The Autonomous Future of Mobility

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This paper looks at the problematic history of cars, infrastructure, and the vehicular landscape and asks how the nature of transportation is changing in light of autonomous mobility. Self-driving vehicles have advanced from research to reality and offer tremendous promise, from reducing emissions and congestion through ridesharing to decreasing the number of driving accidents and deaths. However, autonomous driving is still in its early stages, with safety unproven and spatial potential or perils still unclear. To examine the possibilities that autonomous vehicles may offer in the built environment, architects and urban designers will need to respond to new technological imperatives and ongoing systemic problems tied to the car's legacy.

The author's research acts as a case study that explores how design fields can tackle these issues via mobilizing architectural representation and visualization. This research entails the production of an operable physical model and contingent media to create an experimental testing platform for autonomous driving that examines the following questions. How can architectural representation tactics be employed to innovate in the built environment relative to the broad implementation of autonomous vehicles (AVs), artificial intelligence (AI), and machine sensing? And how might those innovations improve upon the problems that cars have created by decreasing environmental degradation, better serving the disenfranchised, and considering the spatial redefinition of cities?

> Autonomous vehicle technology is heralded as transportation's magic bullet, but it is unclear how the advent of the technology will be organized. In ideal projections of a fluid, smart, digital world, AVs in efficient platoons will perfect driving by increasing mobility, saving fuel, reducing emissions, and increasing productivity…When the magic bullet boomerangs, the optimism turns dire as predictions of increased congestion, emissions and sprawl… How then does the automobile industry, the sharing economy, and transit organize its efforts in the face of these uncertainties?[1]

A BRIEF HISTORY OF MOBILITY

In media and popular culture, cars have acted as a symbol of luxury and freedom.[2] However, vehicular mobility has led to a host of crises, including numerous vehicle crash fatalities, environmental damage, military conflicts, and economic injustice and segregation in cities due to the expansion of highways. This paper understands these catastrophic impacts in relation to five key topics relating to vehicular history: culture, signs, space, energy, and speed.[3]

Cars are deeply enmeshed in American culture as objects of desire; they are tied to personal identity as extensions of the individual. Vehicles are glorified by automobile manufacturers, advertisers, novelists, musicians, and film directors as objects of desire that increase individual freedom. Furthermore, cars are among the select material goods around which an entire culture has developed. In the United States, car culture took off in the 1950s through the car industry's growth and the expansion of vehicle ownership. During this boom, a wide array of buildings dedicated to automobile-centric experiences began to populate the vehicular landscape, including roadside attractions, diners, motels, and drive-in restaurants and theaters.

The car of the 20th and early 21st centuries not only acts as an icon but moves through an ocean of signs. At the close of World War II, the growth of car sales expanded dramatically alongside the mass production of consumer goods, making way for advertising to become a thriving industry. Omnipresent signage began to blanket the built environment. As Robert Venturi, Denise Scott-Brown, and Steven Izenour suggest, "the graphic sign in space becomes the architecture of the landscape."[4] Here, human visual culture and high-speed-legibility construct an environment centered around communication and signification.

Urban space as it was before the automobile—as a collective pedestrian realm—is dissolved. Paul Virilio suggests in Speed and Politics, "the transportation capacity created by the mass production of automobiles became a social assault on space."[5] These changes to space had immeasurable social consequences. With the US Interstate Highway System's development, urban planners introduced highways that destroyed communities, tearing down swaths of cities along racial and economic lines. New arteries allowed individuals to travel

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Figure 1. *Architectural Design of An Experimental Testing Platform For Autonomous Driving*. Isometric rendering of operable model. By Constance Vale's research practice The Factory of Smoke & Mirrors, with Research Assistants Zhuoxian Deng, Min Lin, Mason Radford, Yi Wang, and Yuzhu Wang.

greater distances from home to work, creating sprawling suburbs for middle- and upper-class white Americans, while Black Americans were widely denied suburban home loans by the Federal Housing Administration. The construction of public highways ultimately facilitated the privatization of mobility and space and further entrenched systemic racism.

