Roadmap for Autonomous Cities: Sustainable Transformation of Urban Spaces

Full Paper

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Abstract

Despite the inherent relationship between cars and their physical urban surroundings, many cities are hesitant to embrace the impact of autonomous mobility on urban design. Industry leaders envision autonomous vehicles soon penetrating global markets, although the relationship between autonomous vehicles and their urban context has been poorly discussed. Witnessing rapid technological advancement and tardiness of city planning and execution, the proposed research diverts discourse from intrinsic technology of autonomous vehicles to their impact on urban design. This paper offers a review of historical cars-oriented design and the global surrender to car-culture in the past century. Then, it elaborates on different autonomous technologies and their potential impact on urban form. Furthermore, it shares plural plausible future perspectives to initiate a discussion on tangible implications of autonomous vehicles on contemporary cities. Ultimately, this research suggests a preliminary roadmap to the way autonomous mobility might be incorporated within new and existing cities.

Keywords

Autonomous vehicles, urban planning, mobility, sustainability, persuasive cities, urban design

Introduction

Modern societies continuously require novel ways for sustainability modeling and reporting (Ahmed & Sundaram 2012). The promise of autonomous vehicles (AVs) and gradual shifting towards on-demand transit are leading to a paradigm shift in the way cities accommodate mobility. In many ways, this change has already begun (Stibe & Larson 2016): Recently, after decades of incline, private car ownership went down for the first time in the history of the US. Urban rebirth and 'back to the city' movements are defying suburbia; trucks, cars and bicycle-sharing platforms are changing the way people and goods move in cities. While these trends are projected to increase in coming years, contemporary cities are focused primarily on patching holes in old mobility systems or proposing incremental changes to existing infrastructure. As of today, little research has been offered on a compressive vision for the relationship between AVs and cities.

The importance of such debate is tied to the pace by which new mobility technologies are announced and marketed. Both academic and non-academic publishing is seeing an ever-growing discourse on all angles of this subject. Despite this growing interest, predictions concerning the rate and depth of AVs adaptation are varying dramatically. Certain assumptions conclude that market-ready AVs would become a common commodity within less than 5 years. Others are more skeptical and titling these predictions as 'trends', 'science fiction' or even comparing them to 'moon colonies' as fictional technologies that ultimately vanished. Nevertheless, industry leaders, government officials, policy-makers and large percentages of the public all agree that a change is coming: A recent study done by IHS Automotive concludes that more than 54 million self-driving cars are proclaimed to roam the roads by 2035 and by 2050, all cars will be autonomous. AV market is predicted to amount to $42 billion by 2025 and to reach $77 billion by 2035, when AVs will amount to a quarter of all cars. Recently, US government committed to invest $4 billion in

AV research and development in the next decade. It is therefore hard to imagine that such unprecedented investments could be dismissed as yet another technological promise or an occasional 'hype'.

Background

Mobile phone, cloud computing or the Internet all use some form of physical infrastructure. However, their tangible infrastructures are fairly modest and commonly hidden from the end-users' eye. Unlike much other technological advancement of past decades, AVs are unique in their deep and inherent relationship with their surrounding physical infrastructure. This infrastructure (roads, bridges, parking, maintenance and service area, etc.) will serve AVs the same way it has served horse-carriages or cars in past centuries. These physical elements were all designed and constructed in reaction to past transportation trends and are mirroring the way humans and goods movement was perceived by proto-modern city planning. Although controlled by robotic systems, AVs should act no different in respect to urban infrastructure: they will consume paved roads, parking spaces and most other types of urban infrastructure in different capacities.

Yet currently, the relationship between AVs and their corresponding infrastructure is unbalanced. The pace by which planning and development is being carried out in cities is no match to the rapid advancement of new technologies. Large-scale urban adaptation to new invention was always challenging: The turn of the century 'connected city' revolution brought running water, in-house gas services and new communication systems to every household (Graham & Marvin 2001). These technologies emerged during a short period at the end of the 19th century, forcing western cities to hastily adapt. Cities inability to quickly react to these changes resulted with undocumented and disorganized installations of many of these systems, causing budgetary and technical issues for years to come. In the US, lawmakers are divided in regards to proper reaction and regulation processes of AVs. Currently, only few states have fully permitted AVs testing, but great uncertainties lay in regards to regulating massive fleets of AVs. The fragile liberty granted to AVs development is mostly founded on legal gray-zones more than it is consciously defined in the eyes of the law. Most lawmakers act as bystander amidst many uncertainties: which technologies will prevail, when will they fully penetrate the market, or how consumers will respond. Effectively, market leaders and technology early-adopters are the ones setting the tone in this discussion (Guerra 2016).

