to this function and works to beautify the neighborhood. Third, these high-capacity planters provide a crucial ecological function within this space, working to mitigate the stormwater runoff created from all of the surrounding impervious surfaces.

147 National Association of City Transportation Officials, "Blueprint for Autonomous Urbanism."
148 National Association of City Transportation Officials, 32.

⑥ **Dedicated Bicycle Lanes:** One thing that is currently totally missing along this stretch of E Madison is any sort of bicycle infrastructure. The proposed dedicated bicycle paths would work to fill this void and work to promote alternative modes of transportation through the redistribution of space in the right-of-way. Similar to 10th Ave E, this bicycle network was designed in a manner in which bicyclists are protected from vehicles crossing over these dedicated lanes.

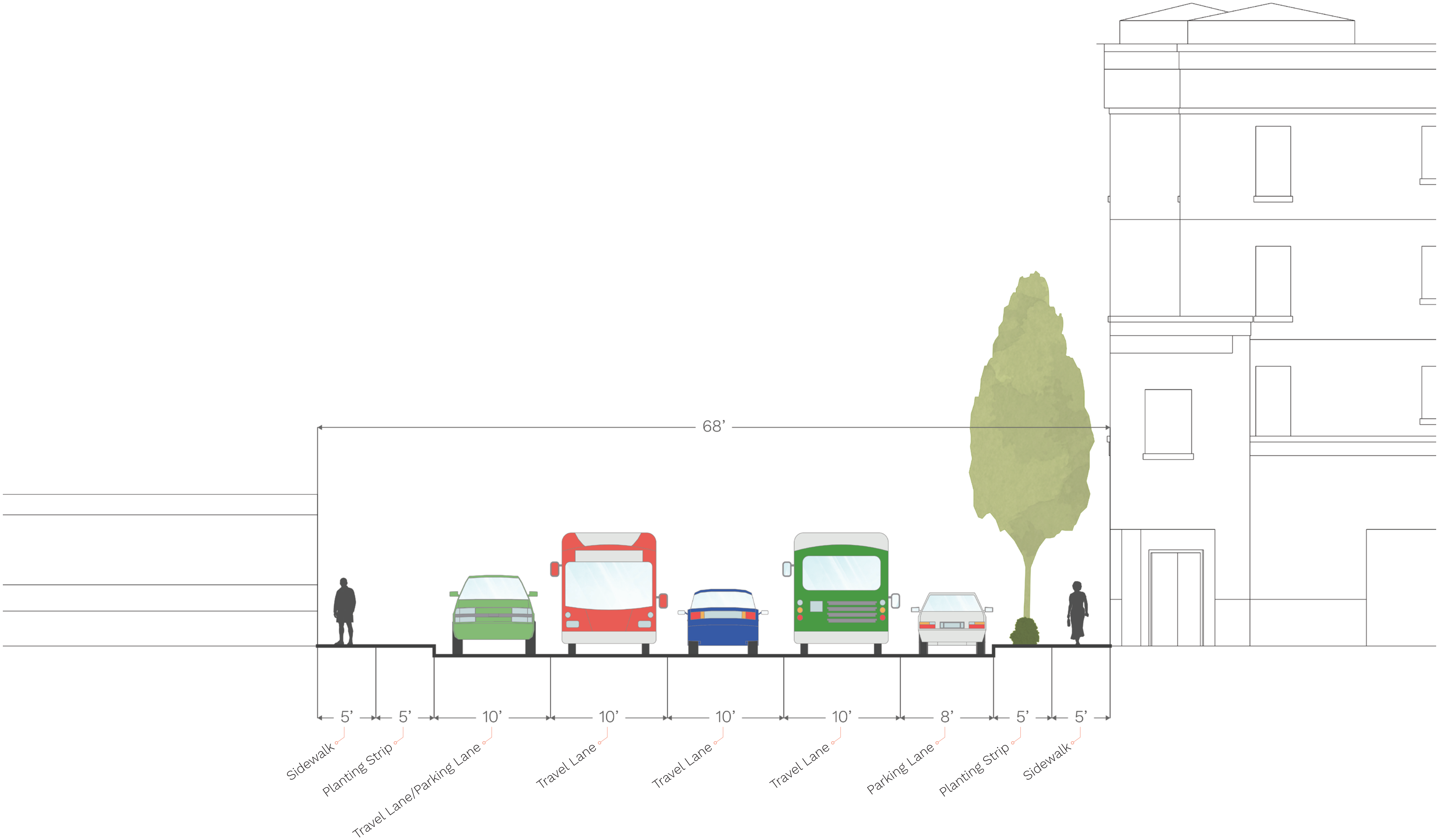


Figure 4.42: E Madison Street Existing Conditions Section (Facing East)

Figure 4.43: E Madison Street Design Proposal Section (Facing East)

CONCLUSION

IMPLICATIONS OF RESEARCH

There are several potential implications of this research that should be considered. These can be broken down into three major categories based on what audience they serve. To begin, for those within the academic community this research attempts to bridge the gap that currently exists within the literature by combining a holistic understanding of the potential impacts of autonomous vehicles with design theory, and then utilizing both sets of knowledge in order to make well-informed design proposals. This method of research has potential to influence future investigations within these two fields by pushing those within the design community to better understand autonomous technology, and by urging those who focus on transportation planning to consider the design ramifications of these vehicles.