Networks of highways fueled industrialization and built the US economy, but they also led to a significant decline in mass transportation in favor of inefficient modes of transit. With this shift came an overwhelming increase in the demand for energy. Chief among the complications this introduced is environmental degradation due to rampant pollution. Vehicle pollution is responsible for the early deaths of tens of thousands of Americans each year, and extracting fuel by building pipeline infrastructure damages ecosystems. Furthermore, in our energy-centric world, control over oil and gas equates to some countries' geopolitical power and others' financial vulnerability. The desire for resource control leaves the world vulnerable to economic crises, military entanglements, and wars that cause untold casualties.

In the frenetic condition produced by the automobile, individual agency and collective society are lost in the pursuit of perpetual motion through a destabilized context. Speed comes with physical and societal risks. Vehicle crashes are one of the leading causes of avoidable injury and death in the US and are the number one cause of death among the young. And the different pace or degree of efficiency desired in society signals an ontological shift. As Virilio observes, the city is transformed into "a point on the synoptic path of a trajectory" wherein "the masses are not a population, a society, but the multitude of passersby."[6] Speed disrupts the communal and the social by privileging infrastructural circulation over civic space and handing ownership of the public street to automobiles. And vehicular speed is not just about acceleration; the quick pace of travel is juxtaposed with infrastructure's slow rate of transformation with enormous networks that are intractable and immovable for decades.

AN INTRODUCTION TO AUTONOMOUS MOBILITY

With this problematic history in tow, the nature of automobiles is changing. In the last two decades, self-driving cars have advanced from research to reality, with autonomous vehicles already on the road in Arizona and California. AVs offer tremendous promise, from reducing emissions and congestion through ridesharing to decreasing the number of driving accidents and deaths. However, autonomous driving is still untested, with safety relatively unproven. The perceptual architecture of AVs is susceptible to malicious attacks; they rely on programming that could be adversely influenced by economic factors if prioritized over public safety concerns, the technology remains rife with potential for mass surveillance, and the spatial potential of their implementation is yet untapped. The promise and perils of AV technology can be assessed through five emerging themes that parallel those tied to vehicular history: networks, sensing, navigation, power, and intelligence.

In the shift toward autonomous mobility, there are a series of questions to ask concerning the history of vehicular transportation and its uncertain future. How does the network of digital infrastructure and the sharing economy stand to change the car's role in culture? How might sign-based roadside scenography be reimagined in a world where human vision image-based communication takes a backseat to machine vision and data-based sensing? How might the nature of space change in an environment tuned to navigation? How might new energy economies change power dynamics in the shift from fossil fuel to electric vehicles and AI agents? How can the slow speed of infrastructural development accommodate technology's pace and account for a new politics—not of politics of speed[7] but one based around intelligence? And what new opportunities does autonomous mobility offer designers to innovate in the built environment in ways that mitigate the longstanding problems of automobiles and make way for new forms of collectivity?

CASE STUDY: THE ARCHITECTURAL DESIGN OF A TESTING PLATFORM FOR AUTONOMOUS DRIVING

This paper frames possible answers to these questions based on a case study. The case study project examined herein is an operable model: a miniature testing platform for autonomous

driving that accommodates a model autonomous vehicle with a full perceptual stack (Figure 1). The 1:8 scale testing platform for autonomous driving is designed to be an immersive environment that encompasses 100' by 30' and is at various heights up to 8' tall (Figure 2). This model engages with interdisciplinary research as a collaboration with associate professor of computer science Dr. Yevgeniy Vorobeychik. Engineering research aims to improve machine learning algorithms. In parallel, architectural research aims to speculate on changes that might be introduced to the built environment in light of the broad implementation of AVs and AI in cities.

COMPUTER SCIENCE RESEARCH METHODS

From the computer science perspective, the proposed project's core innovation is to enable intermediate-scale physical experimentation. This scale platform will allow Dr. Vorobeychik's research team to evaluate the limits of autonomy at significantly lower costs than full-scale experimental facilities. It will also allow for a greater degree of stress-testing, designing the tests to be explicitly adversarial, for example, causing the cars to malfunction or crash.