While early regulation is already taking place in regards to public safety, nearly no discourse has been offered in respect to implications on urban planning and city design. Most major US metropolitans are not including the projected change into their city plans and limited number of research and design projects envision the effects of AVs on city planning or design. Most existing research examines local or regional models that are simulating the behavior of different AVs fleets through supply and demand, effects on road-congestion, air-pollution and environment or parking demands. However, most of these assessments consider infrastructures and cityscapes similar to those exist today. In other words, most of these simulations feature driverless fleets but the streets, the buildings, the sidewalks and parking are all assumed to remain similar to their current state. But even when assuming that AVs will operate within the same urban conditions as today, there are great uncertainties about how, when and to what degree they will be incorporated. Attempts to model AVs effects face lack necessary evidences: *"Because these vehicles do not yet exist but modelers need to incorporate their possible impacts on travel demand, the most straightforward way to understand behavior would be to conduct a stated preference survey… Travel models will need to have major improvements in the coming years… to better anticipate the arrival of this technology"* (Childress et al. 2015).

Therefore, it became apparent that assessing the implications of AVs using existing prediction models is mostly an imprecise effort, as Childress stated: *"impacts of autonomous vehicles are highly speculative. Future impacts depend on technological development, market reactions, and regulatory actions, making it challenging to confidently predict impacts to regional transportation systems. With so many unknown and potential effects of AVs, it is challenging to anticipate long-term effects with certainty. However, some of these impacts should be considered early on… to develop feasible analysis boundaries. With these analyses, agencies can prepare more dynamic long-range plans"* **(**Childress et al. 2015). How could cities do better prepare for this seemingly inevitable change, giving that predictions offer inconsistent forecasts? Here we aim to highlight how AVs potentially impact cities, in particular in relations to their tactile, infrastructural and physical elements. This aims to extend the discussion to ecosystems and roadmaps that are more likely to be affected by this change. We propose a result-driven view of the extents affected by the change, and offers simplified matrices to assess the impact of AVs. Building on those understandings, this paper proposes a modified decision-making process, in which policy-makers and the general public could predetermine the future of autonomous cities.

AVs in the Context of Urbanism

"Forget the damned motor car and build cities for lovers and friends!" (Mumford 1955). The relationships between modern mobility and cities was broadly studied and explored. 'Car culture', Car-dependent urban-planning and 'car-architecture' led to massive changes in urban form, design of neighborhoods and the architecture of buildings. The car gutted buildings and streets, shuffled land-use and redefined the design of landscapes in a manner no technology ever could.

Cars and Cities

One billion cars have been manufactured in the twentieth century; currently, 1.2 billion cars are roaming the world and expected to become 2 Billion by 2035. Subsequently, car-oriented city planning ruled the better half of the 20th century. In the city of Los Angeles, 14% of the county's incorporated land (around 200sq/m) is dedicated to car parks, on-street parking spots and off-street garages and lots. In the urbanized area there are 16 acres of parking for every 100 acres of land, which are more than double the 7 acres of parking coverage from 1950 (Chester et al. 2015). The rapid formation of the American suburb is arguably the most dramatic effect cars had on city form. By 1970, more than 50% of US metropolitan population lived in suburban communities. Between 1970 and 1976, central city population dropped by 3.4% to 60.7 million. In 1980, the suburban portion of the 15 largest metropolitan areas ranged from 83.7% in Boston to 45.1% in Houston. But the effects of that era's car culture was not limited to low density and to the ever-curving, sidewalk absent suburbs streets: New industries and business models were introduced, far from the dwindling city centers; Roadside fast-food restaurants, drive-in movie arenas and shopping malls offered the residents of 'suburbia' similar amenities to those historically offered by the city, but with the accessibility and flexibility offered by private cars. Gradually, massive distribution centers, warehouses and depots were installed in strategic locations around highways intersections, allowing retailers competitive real estate prices.