For those within the transportation planning community, this research may work to further the idea that designers and design thinking need to be at the forefront of this transition. A shift to an autonomous fleet provides a unique and important opportunity to completely rethink the massive amount of urban land dedicated to vehicles, and it is imperative that mistakes made in the past are not repeated. Urban designers need to play a major role in this transformation in order to shift the focus away from simply planning for efficiency, and instead focus on shaping the future of cities in a productive and progressive manner. Although this research was framed around the idea of a fully shared autonomous future, no matter the extent of shared vs. individual autonomous travel, it is crucial that urban designers begin to consider the role they will play in this transition, as well as potential design opportunities for when it occurs.

Finally, there are several implications for those working within the field of urban design. To begin, this research could potentially serve as a useful guide, both within the City of Seattle and for designers in other locations, when preparing for the inevitable shift to autonomous mobility. This includes both the methods utilized when making site location and design decisions, as well as the design proposals themselves. In regard to the site selection methodology, this research provides a framework for creating additional design proposals. Urban designers could continue the use of street and neighborhood typology combinations in order to explore right-of-way changes across a variety of new urban spaces, while utilizing the typology combinations as a structure for choosing where to explore. The method of making design decisions, as well the final design proposals offer additional lessons for urban designers. The basic process of applying broad design principles and polices alongside specific design objectives could be further utilized when rethinking right-of-way allocation and design. The design proposals themselves can serve as examples of how to program newly created pedestrian space based on surrounding neighborhood character.

Finally, this research may also work to advance the notion that urban designers and planners need to begin thinking about this transition now. Though no prospective rollout or adoption of this technology is guaranteed, there is a chance that this technology will continue to advance rapidly. The impending rollout of autonomous vehicles has been compared to the rapid adoption of vehicular travel experienced with the introduction of the Model T in the early 1900s.[149] However, unlike that experience, it is our job to ensure that this revolution in transportation is recognized early on in order to ensure we do not end up in a similar situation to where we are now, where automobiles continue to dominate the urban landscape.

FUTURE INVESTIGATIONS

Future investigations regarding this research could take multiple forms. First, at this current point in time a similar approach could be taken in which additional design explorations are conducted utilizing both the principles established in the Blueprint for Autonomous Urbanism and the established baseline scenario. These explorations could utilize similar neighborhood and street typologies in other urban locations in order to see how these design proposals may differ from what is presented in this research. There is also an opportunity to expand on the scope of this research by exploring additional neighborhood and street typologies combinations. Furthermore, there is an opportunity for those who may want to expand on this research to introduce and explore their own design objectives.

A second approach that could be taken to further this investigation may require waiting to see how autonomous technology advances and how it is adopted. Once more is known about this technology more realistic predictions regarding the future of autonomous travel and its impacts on urban design may be made. Additionally, further developed design frameworks may be introduced as more is known about this technology. At that point in time the baseline scenario would need to be reestablished and a new framework could be utilized for making design decisions. With this new information a similar approach of choosing street and neighborhood typology combinations to explore right-of-way transformations could be undertaken.

LIMITATIONS

It is important to acknowledge that there are a number of limitations to this work. One of the major limitations of this research was the lack of concrete information regarding autonomous technology. While the studies utilized in this research did their best to understand how these vehicles may function and what their impacts on the built environment may

149 Chapin et al., "Envisioning Florida's Future : Transportation and Land Use in an Automated Vehicle World."

be, they were often based on assumptions regarding numerous aspects of autonomous technology. In addition to this, one other limitation of this research is that fact that these design explorations focus solely on a point in time in which the shift to autonomous vehicles is complete. There will likely be changes that occur within the right-of-way throughout this transition that need to be addressed, however these changes will be easier to plan for once more is known about the adoption rate of these vehicles. Finally, it is important to acknowledge that in order for this future to be fully realized there will also be other factors at play. Perhaps the largest of these is the projected establishment of progressive administrative policies at all levels of government that work to encourage the adoption of a shared system and limit potential negative externalities associated with this technology. In addition to government policies, it is important to consider other issues including: the role of the consumer, the potential impact on public transportation, the role of public-private partnerships, land use change outside of the right-of-way, and more. These related issues are worthy of their own in-depth examinations and fall beyond the scope of this research.

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