As opposed to highways, urban streets unleash a host of issues that increase AI vulnerabilities, such as objects that move unpredictably, like cars and pedestrians, or congestion and complex traffic patterns. To design and evaluate AI-based perception in this environment, it is critical to perform physical experiments. The miniature experimental platform is the best way to accomplish this without creating unnecessary risks when experiments are done at full scale with real cars. Ultimately this will improve machine learning algorithms and the AVs' performance to move toward trustworthy AI and increased safety.[8]

ARCHITECTURAL RESEARCH METHODS

Regarding the architectural motives, the platform represents an attempt to enact sociotechnical future narratives[9] that seek to drive emerging technology's introduction to cities via the consideration of its spatial implementation. In this effort, the project engages with the methods of scriptwriters and film directors on the one hand and computer scientists on the other—and adopts their tactics within architectural making and thinking. In this effort, the model is considered as what Trevor Paglen casts as "activations and operations"[10] or what Antoine Picon cites as the "instrumental and mediational."[11] Static architectural representation is replaced by an operable platform, an interface activated by interactivity.

Critical to this model is its ability to move and change over time, to act like the digital platforms or interfaces that we interact with but as a physical simulation. An index of real-world and imagined scenarios has been included for the miniature

Figure 2. *Architectural Design of An Experimental Testing Platform For Autonomous Driving*. One-point perspective rendering of operable model at eye-level. By Constance Vale's research practice The Factory of Smoke & Mirrors, with Research Assistants Zhuoxian Deng, Min Lin, Mason Radford, Yi Wang, and Yuzhu Wang.

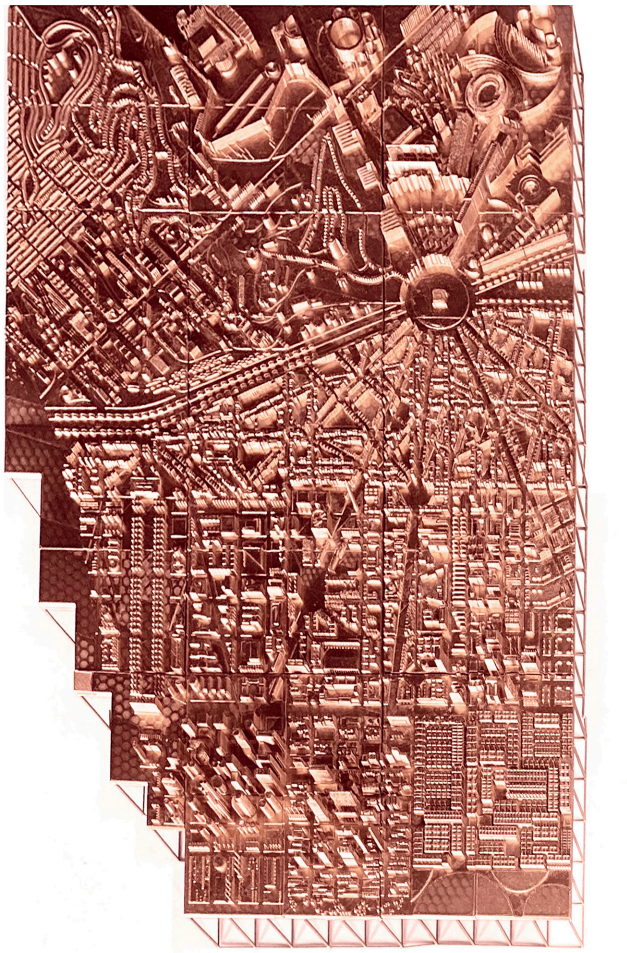

Figure 3. *Autonomous City III*, physical model of wider city scope of *Architectural Design of An Experimental Testing Platform For Autonomous Driving*. By Constance Vale's research practice The Factory of Smoke & Mirrors, with Research Assistants Zhuoxian Deng and Yi Wang.