After nearly a century of suburbanization and sprawl, it is now evident that the global surrender to cars is pivotal in the impetus behind the design of cites. This misconception was described by Sheller and Urry (2000): *"...cars have been conceived of either as a neutral technology, permitting social patterns of life that would happen anyway, or as a fiendish interloper that destroyed earlier patterns of urban life. Urban studies have omitted to consider how the car reconfigures urban life, involving... distinct ways of dwelling, travelling and socializing in, and through, an auto-mobilized time-space."*

Machine Restraining Mechanisms

The implications of cars on 20th century cities and infrastructure were dramatic, but not always irreversible. All through the last century, cities, towns or smaller settlements have continuously elected to avoid cars, reduce traffic or convert into alternative modes of transportation, e.g. bicycling (Millonig et al. 2016). Organizations have pursued different paths in respect to urban mobility and infrastructure design, including strategies harnessing computer-supported influence (Stibe 2015) to persuade communities. Commonly independent, self-sustaining and with centralized planning apparatuses, these cities not only changed the landscape of mobility, but also constructed successful methods of community engagement, decision making and communication that cultivated their initiatives (Stibe & Larson 2016).

The case of Hamburg's Grünes Netz is an example to this use local government domain. In early 2014, the city of Hamburg, Germany declared a plan to construct a connective Green Network (Grünes Netz), which will cover nearly 40% of the city's area. The plan proposed connecting the parks, recreational areas, playgrounds, cemeteries and gardens with a network of green paths. Its main goal is to connect the open and natural landscapes surrounding the city via a network of car-free paths and roads. This strategy is also intended to reduce emissions, improve air and water quality and offer various recreational zones for the city's population. As stated by Jens Kerstan, the parliamentary leader of Hamburg's Green Party: *"Our residents are quite progressive. Many Hamburgers are willing to give up their cars"*.

AVs in the Context of Urbanism: Future Eco-System

The pace of technological advancement is continuously surpassing most urban-scale development processes. For that reason, when planners attempt to predict future, they must generalize impacts of particular technologies. They are doing so by extracting only relevant features of the anticipated technological transformation and utilizing them when constructing feasible frameworks for urban design.

As an example, a 1960's team of planners working on the design of a new major bridge could hardly predict exactly what types of vehicles, at what capacity and for which purpose will it be used several decades later. However, their design assumed certain parameters of future mobility and incorporated them into their decision-making process. Together with their local policy makers, these features where converted into regulations (i.e. the bridge not to be crossed by certain type of vehicle, at a certain weight, height or during certain hours of the day) that mitigated the tangible characteristics of the infrastructural project with their view on how it should function. These features were not a representation of any specific technology but groups of characterizing features that could be employed regardless of the specificities of any future mobility.

Similarly, urban design for AVs cannot currently anticipate how this technology will change or infiltrate into the global market. As shown, most current predictions share great uncertainty about this change. Instead, planners should consider AVs as 'black boxes': unspecified elements that only some of their features are apparent and relevant for present-day decision-making. The many different characteristics of AVs should be redacted to the minimum necessary for planners and urban designer to envision cities for years to come. At this point of time and with the limited knowledge in hand, the features which bare most implication to the surrounding city and infrastructure are related to (1) the degree of automation, and (2) to the question of private versus shared ownership.

Degrees of Autonomy

A growing number of car manufacturers currently offer different degrees of automation in their car models. These features often described as Advanced Driver Assistance Systems (ADAS). It has been forecasted that global ADAS unit shipments in 2020 would exceed 90 million units. Alongside the growth of ADAS market and the introduction of new features every year, few companies are currently pursuing market-ready AVs, which require no interaction from the driver side. Since autonomy features vary significantly, NHTSA regulations offered a clear spectrum of automation between manhandled cars, through ADAS vehicles to full autonomy (Table 1):

No-Automation (Level 0)	The driver is in complete and sole control of the primary vehicle controls – brake, steering, throttle, and motive power – at all times.
Function-Specific Automation (Level 1)	Automation at this level involves one or more specific control functions. Examples include electronic stability control or pre-charged brakes, where the vehicle automatically assists with braking to enable the driver to regain control of the vehicle or stop faster than possible by acting alone.
Combined Function Automation (Level 2)	This level involves automation of at least two primary control functions designed to work in union to relieve the driver of control of those functions. An example of combined functions is adaptive cruise control in combination with lane centering.
Limited Self-Driving Automation (Level 3)	Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The Google car is an example of limited self-driving automation.
Full Self-Driving Automation (Level 4)	The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles.

Table 1. U.S. DOT Policy on Automated Vehicle Development

As Table 1 depicts, the only case where a vehicle is considered 'fully autonomous' is Level 4. It is less likely that ADAS systems (Level 1-3) would have the same impact on infrastructure and urban design as level 4 AVs. Despite improvements to overall safety and performance, ADAS vehicles are not designed to completely replace humans in the driver seat.

As long as human interaction is required even for the smallest part of the trip, the vehicle could not be apprehended as fully autonomous. While some infrastructural changes might trail the incorporation of ADAS and connected vehicles (camera networks, sensors and smart lighting infrastructure, local positioning systems, etc.) their long-term effect on city form would be relatively insignificant (Zhang et al. 2009). However, level 4 AVs, which their main driving capability is based on robotic systems, could bare more significant impact on urban environments.

Ownership Models

A major unknown in regards to mass adaptation of AVs is related to the structure of car ownership in the age of AVs. Since AV fleets are anticipated to network and self manage demand and could be potentially optimized to operate ceaselessly, future fleets of shared AVs could provide transportation systems for the entire city, while reducing or fully eliminating the need for private car ownership. Contemporary ridesharing platforms such as Uber or Lyft already operate synchronized fleets that are self-coordinating massive volumes of trips every day. Uber is also one of the first ridesharing companies to openly acknowledge that it is pursuing a driverless fleet to replace its dependency on human drivers.

The question of car ownership is also related to social, cultural and financial perceptions. Despite national decline in private car ownership, in many places across the US owning a car is still apprehended as a symbol of freedom, matureness or financial stability (Sheller & Urry 2000). In a recent BCG and WEF poll done amongst 6000 participants from 10 different countries, most expressed their wish to maintain car ownership, even if it is capable of self-driving. This approach parallels with recent rates of private car ownership: In the US, ownership rate is nearly 80% (797 out of 1,000 people). In comparison, 800,000 private cars are owned by less than 12% of Singapore's population, much of it a result of the city's renowned transit system.

A recent MIT study estimated that a fleet of 300,000 autonomous shared vehicles could serve the entire population of Singapore (6 million people) within 15-minute waiting time during peak hours. But the acceptance to these changes is not only technology driven; society-wide acceptance of shared transportation will require confidence building and transparency and could be only happen over time. These slow progressions will impact the even slower planning processes, so that a fully shared, fully autonomous city is still considered a futuristic hypothesis.

Roadmap for Autonomous Cities

As described, the degree of autonomy and model of ownership are the most fundamental aspects in the dialogue between AVs and city design. Constructing a decision-making apparatus that is capable of assessing the pros and cons of city-design for AVs should originate from the understating of the tactile elements more prone to be affected by mass adaptation of this technology.

The diagram in Figure 1 aims to highlight these areas within a generic cityscape. Naturally, this section is not referring to any specific city but rather it is intended to display multiple fragments common in generic urban settings. Other functions and land-uses will most likely experience some degree of change upon mass spreading of AVs.

Table 2 summarizes potential changes for each of the given interface points. As a base point for further discussion, this list assumes two extreme conditions: a city where all vehicles are either POAVs (Privately Owned AVs) or SAV (Shared AVs). Evidently, other conditions on this spectrum are most likely to emerge in the coming years, including mixtures between SAVs, POAVs, and regular vehicles. However, in a planning scenario where local authorities actively embrace potential change, these extremities could help realizing a large effect of their design.