AV to encounter. The model is designed to be transformed over time to produce an array of changing conditions. The platform's modular construction allows different scenarios to be played out between various actors. That is, in this project, events play a central role as a "script" animated in an architectural "stage set."

The operability of the model reaches beyond its restaging in multiple scenarios. The platform extends itself out into culture and translates across various scales and media. The model city is based on a series of preceding studies used to catapult research before starting the large-scale project. Initially, a much broader scope was examined, which sampled fragments of real and speculative urban territories in the spirit of Colin Rowe and Fred Koetter's Collage City. A rendering of this iteration entitled *Autonomous City II* was exhibited in *Decoys and Depictions: Images of the Digital* at Des Lee Gallery in 2019 (Figure 3). It has since been built as a physical model along with several other studies used as part of a diorama entitled *Autonomous City III* on exhibit at the Farell Teaching and Learning Center at Washington University in St. Louis' Medical School (Figure 4 and 5). Ultimately, the 1:8 scale model used for testing will be exhibited as a discursive tool that provokes public engagement in conversations about AVs and AI in cities. As a result, the model is operable in its reconfigurability, reconstruction, rescaling, and repositioning in the public realm to provoke thought and discourse about the future of autonomous mobility.

The representation and visualization tactics described above are being mobilized and honed in the platform's production to address questions concerning the history of vehicular transportation and its uncertain future. Returning to the terminology laid out concerning this past and not-so-distant-future, the remainder of this text will examine how research methods are being enacted to explore the questions raised in relation to a set of paradigm shifts: from culture to networks, signification to sensing, space to navigation, energy to power, and speed to intelligence. These sections will clarify the changes taking place in technology and its implications for society and politics, followed by the architectural and urban design strategies being deployed in the platform that re-think and transform the built environment in relation to these changes.

FROM CULTURE TO NETWORKS

In the dawn of autonomous driving's integration in cities, the standard car's role in culture stands to be offset by AVs and their networked intelligence. AVs rely on neural networks that resource vast data sets, index their surroundings using sensors, and rely on electrical power systems. These vehicles' relationship to individuals will likely be restructured through the sharing economy, streamlining traffic and reducing emissions through collective operation and ownership. However, without connecting mass transit to ridesharing systems, congestion and emissions could increase; this is all the more likely as AVs would decrease individual travel given their independence from human labor.[12] With this decrease in cost and no need for engaged driving, riders may increase their commute length, leading to suburban sprawl.[13]

The platform anticipates networked systems that stand to streamline traffic and reduce emission through collective operation and ownership. Thus, rather than prioritizing individualized freedom as symbolized in the car, this prioritizes a collective of human and non-human actors. The model is designed as a series of "stage flats" and "risers" that allow us to explore facades and ground planes. As such, we are modulating aperture and access designed to integrate both human and vehicular occupants. Simultaneously, through a series of drawings that refer back to that model but embrace a wider scope, we're thinking in terms of interconnected digital and infrastructural networks that will make our cities more likely to benefit from machine intelligence through their embedded spatial intelligence.