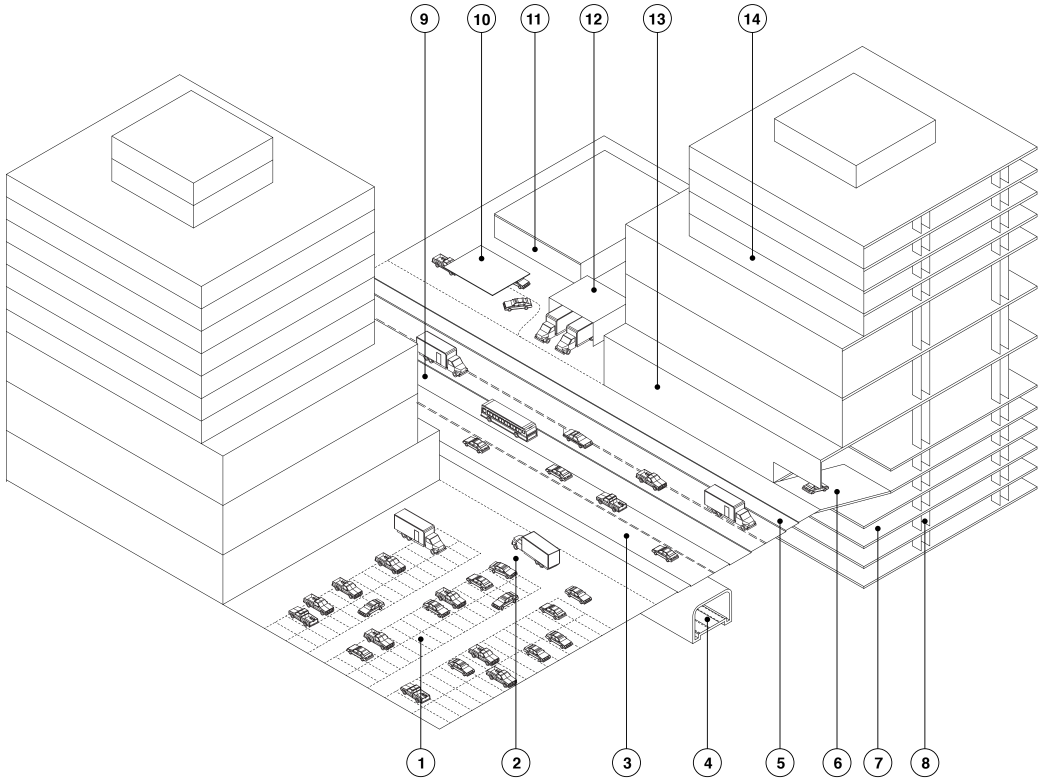

Figure 1. Interfaces of Autonomous Cities

#	*Use or function*	*Description and Current State*	*Potential change POAV*	*Potential change SAV*
1	*Parking Lots, car lots, car parks*	Estimated are 500 million parking spaces are in the US. Each parking spot is roughly 270 sq/ft, amounting to almost 4850 sq/mi, 3 times the size of Rhode Island. In the states of Illinois, Indiana, Michigan and Wisconsin 486 sq/mi or 5% of urban land use are parking lots holding a ratio of 2.5-3.5 parking spaces per car.	POAV could self navigate to parking after drop-offs. While they could also return home or travel to remote parking, this added trips will intensify fuel consumption and maintenance and might require more waiting time when AV is called back. Therefore, it is more likely that parking lots or parking structures will be offered within the city core while consuming valuable real estate. If POAVs will discourage public transit usage, parking lots and their service roads might become even more congested.	When fully shared, AVs could roam towards high-demand areas. This means that parking lots – especially within the city center – could become redundant. Other parking solutions might be needed outside the city centers, for long-term storage and maintenance of AVs, but these could be poised on less valuable or undevelopable land. Short-term parking might still be used for drop-offs, shipments and deliveries but these might be offered within the buildings' perimeter and not on large scale dedicated lots.
2	*Delivery and supply net-works*	In New York City, 400 million tons per year or 91% of all the city's goods are delivered via trucks. Growth of online shopping and delivery services expected to increase by 46 percent in the next 25 years.	Delivery systems might become autonomous even prior to private transportation and could operate similarly in both SAV and POAV scenarios. Unmanned trucks or smaller delivery vehicles could operate on demand, thus reducing the need for consolidation of deliveries into a single trip. However, if congestion problems will rise in POAV scenarios, increased banning of trucks and other large vehicles from city centers might be promoted, forcing deliveries to be handled by other means of transportation.	