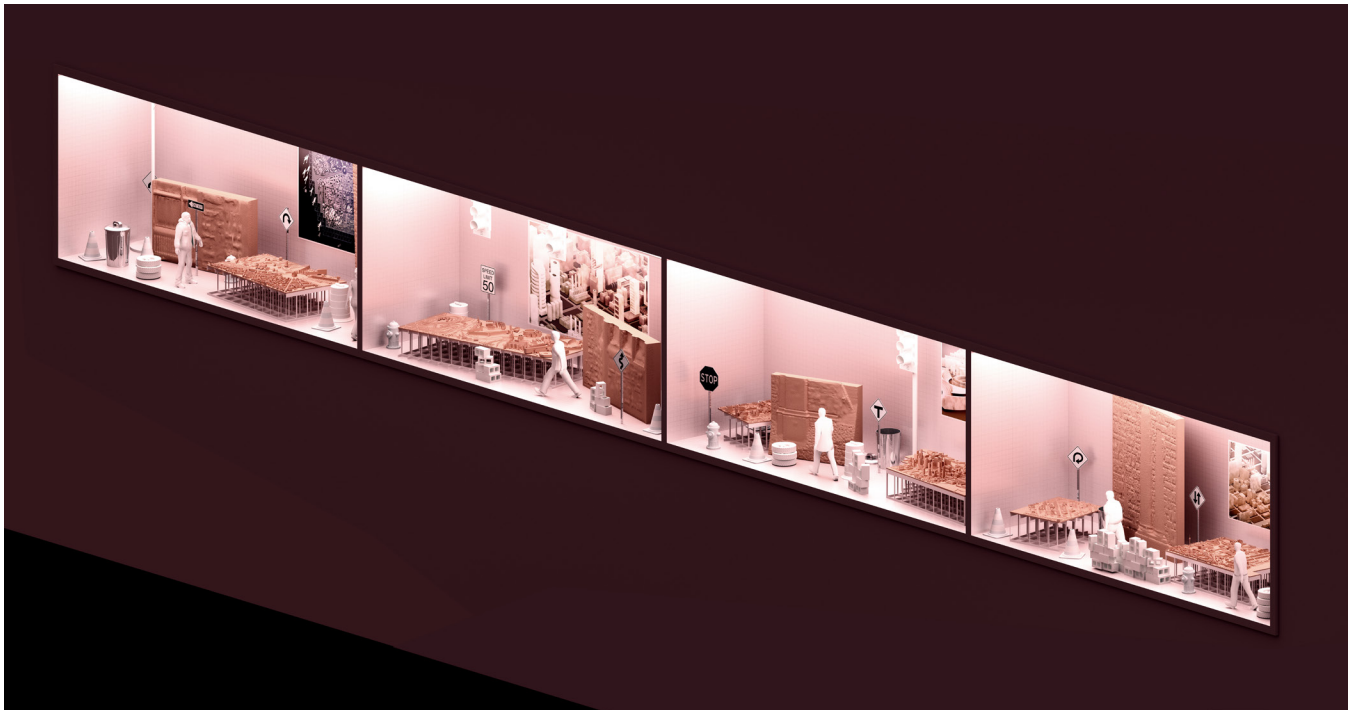

Figure 4. *Autonomous City III*, rendering of diorama model with prototype models for *Architectural Design of An Experimental Testing Platform For Autonomous Driving*. By Constance Vale's research practice The Factory of Smoke & Mirrors, with Research Assistants Zhuoxian Deng, Yi Wang, Yuzhu Wang, and Zhao Yang.

FROM SIGNIFICATION TO SENSING

As AVs, drones, and autobots are ever more present in the built environment, they shift the image-based perception of signs toward data-driven sensing. The images generated or surveyed by multicamera attachments and sensors are not seen but interpreted based on pixel configurations. It is possible to imagine a different urban scenography freed from human legibility and animated by collective data and interactivity. Simultaneously, with motion and vision becoming fully automated, the data they assess can easily be digitally mined. Governments and corporations may use such invasive datasets in surveillance for financial gain, as Trevor Paglen suggests, "unambiguously serving (their own) interests at the expense of vulnerable populations and civic life."[14] Sensing operates outside the scope of vision and can be used as a weapon of injustice as it activates hidden networks of power.

The model is a physical simulation, one that, by necessity, takes on the qualities of realism. Creating a hyper-real environment for testing is critical for research to be meaningful to the development of machine learning algorithms and applied to full-scale AVs. Material translations between full and miniature scale and atmospheric interference like fog smog, rain, and glare are required. Software is being used in design to accurately records real-world environments, transferring effects between full and miniature scales. As such, the platform is modeled in part through photogrammetry, affording opportunities to think about spaces calibrated to remote sensing and navigation technology rather than human optics. To that end, image-based machine communication applied to surfaces is being researched and integrated into the environment to function in place of typical signage. At once, the model anticipates that data camouflage may be just as crucial as data communication. Paired with the platform's realism and its reconfigurability, the model acts as an immersive world.

FROM SPACE TO NAVIGATION

Navigation is beginning to overtake spatial inhabitation. Navigational interfaces—like Global Positioning Systems and web mapping services—play a significant role in our day-to-day travel and reshape "our sense of spatial and temporal orientation."[15] With these systems, data is charted to replicate the real. However, these data interfaces are not merely reflections of the world; they become worlds unto themselves, ones that are generative and active, tracking and reacting to our movements within them. Harun Farocki noted, "A computer animation is less a reproduction and more a production…or creation of a model world."[16] In their operational capacity, navigable images reveal themselves as models updating in real-time. Navigational images as model worlds, productions, operational tools, and animations reflect the nature of the networked cities they portray.

In the model city, navigation is the primary model of inhabitation. The miniature vehicle must first construct a digital twin of the physical model, a map that the car can locate itself within.

Figure 5. *Autonomous City III*, diorama model with prototype models for *Architectural Design of An Experimental Testing Platform For Autonomous Driving*. By Constance Vale's research practice The Factory of Smoke & Mirrors, with Research Assistants Zhuoxian Deng and Yi Wang.

As the vehicle moves, it responds to the environment based on the data inputs. These inputs are generally discarded, but for this project, they will be collected and used to inform visualizations of the platform. These further translations of the model will function as a diagnostic tool to understand how the environment is read and inform future calibrations.

FROM ENERGY TO POWER

At present, vehicles are moving away from the fossil fuel energy toward electrical power used in AVs and the digital technologies on which they rely. This change in energy economies could stand to productively destabilize past political power dynamics. However, vehicles and data centers full of servers, electronic devices, and AI agents are powered by exceptional electrical loads. Our digital energy consumption is rapidly catching up to that of our mobility and creating a wide array of demands that often return to fossil fuels and result in pollution. Collectivity must be addressed in our transportation via mass transit and ridesharing options. And the spatial arrangement of cities should account for models of urbanism that decrease everyday travel distance.

Through the design of a mobility hub within the model, the project examines the potential of new public spaces in cities. These speculations explore how we might offset the prioritization of the individual and offer new modes of collectivity in ridesharing and civic space. The hub also operates as a connection point to mass transit to explore streamlining traffic and reducing emissions and sprawl. The model and contingent research in drawings attempt to merge digital, spatial, and infrastructural networks and yield new models of synthetic intelligence.

FROM A POLITICS OF SPEED TO A POLITICS OF INTELLIGENCE

AVs and a symphony of other robotic entities operate in the world with embedded intelligence and create the possibility of a different kind of politics. These agents populate not only the road but every corner of our world, producing a vast fleet of robotic actors that are becoming "uncanny new occupants for architecture."[17] This network of autonomous technology has significant implications as a social and political project, one which deals with "the quality of urban life and sustainable development through close management of technological resources and infrastructure."[18] Perhaps most promising is James Bridle's position that "the self-driving car necessitates a return to the communal and the social" through "greater collaboration with our technologies."[19] With the broad introduction of artificially intelligent vehicles in cities, new sociopolitical paradigms are beginning to take shape.

Spatial intelligence paired with machine intelligence might better serve the disenfranchised by providing greater access to transit for those outside of train and bus routes and reducing

the need for further increases in the scale of roadways. To the latter point, the platform anticipates that fewer lanes would be sufficient; AVs could work in concert to shift the center lane's priority in response to traffic patterns, affording more room for public space and contracting rather than expanding roadways. The platform suggests the car's changing role in culture through the street's reclamation as a safe pedestrian space that reduces the risk of vehicle crash deaths to those inside and outside the car. This shift in priority occurs through a sociopolitical revision of the street's role as public via the technology's capability to increase safety.