3	*Roads, streets and other vehicles permitted pathways*	Streets and drivable paths in the US make roughly 30% of the cities' land use. In Los Angeles there are 7.6 Lane miles per sq/mi, where in Boston there are 2.9.	The sheer number of POAV trips is anticipated to arise due to the connivance of autonomous mobility. The ability to maintain suburban lifestyle without the hassles of daily commute could push more to prefer living in suburban communities thus increasing highways and road construction.	Reduction of street capacity is already taking place in cities where successful transit and alternative modes of transpiration gradually replace cars. SAVs could increase this trend by offering on-demand transit solutions and so tackling the 'first mile, last mile' problem for well-connected transit systems.
4	*Under-ground transit infra-structure*	Around 15 metropolitans in the US operate underground transit systems, serving up to 9 million riders per day in the case of New York City. In 2012, the Second Avenue Subway line project had a budget of $4.5 billion for a mile-and-a-half segment.	The connivance offered by POAVs would eventually challenge mass used public transit systems, especially when mass market adaptation will make AVs more affordable. Since underground transit systems are extremely expansive and rarely profitable, suburban cities – which might flourish with POAVs - will make these investments even less likely to occur.	While SAVs might pair with existing transit systems to support denser urban form, making the case for new and expensive investments in underground systems could become difficult. Other cheaper and more accessible transit (such as ABRT) solutions might couple better with SAV fleets and could reduce the need for massive infrastructural projects.
5	*Sidewalks and pe-destrian areas*	Many cities in the US under preform in regards to sidewalk and pedestrian accessibility: Austin, Texas is missing sidewalks on 49% of its street frontages. Similar sidewalk conditions are in Charlotte (50%), Houston (42%), and Nashville (77%).	POAVs are anticipated to induce trips and usage of vehicles in lieu of walking or biking. As with contemporary suburban streets design, the necessity and utilization of sidewalks is minimal amid car culture. City centers might still offer a well-connected network of sidewalks and bike lanes but these could be confined to shrinking areas.	As a result of the reduction in drivable streetscapes, sidewalks, bike lanes and other pedestrian amenities might enjoy a renaissance in walkable cities. Vehicle access would be still permitted in most cases (for delivery, services or emergency) but it could be dissolved within new streetscape and walkability-centric urban design.
6	*Buildings' car access (parking, delivery, drop-offs)*	Design for car access dictates reduction of retail, commercial or other usages on street-level façades and creates disruptions in street continuity.	Since POAVs will be able to park themselves, new buildings could use detached or semi-remote parking solutions, for which certain radiuses and thresholds will dictate usability and affordability. These could reduce construction costs and project duration with the reduction of complex underground works. While it might result with fewer vehicles accessing buildings, generous drop-off area designed to sustain rush hour and large deliveries will still be required. Older buildings will probably maintain their access points and underground parking which could become even more valuable with mass adaptation of POAVs and increasing numbers of private vehicles entering the city during working hours.	Assuming SAVs will be designed to self-navigate, new buildings could require less parking and underground access and reducing construction costs. New large-scale construction projects will probably re-emphasis the street level entry and will increase capacity of pedestrians entering through main lobbies. Since less vehicles will access the building itself, generous drop-off areas designed to sustain rush hour and sizeable deliveries will still be required. In old buildings, these access points and underground spaces could be repurposed with new functions - storage, retail or culture - that usually require less natural light and direct street access. Over time, construction of less unground spaces could result with simplified and cheaper below grade infrastructural systems.
7	*Under-ground parking*	On average, the cost of underground parking in the US is $103 for sq/ft or $34,000 per parking space. This is $10,000 more than the cost of aboveground parking ($24,000). For example, minimum parking requirements increase the cost of a shopping center construction by up to 93%.		
8	*Vertical circulation systems*	In buildings with underground parking, passengers' access commonly occurs		