THE AUTONOMOUS FUTURE OF MOBILITY

The testing platform for autonomous driving offers a significant opportunity to innovate in architecture, urban design, and engineering disciplines, with efforts to rectify longstanding problems created by automobiles. In hybridizing architectural and scientific research, the platform hovers between being a framework for advancing AV technology and its implications in cities.

The platform is still in the preliminary stages of research. While design and prototypes are complete, the model is under construction. Research into fabrication methods and further exploration of the consequence of machine vision are ongoing. The latter will afford opportunities to understand better the implications of machine vision on the built environment. This work with machine vision will create a feedback loop, using the machine vision to inform the model's ongoing transformation. In its disciplinary hybridity, the model hovers between being a framework for advancing technology and an artistic endeavor that contributes to visual culture and engages with the public through exhibitions and discourse.

Rather than understanding models as passive objects, the platform proposes representation that activates space through its operability. The platform echoes the behavior of architecture, cities, and technology based on a logic of events, situations, and scenarios. By envisioning models as activated objects, it is possible to afford new opportunities for architects to participate in the changes taking place in emerging technology. Furthermore, James Bridle anticipates "return to the communal and the social" is facilitated through "greater collaboration with our technologies."[20] The project hopes to advance individuals' agency in society and grant new agency to machines. In so doing, the platform argues for the contributions architects stand to make as technologies are integrated into the built environment.

ENDNOTES

1. Keller Easterling, "Switch" *E-flux Architecture*, accessed November 01, 2020, https://www.e-flux.com/architecture/positions/151186/switch/.
2. Ibid.
3. These themes were used to organize an exhibition curated by Constance Vale in 2020 at the Kemper Museum of Art, entitled *The Autonomous Future of Mobility.* The text in this section is drawn from that exihibition.
4. Robert Venturi, Denise Scott Brown, and Steven Izenour, *Learning from Las Vegas* (Cambridge, MA: MIT Press, 2017), p. 7, 9-13.
5. Paul Virilio, *Speed and Politics* (Los Angeles, CA: Semiotext(e), 2006), p. 50.
6. Ibid., p. 29-31.
7. Ibid., p. 29-31.
8. This section draws on a grant proposal co-written with Dr. Yevgeniy Vorobeychik and encompasses his research.
9. Antoine Picon, *Smart Cities A Spatialised Intelligence – AD Primer* (Erscheinungsort Nicht Ermittelbar: Wiley, 2015), p. 34-37.
10. Trevor Paglen, "Invisible Images (Your Pictures Are Looking at You)." *The New Inquiry* (December 8, 2016), accessed November 01, 2020, https://thenewinquiry.com/invisible-images-your-pictures-are-looking-at-you/.
11. Virilio, *Speed and Politics,* p. 17.
12. Easterling, "Switch".
13. Ibid.
14. Paglen, "Invisible Images (Your Pictures Are Looking at You)."
15. Hito Steyerl, "In Free Fall: A Thought Experiment on Vertical Perspective" from *The Wretched of the Screen* (Berlin: Sternberg Press, 2013), p. 14.
16. Tom Holert, Doreen Mende, et. al., "Editorial: 'Navigation Beyond Vision, Issue One'"," *E-flux Journal* #101 (June 2019), accessed November 01, 2020, https://www.e-flux.com/journal/101/274019/editorial-navigation-beyond-vision-issue-one/.
17. Andrew Witt, "Feral Autonomies," from "Software as Infrastructure" *E-flux Architecture* (2019), accessed November 01, 2020, https://www.e-flux.com/architecture/software/341087/feral-autonomies/.
18. Picon, *Smart Cities A Spatialised Intelligence*, p. 24.
19. James Bridle, "Failing to Distinguish between a Tractor Trailer and the Bright White Sky," from "Navigation Beyond Vision, Issue One," *E-flux Journal* #101 (June 2019), accessed November 01, 2020, https://www.e-flux.com/journal/101/271654/failing-to-distinguish-between-a-tractor-trailer-and-the-bright-white-sky/.
20. Ibid.