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<tr><td></td><td></td><td>through elevators and underground stairs. This condition often results with reduced street level activity.</td><td></td><td></td></tr>
<tr><td>9</td><td>Dedicated transit lanes, light rails and other over-ground transit solutions</td><td>Dedicated over ground transit lanes provide uninterrupted movement for light-rail, buses and BRT routes. Between 2004 and 2014, transit in the United States grew slightly faster than urban population, from 13.1km of rapid transit lanes (RTL) per 1 million inhabitants to 14.3.</td><td>With mass adaptation of POAVs and the convenience it brings to everyday commute, public transit might loose appeal and will face even more hurdles in future development plans. As with underground transit, effectively connecting ever-growing suburban expansions will become difficult, thus reducing ridership and reliance on these transit solutions.</td><td>SAV’s could either coexist or gradually replace inner-city rapid transit solutions. With reduced congestions and optimized connectivity, SAVs might perform well even without dedicated lanes. However, throughout the period of adaptation to SAVs which could last several decades, it is possible that dedicate lanes would use to coordinate between regular and automated traffic, thus increasing the need for dedicated infrastructure and more complex street sections.</td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">Gas stations, garages and other car servicing and utility structures</td><td rowspan="2">More than 120,000 gas stations exist in the US. The average size for a gas station site (including parking, services and adjunct retail) is 53,000 sq/ft or more than 220 sq/mi of land in the US. Gas stations and underground oil storage are major causes of soil and water pollution in their surrounding areas.</td><td colspan="2">In both scenarios and even before mass adaptation of AVs, major forces in the car and energy industries are promoting renewable sources to replace oil in car use. Nevertheless, the two trajectories (AVs and clean/renewable energy) might not immediately merge and early AVs will maintain internal combustion oil-based systems.</td></tr>
<tr><td>If POAVs will still use oil instead of electrical or other renewable energy sources, gas stations will need to adapt to driverless refueling. This could result with less retail-oriented settings and more automated-centric design.</td><td>SAV would optimize refueling and servicing and will be able to self assess their maintenance needs. This could result with relocation of most gas and service stations, especially those occupying valuable real estate within the city.</td></tr>
<tr><td>11</td><td>Car-de-pendent retail and leisure</td><td>Averaging more than 50,000 sq/ft, Superstores, Megastore or Big-Boxes sprawled all over US’s major infrastructure arteries since the 1960’s. In Massachusetts, the average distance from any big box store to the nearest highway is 2.78 miles.</td><td>With continuous sprawl and estimated growth of suburban typologies, car dependent retail would have no incentive to decline. POAV will make trips to shopping centers and big retail stores easier and more convenient. These will have to be strategically designed and poised to serve newly dispersed communities. Parking lots might still be one of the main features of these stores but they might be located remotely, thanks to self-parking capabilities.</td><td>In condensed urbanism, retail tends to foster in smaller and more local scale. Walkable cities commonly feature street-level storefronts; big retailers tend to adapt smaller parcels for their stores. With on-line shopping, autonomous shared mobility and delivery systems, trips to big boxes and low-cost retailer could become less needed. Yet since real estate values within cities will still be higher, suburban retail might still be more competitive.</td></tr>
<tr><td>12</td><td>Supply depot and truck bays</td><td>Similar to regular car access (6), supply depots and truck bays consume significant landscape and façades area for logistics.</td><td colspan="2">As with delivery networks (2), the service hubs and depots that provide access to trucks shipments and deliveries would be designed in response to future road congestions and city regulations. In both scenarios, smart and decentralized delivery systems could reduce truck trips within cities and might provide delivery-on-demand in smaller volumes. Large retailers might still use large trucks but could adjust autonomously to deliver off pick hours. If current trends in cities will continue, trucks and other polluting automobiles would gradually enter less into city centers in favor of smaller and more sustainable shipping methods.</td></tr>
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13	*Street level facade function*	Active street level is important to the viability of the urban realm. After many years of 'Main Street' decline, vacancy rates in the US are more modestly reducing from 13% to 11% in Q1 2017.	Street level retail is highly relying on active sidewalks. Favoring car lanes and parking spaces reduces accessibility to storefronts and the activity on the street level. As well, there is strong correlation between the appearance of malls, superstores and big boxes and the decline of street commerce.	With sidewalk expansions (5), reduced parking spaces (1), reduced physical interruptions to street facades (6) and induced street level vibrancy, SAV oriented design could help revitalize disjointed retail streets.
14	*Mix use and program division*	Program allocation has relationship with adjunct infrastructure and is impacted by noise, pollution, light and other factors. Historically, retail and other street-level functions were situated to void the building's main program (residential, offices) from the street level.	In that sense, mono-functional land use would become more appealing with POAVs, since multi-use complex construction projects would decrease amid the connivance of moving between different buildings or urban amenities.	In SAV scenario, programs that commonly opt to avoid street level (such as offices, high-end retail and residential), due to noise and pollution, might be reintroduced into ground zero. This could result with effects on street property values and transform the design of street level facades.

Table 2. Typology of Autonomous Cities

Plural Futures

The difficulty to predict how AVs will be merged into existing urban settings will eventually promote three principal approaches towards city design: passive, adaptive or active.

Passive: This approach follows similar path by which urban design for mobility was conceived in the past century. It suggests ad-hoc reflections on transportation issues and patchwork of solutions when long term plans fail, all within a rigid and inherently bureaucratic planning system. The main concern with this approach is that the current pace of technological changes will make cities and transportation plans redundant faster than ever before. This approach actively promotes market-based decision-making, which in the case of AVs would sanction industry to dictate ownership models, degree of autonomy as well as capacity of these vehicles. A potential consequence of 'passive' planning for AVs could result with rapid change in urban form: Since AVs will enable users to spend commuting time for work or leisure purposes, AVs might encourage people to live further out from urban cores and commute longer distance; subsequently, these transformations could increase sprawl and congestion. *"If they're privately owned and you can summon them to pick you up and drop you off and then go park someplace, that actually will result in more trips on the streets, and more congestion."* (Kiger 2015)

Adaptive: As Gifford (1994) suggests, incorporating adaptable measures in transportation planning might relieve some of the issues that emerge when new technologies are introduced. Yet governmental and intensely bureaucratic structures cannot easily adapt to dynamic changes. For example, approval of a certain budget must go through endless channels and numerous decision makers before getting approved. Incorporating flexibility in all of these channels might result with anarchy of the system and lack of clear decision-making. As well, the concrete form of transportation infrastructure limits flexibility and requires rigor in early planning stages. It is however possible to introduces certain amount of adaptability into smaller governments, such as local municipalities or small city-states.

Active: An active planning approach will aim to set ground rules in regards to the nature and operation of a city, while potentially diverting from global tendencies. This approach builds upon the capability and willingness of certain cities to elect different planning paths, in a way, which may contradict city planning trends and zeitgeist. In the core of this approach is the successful building of consensus and strong community collaboration; The capacity to ban cars, choose walkability or divert city's infrastructure into green landscapes has to be drawn from a supportive majority of the public, actively willing to sacrifice some contemporary norms for the sake of an alternative future. These cities are the uncommon minority that deliberately chooses which forces will have a domain over their planning apparatuses.

Further

More than most other technological advancement, cars have had crucial impact on the way cities were designed, built and grew. This impact was mostly formalized through ad-hoc processes and retroactive measures, commonly lacking comprehensive and long-term approach. Mass-suburbanization, amassing infrastructures, congestion and pollution are the result of complete surrender to car-architecture and to the industry that kept developing, manufacturing and shipping billions of vehicles. Three main urban conditions will phase the autonomous cities revolution: The existing city with mixed autonomous and non-autonomous vehicles (Augmented Autonomy); the existing city served only through autonomous mobility (Full Autonomy) and the new city, fully autonomous by design (Future Autonomy). Each of these conditions has unique formal and operational features that should be investigated from the citywide perspective to the zoomed-in street scale design.

The ongoing revolution of AVs has great implication on sustainable transformation of modern societies. After years of stagnation, a new wave of innovation stimulates a global discussion about future mobility. By emphasizing the relationship between AVs and their immediate urban surroundings, we suggest that active and results-driven planning approach is necessary for successful adaptation of this innovative technology. The different AV technologies and their relevant aspects that have been discussed in this paper can be further explored and applied to urban planning and architecture. The introduced typology of autonomous cities can serve as a base point for discussion on tangible implications of AVs on contemporary cities. Ultimately, the created roadmap for autonomous cities can become instrumental for decision makers and stakeholders to identify how autonomous technologies could be successfully incorporated within new and existing cities.

REFERENCES

Ahmed, M. D., & Sundaram, D. (2012). Sustainability Modelling and Reporting: From Roadmap to Implementation. *Decision Support Systems*, *53*(3), 611-624.

Carroll, J. 2005. “The Blacksburgh Electronic Village: A Study in Community Computing,” in *Digitial Cities III: Information Technologies for Social Capital*, P. van den Besselaar and S. Kiozumi (eds.), New York: Springer-Verlag, pp. 43-65.

Chester, M., Fraser, A., Matute, J., Flower, C., & Pendyala, R. (2015). Parking Infrastructure: A Constraint on or Opportunity for Urban Redevelopment? A study of Los Angeles County parking supply and growth. *Journal of the American Planning Association*, *81*(4), 268-286.

Childress, S., Nichols, B., Charlton, B., & Coe, S. (2015). Using an Activity-Based Model to Explore Possible Impacts of Automated Vehicles. In *Transportation Research Board 94th Annual Meeting, Washington DC, TRB*.

Gifford, J. L. (1994). Adaptability and Flexibility in Urban Transportation Policy and Planning. *Technological Forecasting and Social Change*, *45*(2), 111-117.

Guerra, E. (2016). Planning for Cars that Drive Themselves: Metropolitan Planning Organizations, Regional Transportation Plans, and Autonomous Vehicles. *Journal of Planning Education and Research*, *36*(2), 210-224.

Millonig, A., Wunsch, M., Stibe, A., Seer, S., Dai, C., Schechtner, K., & Chin, R.C.C. (2016). Gamification and Social Dynamics Behind Corporate Cycling Campaigns. *Transportation Research Procedia*, *19*, 33-39.

Mumford, L. (1955). The Brown Decades: A Study of the Arts in America, 1865-1895 (Vol. 200). Courier Corporation.

Sheller, M., & Urry, J. (2000). The City and the Car. *International Journal of Urban and Regional Research*, *24*(4), 737-757.

Stibe, A. (2015). Advancing Typology of Computer-Supported Influence: Moderation Effects in Socially Influencing Systems. In *International Conference on Persuasive Technology* (pp. 253-264).

Stibe, A., & Larson, K. (2016). Persuasive Cities for Sustainable Wellbeing: Quantified Communities. In *International Conference on Mobile Web and Information Systems* (pp. 271-282).

Zhang, Y., Gantt, G. W., Rychlinski, M. J., Edwards, R. M., Correia, J. J., & Wolf, C. E. (2009). Connected Vehicle Diagnostics and Prognostics, Concept, and Initial Practice. IEEE Transactions on Reliability, 58(2), 286-294.